PRE-SERVICE ELEMENTARY TEACHERS' UNDERSTANDINGS OF KNOWLEDGE DOMAINS AND EFFICACY BELIEFS IN MATHEMATICS AND SCIENCE TEACHING

by

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CHAPTER 1 – THEORETICAL FRAMEWORK

Introduction

Mathematics and science are separate disciplines; yet, they are frequently grouped together in both educational and professional arenas. Such groupings likely occur due to the similarities between the two subjects. Both the learning and teaching of science and mathematics hold striking correspondences, and how pre-service teachers view scientific and mathematical knowledge and the role of that knowledge in teaching and learning will affect the pedagogical approaches they use in the future. While content knowledge is necessary for effective teaching, it is not sufficient. Efficacy beliefs, pedagogical knowledge and personal teaching philosophies all play vital roles in student learning outcomes.

Through an analysis of classroom discussions, this study gains perspective on what types of knowledge a cohort of pre-service elementary teachers believe is necessary for successful science and mathematics teaching. An in-class activity, called the Pre-Service Elementary Teachers' Science and Mathematics Activity (PETSMA), was given to the pre-service teachers in order to promote discussion regarding factual/procedural versus conceptual knowledge, and the roles of each type of knowledge in mathematics and science education. In particular, the study examined pre-service elementary teachers' perceptions of the significance of factual/procedural and conceptual knowledge within each discipline. Knowledge for teaching differs from knowledge required to answer content questions. Pre-service teachers, however, often fail to recognize this distinction and many times lack thorough understandings of one or both of the types of knowledge required for successful science and mathematics teaching (Abell & Smith, 1994; Ball, 1988; Borko et al., 1992; Carlsen, 1991; Grossman, 1989; Lowery, 2002; Stevens & Wenner, 1996; Yilmaz-Tuzun & Topcu, 2008). By researching pre-service elementary teachers' perceptions of the knowledge required for teaching, further insights on how appropriate perceptions can be developed may be achieved.

Additionally, this study compares the mathematics and science teaching efficacy beliefs of pre-service elementary teachers, as measured by the Mathematics Teaching Efficacy Beliefs Instrument (MTEBI) and the Science Teaching Efficacy Beliefs Instrument: A Pre-service Elementary Scale (STEBI-B), to self-efficacy measures related to specific mathematical and scientific content questions, as determined by the PETSMA. These comparisons are performed in an effort to better understand how subject specific teaching efficacy beliefs relate to confidence in completing and teaching certain tasks in mathematics and science. Since teaching efficacy beliefs can serve as predictors for classroom behavior, the development of appropriate teaching efficacy beliefs in pre-service teachers is a valuable area of study (Brouwers & Tomic, 2000; Coladarci, 1992; Midgley, Feldlaufer, & Eccles, 1989; Swars, Daane, & Giesen, 2006; Wheatley, 2002). Moreover, by studying self-efficacy beliefs related to specific science and mathematics content, conclusions may be drawn regarding pre-service elementary teachers' beliefs about the knowledge necessary for successful mathematics and science teaching.

In what follows, the nature of mathematics and science are discussed, as well as pedagogical content knowledge and teaching efficacy beliefs. These theoretical frameworks are examined in order to evaluate what is currently considered vital to becoming an effective elementary teacher of mathematics and science.

The Natures of Mathematics and Science

Mathematics and science are both complex disciplines, noted for their emphasis on logical, rigorous and reproducible methodologies. Both disciplines are utilized in describing the physical world and observed phenomena; and thus, they often rely on patterns. Research in mathematics and science is often communal in nature; relying on previously held theories and discoveries in order to reach new conclusions. Yet, they remain distinct disciplines. Many branches of mathematics hold no interest in the physical world and exist only within the human mind. Likewise, many areas of science find little use for mathematics. However, both disciplines emphasize the fecundity of research and the creativity of thought in developing new theories. Unfortunately, many pre-service teachers have limited experience with the true natures of mathematics and science, and view these disciplines only within the scope of their school science and mathematics experiences, which leads to inaccurate understandings of the knowledge required for teaching mathematics and science.

In education, mathematics and science are too often presented as "cookie-cutter" experiments (science) and calculation problems (mathematics) with singular solutions. In the case of mathematics, the creativity and communal approaches are frequently overlooked. Instead, many pre-service teachers perceive mathematics as a series of operations and procedures that require memorization (Ball, 1988; Borko et al., 1992; Hill & Ball, 2009; King, 1992). Similarly, school science can appear far more restrictive than real scientific research. While many sources advocate for inquiry learning, too often time for student questioning is cut in favor of teacher led instruction (Abell & Smith, 1994; Adams & Hamm, 1998; Brickhouse, 1990; Carlsen, 1991; National Research Council [NRC], 1996; National Science Foundation [NSF], 1999; National Science Teachers Association [NSTA], 2008). Misconceptions regarding the natures of science and mathematics lead teachers to present content in ways which fail to display their intricate and intertwined characteristics (Adams & Hamm, 1998; Ball, 1988; Borko et al., 1992; Carlsen, 1991; Cobb, Boufi, McClain, & Whitenack, 1997; Furner & Kumar, 2007; Grossman, 1989; Hill, Rowan, & Ball, 2005; National Council of Teachers of Mathematics

[NCTM], 2000; NRC, 1996; NSF, 1999; NSTA, 2008; Stevens & Wenner, 1996).

Understanding the manner in which pre-service teachers develop their conception of mathematics and science is beneficial to teacher education research. Teachers' conceptions of mathematics and science influences the how they teach the related content (Abell & Smith, 1994; Ball, 1988; Borko et al., 1992; Brickhouse, 1990; Carlsen, 1991; Grossman, 1989; Hill & Ball, 2009; Lerman, 1990; Mellado, 1997; Yilmaz-Tuzun & Topcu, 2008). By fostering appropriate conceptions of mathematics and science in pre-service elementary teachers, teacher educators may have a more positive impact on pre-service teachers' understandings of the knowledge bases necessary for teaching mathematics and science.

Defining PCK, MKT and PCK for Science Teaching

Prior to an article written by Shulman (1986), teachers' knowledge bases had been largely neglected in educational research. Shulman (1986, 1987) described the manner in which teachers' knowledge stemmed beyond the content being displayed. Of particular interest to the educational research community was the construct of pedagogical content knowledge (PCK), or the mixture of knowledge of content and pedagogy, which results in successful teaching (e.g., positive learning outcomes, lower attrition, etc.). Teachers' professional understandings are constantly changing, and PCK is a construct that describes the dynamic blend of domains of knowledge required for teaching. Since the conception of PCK, educational researchers have attempted to build upon the idea of PCK in order to determine what knowledge is required for teachers to achieve positive results in the classroom.

Inspired by Shulman's (1986, 1987) construction, Ball, Thames and Phelps (2008) defined a knowledge base specific to mathematics teachers called Mathematical Knowledge for Teaching (MKT). MKT is comprised of six domains: 1) *common content knowledge*, 2) *horizon* *content knowledge*, 3) *specialized content knowledge,* 4) *knowledge of content and students,* 5) *knowledge of content and teaching,* and 6) *knowledge of content and curriculum*. Many attributes of MKT parallel the PCK model. MKT is mixture of pedagogical knowledge and content knowledge, including PCK as a subdomain. However, MKT does address a unique domain of knowledge called specialized content knowledge (SCK). Specialized content knowledge refers to mathematical knowledge that is only used by teachers. In spite of this singular domain, MKT forms a knowledge base for mathematics teaching that is remarkably similar to the original PCK framework that inspired its design.

Educational researchers in the sciences also have formed a knowledge base unique to their discipline (Carlsen, 1999; Magnusson, Krajcik, & Borko, 1999; Zembal, Starr, & Krajcik, 1999). Utilizing the theoretical framework created by Shulman (1986, 1987), five domains of knowledge are described as forming the PCK for Science Teaching: 1) *orientation to teaching science,* 2) *knowledge and beliefs about science curricula,* 3) *knowledge and beliefs about assessment of scientific literacy*, 4) *knowledge and beliefs about students' understanding of science,* and 5) *knowledge of instructional strategies*. The primary domain within this knowledge base is the orientation to science teaching, which describes the individual conceptual framework a teacher uses in their approach to science teaching. Interestingly, the idea of how a teacher's personal philosophies orient their approach to teaching is not explicitly mentioned in either PCK or MKT. Thus, while the knowledge bases may be similar, each discipline holds unique facets that yield varying knowledge bases necessary for teaching.

Discussion of Teaching Efficacy Beliefs

The possession of knowledge, however, does not guarantee that an individual will be an effective teacher. An equally important construct in studying teacher effectiveness is teaching efficacy, or the belief in one's own ability to successfully teach students. There are two prominent conceptual theoretical bases regarding teaching efficacy beliefs. One stems from the work of Rotter (1966) and the Research and Development (RAND) researchers, which describes teaching efficacy as "the extent to which teachers believed that they could control the reinforcement of their actions, that is, whether control of reinforcement lay within themselves or in the environment" (Tschannen-Moran, Woolfolk-Hoy, & Hoy, 1998, p. 202). In a 1976 study, RAND published two items pertaining to teacher efficacy. One item is described as evaluating general teaching efficacy (GTE), which measures teachers' beliefs regarding the influence of teachers and schools on student achievement compared to the influence of outside factors. The second item describes personal teaching efficacy (PTE) or teachers' beliefs about what they as an individual can accomplish with regard to student learning and achievement. Hence, by this theoretical framework, teacher efficacy is a construct designed to describe the extent to which a teacher believes that student motivation and learning are controlled by the teacher (Tschannen-Moran et al., 1998).

The second noteworthy theoretical framework regarding teaching efficacy beliefs is attributed to Bandura (1977). Bandura's social learning theory describes self-efficacy as beliefs regarding action-outcome expectancies developed through life experiences. This theoretical framework differentiates between self-efficacy and outcome expectancies. Self-efficacy is defined as an individual's belief in their ability to successfully complete a task. Outcome expectancy refers to an individual's belief about the likely consequences involved if the task is completed (Bandura, 1977; Bandura, 1981; Tschannen-Moran et al., 1998). Moreover, Bandura (1981) defines self-efficacy as being situational, so individual efficacy levels may vary greatly depending upon the factors of the situation. Bandura's concept of self-efficacy differs from that of Rotter (1966), in that Rotter describes an individual's belief that a certain outcome is internally or externally controlled while Bandura describes a person's confidence in their ability to accomplish the necessary actions (Tschannen-Moran et al., 1998). The differences in these constructs are important because self-efficacy, as described by Bandura (1977), is a strong predictor of behavior, while locus of control is a weaker predictor (Tschannen-Moran et al., 1998). Given that Bandura's conception of self-efficacy is a better predictor of behavior than the RAND-Rotter construct, this study will utilize instruments stemming from Bandura's social learning theory.

Research Questions

The aforementioned theoretical frameworks all contribute to the definition of a successful mathematics and/or science teacher. However, many pre-service teachers have preconceived notions regarding the teaching of mathematics and science that overlook the sophisticated similarities and differences in teaching each discipline. This study observed a group of thirty-five pre-service elementary teachers with the intention of taking a portrait of their views regarding science and mathematics teaching at the beginning and middle of their teacher preparation program. The snapshot representations of their perceptions of science and mathematics teaching are compared in an effort to further understand the conceptions of mathematics and science teaching held by the given sample of pre-service elementary teachers.

The data analyses incorporate both qualitative and quantitative methods. Quantitative techniques are used to analyze the pre-service elementary teachers' responses on the MTEBI, the STEBI-B, and the PETSMA. The PETSMA includes questions over topic specific factual/procedural knowledge and conceptual knowledge in science and mathematics for the K-6 levels, confidence being able to answer each question, and confidence in being able to teach the related content for each question. Furthermore, the activity was created to invoke some cognitive disequilibrium amongst the pre-service elementary teachers with regard to their scientific and mathematical knowledge bases. Internal comparisons were conducted to gain insight into the understandings and knowledge bases of pre-service elementary teachers, and their personal confidence on the selected topics.

The qualitative approaches in this research project focus on the opinions of the participants and their perceptions regarding science and mathematics teacher knowledge. Classroom discussions were analyzed to gain greater insights on the understandings of the pre-service teachers in this study at both the beginning and end of the first two semesters in their teacher preparation program. The classroom discussions yield some insight as to the pre-service teachers' understandings of the natures of mathematics and science and the role of knowledge in teaching.

Hence the overall research question being investigated in this study is:

- Given the cohort of pre-service elementary teachers, how do their perceptions of mathematics teaching compare to their perceptions of science teaching?

The sub-questions that are researched using qualitative analyses are as follows:

1. What are the cohort's perceptions of the nature of mathematics and the knowledge required for mathematics teaching?
2. What are the cohort's perceptions of the nature of science and knowledge required for science teaching?

The sub-questions being investigated through quantitative analyses are as follows:

3. How does the cohort's factual/procedural knowledge compare to conceptual knowledge in elementary level mathematics and science?

4. How does the cohort's knowledge of elementary mathematics and science change between the beginning and end of their junior year in their teacher preparation program?
5. How confident are the pre-service teachers about elementary level mathematics and science?
   a) Confidence regarding their knowledge of facts/procedures versus concepts?
   b) Confidence regarding their ability to teach facts/procedures versus concepts?
6. How does their confidence change between the beginning and end of their junior year in their teacher preparation program?
7. How does confidence in answering elementary level mathematics and science questions compare to confidence in teaching?
8. What are the relationships among measures of science and mathematics knowledge, confidence, and efficacy?
   a) How do measures of mathematics teaching efficacy relate to confidence in teaching specific mathematics content?
   b) How do mathematics confidence and efficacy measures relate to knowledge scores?
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11. How does the cohort's mathematics teaching efficacy beliefs compare to their science teaching efficacy beliefs?

Chapter 2 – LITERATURE REVIEW

In order to teach mathematics and science, teachers require deeper understandings of the natures of mathematics and science than the average individual. Flawed conceptions about the practice of mathematics and science can lead to "cookie-cutter" education in these subjects (Ball, 1988; Borko et al., 1992; Brickhouse, 1990). Furthermore, a lack of understanding about the natures of mathematics and science may alter efficacy measures with regard to each discipline (Bursal & Paznokas, 2006; Swars et al., 2006; Yilmaz-Tuzun & Topcu, 2008). The knowledge required for teaching mathematics and science stretches beyond the knowledge required for practicing mathematics and science in many respects (Ball, 1988; Ball et al., 2008; Grossman, 1989; Grossman, 1990; Hill & Ball, 2009; Magnusson et al., 1999; Morine-Dershimer & Kent, 1999; Zembal et al., 1999). As pre-service teachers prepare to enter the classroom, they develop perceptions of mathematics and science and teaching efficacy beliefs which will influence their future practices.

This study focuses on the comparison of the knowledge necessary for teaching mathematics versus science from the perspectives of a cohort of pre-service elementary teachers. In what follows, there is a comparison between the nature of mathematics and the nature of science. Subsequently, there is a discussion regarding the similarities and differences in learning mathematics and science. Since mathematics and science are remarkably similar disciplines, a review of research regarding the knowledge domains required for teaching mathematics and science arises. Next, the nature of teaching efficacy and self-efficacy beliefs in mathematics and science teaching are considered. All of the previously mentioned sections involve theoretical discussions from the education research community. Stemming from those theoretical bases, examinations of research regarding pre-service teachers' understandings of mathematics and science are included. Additionally, studies regarding the manner in which conceptions of mathematics and science and teaching efficacy beliefs in mathematics and science influence teaching are reviewed.

The Natures of Mathematics and Science

This study intends to compare perceptions of mathematics teaching to perceptions of science teaching for a group of pre-service elementary teachers. Thus, the natural question arises: Why focus on mathematics and science? Mathematics and science are separate disciplines. Yet, their concepts, operations, and methodologies frequently overlap. Moreover, there is evidence of strong similarities between the learning processes of mathematics and science (Bosse, Lee, Swinson, & Faulconer, 2010). The fundamental similarities between mathematics and science only further blur the lines of demarcation between the two disciplines. In particular, the physical sciences and applied mathematics may appear identical to an individual who does not work in either the scientific or mathematical realms. However, certain aspects are unique to each field. While science and mathematics may differ in a variety of ways, the mutually beneficial and intertwined nature of their relationship is undeniable.

Science is the process by which humans attempt to develop an abstract understanding of their surroundings (Wolpert, 1992). Since science describes human surroundings and experiences, the "truth" of scientific statements can be tested against nature. However, exact proof of scientific statements is not possible, so experimentation verifies (and does not prove) scientific conclusions (Lakatos, 1977; Wolpert, 1992). Additionally, scientific theorems are distinguished by the existence of some criterion capable of disproving the scientific statement (Lakatos, 1977). Tenacious scientific theorems further the development of new technology, assist in advances in medicine, and serve to benefit humanity in numerous respects. When scientists use mathematics as a tool for translating scientific theorems into symbolic representations which are then used to help humanity, science is displaying the usefulness of mathematics. Thus, science assists mathematics by giving mathematics a clear application.

Mathematics is not limited to being a tool for scientists (Ogilvy, 1956). The world of mathematics extends greatly beyond applications found within the sciences. Through the use of a symbolic language, mathematics is able to represent the invisible (Devlin, 1998a; King, 1992). Mathematics utilizes rigorous approaches in connecting concepts and recognizing patterns within itself. Mathematics is a construct of the human mind that is often used by mathematicians as an analogy for reality, but a simplified reality that can be expressed symbolically (Devlin, 1998b; King, 1992).

> Mathematics is a product – a discovery – of the human mind. It enables us to see the incredible, simple, elegant, beautiful, ordered structure that lies beneath the universe we live in. It is one of the greatest creations of mankind – if it is not indeed the greatest. (Devlin 1998b, p. 209)

Since mathematics can serve as an analogy for reality and science seeks to explain the physical world, science benefits greatly from the use of mathematics.

Similarities between mathematics and science.

There are a multitude of similarities between mathematics and science. One of the most basic similarities is that one word is used to describe a variety of areas of study. Science includes all behavioral sciences, physical sciences, biological sciences and technological sciences. Each type of science includes distinctive disciplines within itself. Mathematics includes arithmetic, pure mathematics and applied mathematics, with each area encompassing many different branches of mathematics. Since mathematics and science are words that are used to describe so many different disciplines, the concept of demarcation is quite difficult. Thus, individuals who do not operate in scientific and mathematical fields are left with an unclear understanding of the true natures of both science and mathematics. A lack of demarcation is particularly problematic to science and mathematics educators. Strong conceptual understandings of the natures of science and mathematics are pivotal to a teachers' ability to provide effective learning opportunities in each discipline.

Science and mathematics are distinctively different from other disciplines by the types of questions they are designed to answer and the methodologies utilized to answer those questions (Devlin, 1998a; Gieryn, 1983; Lakatos, 1977; Lindberg, 1992; NSTA, 2008; Ogilvy, 1956). Neither science nor mathematics attempts to approach philosophical, religious, or personal questions. Instead, science and mathematics focus on questions with logical and reproducible explanations. "Scientists are ultimately engaged in developing persuasive arguments around competing explanations for natural occurrences" (NSTA, 2008, p. 2). Moreover, a rigorous methodology is crucial to both disciplines. The precise methodology may differ between science and mathematics, but a meticulous and thorough approach is a requirement of both fields. However, science and mathematics stretch beyond procedural knowledge. Both scientific and mathematical research is subject to peer review. Hence, the use of a refined methodology adds credibility to the research. The importance of communication in science and mathematics are too often overlooked in school science and mathematics (Adams & Hamm, 1998; Ball, 1988; Borko et al., 1992; Brickhouse, 1990; Cobb et al., 1997; Lerman, 1990; Mellado, 1997; NSF, 1999; NSTA, 2008). Reflective communication is beneficial to both research and education in science and mathematics (Cobb et al., 1997).

In addition to requiring peer communication, scientific and mathematical research is also theory-laden (Gieryn, 1983; Ogilvy, 1956; Wolpert, 1992). Research communities rely on previously determined axioms to assist in developing new theorems and laws. Rarely do scientists and mathematicians approach problems without some hypotheses as to the results of the problem. The same can be said for students learning science and mathematics. Students do not enter the classroom as blank slates. The information held within ones' canons of knowledge often determines their approach to a given problem. In research, previously held theories may affect objectivity; however, knowledge of widely accepted theories allows scientific and mathematical researchers to focus on the development of new concepts, as opposed to reconstructing existing ones. In education, science and mathematics teachers build upon previous knowledge, and correct misconceptions, in order to enhance students' comprehensions. Science and mathematics are both designed to build upon existing knowledge in order to gain greater understandings.

Increased understandings are an expectation in scientific and mathematical research. Research in science and mathematics is not published unless it offers some fecundity within its discipline; that is, the research is both reproducible and fruitful. Scientific and mathematical research is meant to not only investigate a single question, but also produce new avenues of exploration. Similarly, in science and mathematics education effective learning opportunities allow students to not only answer a given question, but to make connections to related concepts (Adams & Hamm, 1998; NCTM, 2000; NRC, 1996; NSF, 1999; NSTA, 2008). Recognizing the similarities in given problems and being able to extend previously learned approaches to apply to new situations is a goal of both mathematics and science education (NCTM, 2000; NSTA, 2008).

The ability to recognize the similarities and differences in scientific and mathematical questions is an example of how science and mathematics rely on patterns. Devlin (1994, 1998b) describes mathematics as a type of science, 'the science of patterns' to be specific. "As the 'science of patterns' mathematics is a way of thinking about the world – one way among many. Thinking mathematically about our world helps us understand it" (Devlin, 1998b, p. 14). Mathematics identifies and creates patterns, which are represented using symbols, and then draws conclusions based upon the patterns. For example, coding and decoding algorithms are utilized in military and technological fields. Such algorithms are an example of a mathematical consideration of patterns. Additionally, analysis of curves, objects, and numbers allows patterns and symmetries to be translated into mathematical symbols; thus, yielding a simplified symbolic explanation of an otherwise difficult concept.

> When you get beyond the symbols and the formulas, you find that mathematics actually makes the world simpler. Mathematicians strip away the complexity and look at the world in the simplest possible way. They look at it in such a simple way that the only way of capturing that simplicity is with symbols, with numbers, with algebra, and with graphs. (Devlin, 1998b, p. 206)

Science also seeks patterns in nature. Scientific theories and laws are attempts to explain observed patterns in nature, such as Newton's Laws of Motion. Moreover, when natural occurrences deviate from the regular pattern, new scientific discoveries are made (e.g., Einstein's Theory of General Relativity superseded Newton's Laws of Motion). Therefore, the existence of patterns is fundamentally important to the development of both mathematical and scientific theories.

Through methodical consideration of patterns, science and certain areas of mathematics develop theorems that have predictive values. The predictive value of a theory is exceptionally important within science. The reliability with which a scientific theory predicts events is often used to determine the tenacity of the theory. The greater the predictive value of a theory across a variety of circumstances, then the more widely accepted that particular theory becomes. While science is deeply concerned with the predictive value of theories, only certain areas of mathematics seek predictive value in the natural world. Mathematics is a construct of the human mind, and therefore does not always consider the physical world when creating theories. However, many branches of mathematics, such as applied mathematics and statistics, do focus on modeling actual events. For instance, the mathematical modeling of fluid has shown predictive value in gastroenterological studies. Moreover, statistics are frequently utilized for their predictive value. Understanding the differences between scientific and mathematical theories is important to mathematics and science education. In order for students to learn the distinctive roles of theories between disciplines, the teacher must have a clear perspective regarding the differences and similarities between scientific and mathematical theories and how such theories influence our interpretations of the physical world.

Mathematics and science both yield compelling ways of viewing the world. The rigorous methodologies utilized in scientific and mathematical thinking offer rare perspectives. Teaching such rigorous subjects often proves difficult. Teachers must simultaneously emphasize the importance of process and rigor, while allowing for exploration and creativity. Both disciplines are characterized by their approaches to investigating questions and by the types of questions they consider. However, when a student utilizes a new approach, many teachers have difficulty determining if the approach is valid or invalid (Ball, 1988; Borko et al., 1992; Carlsen, 1991;

Cobb et al., 1997; Howitt, 2007; Lowery, 2002; Niess, 2005; Wolpert, 1992). Science and mathematics are both analytical modes of thought which gives a critical view of how certain objects operate. Additionally, both disciplines seek patterns to assist in building understandings within their respective fields. Thus, in-service teachers must have conceptual understandings of science and mathematics in order to recognize appropriate procedures and operations. The numerous occurrences of scientific and mathematical ideas overlapping are demonstrations of the strong similarities between the two disciplines.

Recognizing the similarities and differences in the natures of mathematics and science informs pre-service teachers of the roles of mathematics and science in both education and society. Teachers require strong conceptual understandings of mathematics and science to be able to determine if a given lesson or methodology is appropriate. Such insights assist teachers in developing the knowledge bases and pedagogical approaches that will aid their future students in learning mathematics and science.

Learning Mathematics and Science

Given the rigorous methodologies and occasionally abstract thought processes associated with mathematics and science, students are often overwhelmed by the learning of mathematics and science. Both disciplines are associated with the ability to extend concepts and rationalize arguments. However, school science and mathematics are frequently approached in different ways. The following discussions examine the similarities and differences in the learning processes associated with mathematics and science.

Similarities in the learning processes of mathematics and science.

In addition to the many similarities in the natures of mathematics and science, there are profound similarities in the learning processes of mathematics and science (NCTM, 2000; NRC, 1996; NSTA, 2008). Bosse et al. (2010) performed an investigation of the similarities between the process standards of the Principles and Standards for School Mathematics (i.e., problem solving, reasoning and proof, communication, connections, and representations) and the 5 Es from the National Science Education Standards (i.e., engagement, exploration, explanation, elaboration/extension, and evaluation). The study involved two experts (one in science education and the other in mathematics education) writing short sentences describing the most salient characteristics of each of the learning processes, independently. Next, the two researchers met with a mediator and the sentences were translated into a list of characteristics for each of the learning processes. The sentences were then codified and translated into short descriptors. Interestingly, 41 of the total 51 descriptors were found to be common to both mathematics and science learning. No one mathematical learning process was found identical to any one science learning process, but the overlap among the subject areas is still relatively significant (Bosse et al., 2010). Knowledge of the similarities and differences in the learning processes of mathematics and science can greatly assist teachers in embracing methods that better demonstrate the true natures of mathematics and science.

Science and mathematics are often presented by textbooks as clean, direct processes, in which certain specific steps are followed in a specific order to obtain the correct answer. However, both the NCTM process standards and the 5 Es of science note the difference between formal and informal language and communication utilized in mathematics and science (NCTM, 2000; NRC, 1996; NSTA, 2008). While the results of scientific and mathematical studies may appear concise and professional, the process of doing science and mathematics is very different than writing about science and mathematics (King, 1992; NSTA, 2008). Therefore, the manner of scientific and mathematical discourse changes as understanding increases (Cobb et al., 1997).

Additionally, both disciplines mention the disequilibrium created when approaching a new problem (Bosse et al., 2010). While this disequilibrium may result in some students avoiding scientific and mathematical fields, it is intended to generate curiosity. Both science and mathematics learning require systematic exploration and organization of thoughts; and if a student is not curious about a problem, then they are unlikely to explore solutions (Bosse et al., 2010; Furner & Kumar, 2007; NSTA, 2008). Thus, the dilemma faced in inquiry-based (and problem-based) science and mathematics education is finding problems that both demonstrate important content and establish interest (NSTA, 2008).

Once a problem or investigation is established, the student then has the issue of translating the problem into an appropriate scientific or mathematical context/procedure. Hence, another important descriptor to both mathematics and science learning is the concept of making models (Bosse et al., 2010). Inquiry-based (or problem-based) instruction calls for a multimodal approach to learning, where students not only hear instruction but also discuss topics and use manipulatives to increase understanding (Furner & Kumar, 2007; NCTM, 2000; NRC, 1996; NSTA, 2008). Models can serve as a hands-on approach to student learning. Creating models is a method by which problems are translated into a measurable or observable operation. Model-making allows for data to be collected, patterns to be recognized, or connections to be made to previous learning experiences. In mathematics, model-making serves as a translation between the world of mathematics and the physical world. "The rules and procedures learned in school are merely the tools you need to do 'real' mathematics. Mathematics – real mathematics – is about trying to understand ourselves and the world we live in" (Devlin, 1998b, p. 2). While the types of models created can differ between science and mathematics, their purpose remains similar. Models are utilized to give students a new perspective on a given problem. Thus, model-making gives a multimodal approach to learning science and mathematics, and recognizing the importance of model making can assist teachers in promoting deeper understandings.

Conceptual understandings in mathematics and science are achieved when students can not only obtain the correct answer, but also rationally explain how the answer was obtained and expand upon their explanation to include similar situations. Hence, inquiry-based (or problem-based) learning, which requires students to communicate, justify and defend their solutions, is encouraged in both science and mathematics (Bosse et al., 2010; Furner & Kumar, 2007; NCTM, 2000; NRC, 1996; NSTA, 2008). The ability to construct a rational argument is important to both scientific and mathematical learning (NSTA, 2008; Richards, 1983). However, many pre-service teachers fail to recognize the role of communication and group reasoning prevalent in the nature of mathematics and science (Abell & Smith, 1994; J. Szydlik, Szydlik, & Benson, 2003). Science and mathematics are both modes of thought that require rationality. The ability to create a rational argument for a given solution demonstrates students' ability to think in a rational manner. Through defending solutions, students learn to elaborate upon what they learned, which in turn can improve their ability to synthesize the information. Moreover, reflective discourse in science and mathematics often corrects misconceptions (Cobb et al., 1997). Scientific and mathematical discourse yields a social aspect to learning, which adds to the multimodal approach encouraged in inquiry-based (or problem-based) learning (Bosse et al., 2010). Additionally, justifying solutions allows students to demonstrate their understanding of the concepts that led to the solution of a given problem. Ergo, justifying and defending solutions are important aspects in both scientific and mathematical learning.

Through reflective discourse in science and mathematics, students learn not only to explain their reasoning, but also to make connections between topics. An intriguing aspect of both science and mathematics is that concepts are applicable across many different fields. For example, the pressure, temperature, and volume relation may easily be discussed in chemistry, physics, geology, or meteorology. Likewise in mathematics, the average rate of change relates to the difference quotient in algebra, which is remarkably similar to the rule of derivatives in calculus. Thus, knowledge obtained in one area frequently has applications in a variety of areas. Bosse et al. (2010) included the descriptor of being able to apply understanding and extend knowledge to new ideas and future investigations as a common tenet for science and mathematics learning. Central to science and mathematics learning is the knowledge that concepts are applicable to more than one scenario (NCTM, 2000; NRC, 1996; NSTA, 2008). Making connections and developing knowledge of the relationships between concepts helps to solidify understandings in both science and mathematics (Bosse et al., 2010). Thus, scientific and mathematical learning are similar in that the ability to apply a concept to one specific scenario does not appropriately demonstrate learning. However, when teachers fail to note such connections, student learning can suffer. True learning occurs when students are able to extend concepts to new ideas and investigations (Bosse et al., 2010; NCTM, 2000; NRC, 1996; NSTA, 2008). Since science and mathematics both build upon previously learned concepts, studying science and mathematics requires thorough understandings of basic principles and a strong appreciation of the respective methodologies. Strong conceptual understandings of science and mathematics allow teacher to explore various avenues of learning, which could otherwise remain overlooked. Therefore, scientific and mathematical learning processes have many common facets that must be understood by teachers in order to foster true learning.

Differences between the learning processes of mathematics and science.

While scientific and mathematical learning may be very similar, science and mathematics are distinct disciplines. Bosse et al. (2010) determined ten (of 51) descriptors that could not be united between the NCTM process standards and the 5 Es of science education. The differing descriptors included: risk taking (mathematics), fostering ownership (mathematics), viewing holistically (mathematics), select/apply/translate connect among (mathematics), solve problems (mathematics), movement toward equilibrium (science), patterns and relationships (science), students receive feedback (science), able to answer open-ended questions (science), and evidence of development of thinking/behavior (science). Moreover, the descriptors determined by the study were frequently associated with multiple learning processes, so no single mathematical learning process was identical to any one scientific learning process. Therefore, mathematics and science learning processes, although strikingly similar, have different nuances that make them unique.

In the classroom, the concept of trial and error is approached quite differently in mathematics and science. Trial and error is occasionally utilized in solving mathematical problems, but its use is limited. School mathematics is seeking the students' ability to demonstrate an understanding of the process by which problems are solved, and while the "guess and check" method may occasionally yield a correct answer it in no way demonstrates conceptual understandings and problem-solving ability (NCTM, 2000). Conversely, trial and error is a necessity in scientific experimentation. For example, if students are given three types of metal and asked which type of metal is the best conductor of heat, determining an answer would require the "guess and check" approach to problem solving. For science, trial and error is a means by which students may seek evidence, and seeking evidence is a necessary conversation in science inquiry learning (NSTA, 2008). Additionally, errors in science are more likely to be seen as a learning experience that allow learners to move towards equilibrium, where errors in mathematics are more likely to be perceived as a lack of mathematical ability (Adams & Hamm, 1998). Teachers must understand the role of trial and error in both science and mathematics to determine if its use is applicable to a given problem. Thus, while trial and error may appear to be an aspect of both mathematics and science learning, the purpose of trial and error differs between the subjects.

From the research/association perspective, both science and mathematics education has been shifting away from rote memorization and drill sessions (Adams & Hamm, 1998; NCTM, 2000; NRC, 1996; NSTA, 2008). However, classroom mathematics still focuses largely on the determination of exact solutions to problems. On the contrary, school science is better able to ask and answer open-ended questions (Bosse et al., 2010). Science is the process by which people make meaning from experiences. Students will continue to have experiences with the physical world for their lifetime, so the purpose of school science is to develop a mental framework that allows students to analyze and understand their experiences (NSF, 1999). In science, understanding the methodologies necessary for scientific thinking is more important than canonical knowledge (NSF, 1999). Conversely, doing mathematics requires knowledge of mathematical symbols and their operations, and problem solving can lead to a conceptual understanding of those operations (Adams & Hamm, 1998). While reflective communication is important to mathematical learning, frequent problem solving develops number sense and computational skills (Adams & Hamm, 1998; NCTM, 2000). Hence, mathematics education asks fewer open-ended questions in order to enhance the skills needed to practice "real mathematics" in the future (Adams & Hamm, 1998; Bosse et al., 2010; Devlin, 1998b; NCTM, 2000). Thus, different types of questions are often utilized in teaching and developing the skills necessary to practice real mathematics and science.

Another attribute which differentiates science and mathematics learning is that, in school, mathematics tends to be viewed more holistically than science (Bosse et al., 2010). In mathematics, concepts learned in arithmetic are still utilized in algebra, and knowledge of algebraic concepts is necessary for solving calculus problems. Since science encompasses a multitude of diverse areas, certain subject matter can be viewed as distinct within a field. For example, knowledge of cell structure has no apparent application in geology. Similarly, the ability to classify rocks as conglomerate, igneous, or metamorphic offers no clear application to biology. While numerous concepts do overlap across scientific disciplines, science learning is less focused on these overlaps and more concerned with students' abilities to recognize science in their daily lives (NRC, 1996; NSF, 1999; NSTA, 2008). NCTM (2000) notes the importance of students' ability to recognize mathematics and its uses in real-world situations, but mathematics offers more opportunities to use previously learned operations and concepts in later courses. Ergo, many mathematical objectives are revisited throughout the school experience and the ability to make connections to previously learned concepts becomes a requirement of success in mathematics (NCTM, 2000; NSF, 1999). While recognizing the applicability of scientific methodology across various scientific fields is important to science learning, mathematics has more occasions to make connections within the discipline that yields a holistic view of the subject.

Science and mathematics are both modes of thought, and learning mathematics and science are similar in that they should lead to a more rational approach to problem solving. However, the science learning process standards include influencing behavior as well as thought

(Bosse et al., 2010; NRC, 1996; NSTA, 2008). Altering the students' beliefs or practices is not included as a goal for the learning standards of mathematics (NCTM, 2000). "While mathematics educators certainly wish for students to learn to think mathematically, science educators wish for the learning of science to change the thinking and behavior of students" (Bosse et al., 2010, p. 268). For example, students learning about biology should become more aware of the implications of their behaviors on the environment in which they live. Interestingly, the concept of improving behavior is noted within the mathematics standards, but not in the learning processes of mathematics (NCTM, 2000). Science views transformations of behavior as a part of the process to learning science, while mathematics views behavioral transformations as a goal of mathematics education, rather than a stated standard for learning mathematics (NCTM, 2000; NRC, 1996; NSF, 1999). Impacting both thinking and behavior is a commonality between science and mathematics, but when and how the changes occur represents a difference between science and mathematics learning.

Mathematics and science have remarkably similar learning processes, and neither is learned by simply repeating procedures performed by the teacher during classroom lectures. The ability of a student to cite vocabulary or repeat multiplication tables does not demonstrate scientific or mathematical learning. As pre-service teachers develop their understandings of the natures of science and mathematics, they begin to recognize the roles of communication and exploration in scientific and mathematical learning (Abell & Smith, 1994; Szydlik et al., 2003). The ability to construct questions and seek explanations utilizing rational methodologies is necessary for both subjects. However, the precise approaches will often vary with respect to the problem. In both science and mathematics, a plethora of approaches may be used to successfully answer a single question. Understanding the manners in which science and mathematics are learned is critical to teaching.

Teaching Mathematics and Science

Teacher knowledge holds many facets, including content knowledge, knowledge of students' learning processes, and pedagogical knowledge. Knowledge of subject matter and the belief in one's ability to teach are necessary to becoming an effective teacher, but not sufficient. The knowledge bases required for successful teaching are far more complex. As pre-service teachers develop understandings of mathematics and science, attention must be paid to the intricate lattice of knowledge needed to best foster student learning in mathematics and science. Thus, considerations of the required knowledge bases for science and mathematics are included.

In what follows, there is a discussion of the theoretical framework of teacher knowledge as defined by Shulman (1986, 1987) and the development of the construct of pedagogical content knowledge (PCK). Educational research continues to build upon the notion of PCK and its complexities. Two subject specific knowledge bases, namely Mathematical Knowledge for Teaching (MKT) and PCK for Science Teaching, are examined. While both subject specific knowledge bases were derived from the same theoretical framework, certain key differences are identified.

Pedagogical content knowledge (PCK).

In 1986, Shulman produced a thought-provoking conception of content knowledge unique to teaching. Shulman (1987) postulated that teaching requires a sophisticated, professional knowledge which stems beyond simply being able to perform tasks or manage classrooms. This construct prompted a paradigm shift in educational research and helped to redefine teaching as a profession with its own unique knowledge base (Ball et al., 2008; Carlsen, 1999; Shulman, 1986). The major categories of teacher knowledge as described by Shulman (1987) are as follows:

- Content knowledge;
- General pedagogical knowledge, with special reference to those broad principles and strategies of classroom management and organization that appear to transcend subject matter;
- Curriculum knowledge, with particular grasp of the materials and programs that serve as "tools of the trade" for teachers;
- Pedagogical content knowledge, that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding;
- Knowledge of learners and their characteristics;
- Knowledge of educational contexts, ranging from workings of the group or classroom, the governance and financing of school districts, to the character of communities and cultures;
- Knowledge of educational ends, purposes, and values, and their philosophical and historical grounds
- (Shulman, 1987, p. 8)

Research has paid special attention to the category of pedagogical content knowledge (Ball et al., 2008; Carlsen, 1991; Carlsen, 1999; Grossman, 1989; Grossman, 1990; Lowery, 2002; Magnusson et al., 1999; Niess, 2005; Zembal et al., 1999). Grossman (1990) discussed the manner in which teachers orientations to content influenced the means by which they taught that content. For the pre-service teachers in this study, examining their orientations to science and mathematics assists in understanding the development of their subject specific teacher knowledge bases. Carlsen (1991) specifically noted that biology teachers are more likely to discourage discourse when they are uncertain of their own ability to explain the material. Thus, pedagogical content knowledge refers to the combination of teachers' knowledge of content and pedagogy to create effective representations of content to young learners.

Pedagogical content knowledge (PCK) represents both the conceptual and contextual complexities of teaching. Defining subject matter for teaching is an important task for both teachers and educational researchers. However, PCK contributes additional dimensions to the concept of subject matter knowledge for teaching. Shulman (1987) defines PCK as:

> The most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations – in a word, the most useful ways of representing and formulating the subject that make it comprehensible to others … Pedagogical content knowledge also includes an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and back grounds bring with them to the learning of those most frequently taught topics and lessons. (p. 9)

Grossman (1990) describes PCK as the area of teacher knowledge with the greatest impact on classroom actions. Given the impact of PCK on teachers' classroom behaviors, the research purposed in this study intends to examine pre-service teachers' perceptions of the knowledge domains for teaching mathematics and science.

The educational research community has been intrigued by Shulman's (1987) concept of PCK. As a construct, PCK encompasses both the necessary subject-matter knowledge for teaching and the skills required to use that subject-matter knowledge in a manner that is beneficial to the learner. Moreover, PCK includes general and personal pedagogical knowledge.

In other words, PCK includes teachers' knowledge of accepted instructional techniques, classroom organization and management, classroom discourse, and personal orientations and perceptions about teaching.

Grossman (1990) further built upon the notion of PCK to include four primary dimensions: 1) *Knowledge of students' understandings, conceptions and misconceptions;* 2) *Curricular knowledge;* 3) *Knowledge of instructional strategies and representations for teaching particular topics;* and 4) *Knowledge and beliefs about the purpose of teaching ones subject*. These dimensions differ slightly from Shulman's (1986, 1987) construction of PCK. Shulman (1987) had noted curricular knowledge and educational goals and purposes as being separate from PCK. However, since PCK is a mixture of subject matter knowledge and pedagogical knowledge, the strong interrelation of other teacher knowledge bases with PCK is not surprising.

PCK is unique with respect to its relationships with the other knowledge bases. As more educational research is produced, deeper understandings are achieved regarding the interplay between PCK and other knowledge bases associated with teaching. From an analysis of the literature concerning PCK, Morine-Dershimer and Kent (1999) constructed a framework of the categories contributing to PCK as displayed in Figure 1. PCK is central to teacher knowledge with almost all other domains of teacher knowledge being directly linked to PCK. In fact, knowledge of general educational contexts is the only sub-category not directly connected to pedagogical content knowledge. Given the central nature of PCK within teacher knowledge, research regarding the development of PCK in pre-service teachers holds a great deal of potential in aiding teacher education.

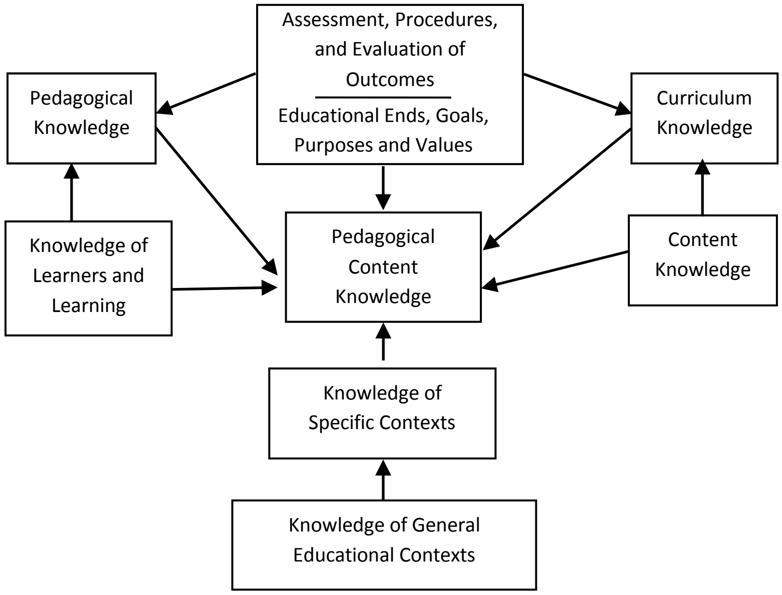


Figure 1. Flow chart of categories contributing to PCK. Reprinted from "The Complex Nature and Source of" by G. Morine-Dershimer & T. Kent, 1999, In J. Gess-Newsome and N.G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education*, Dordretcht, Netherlands: Kluwer, p. 22. Copyright 2012 by Heather Peace. Reprinted without permission.

As novice teachers move from student - to student-teacher - to teacher their teaching knowledge bases grow and develop (Carlsen, 1999). Thus, adopting a perspective that PCK is a fixed model devoid of context yields an inappropriate view of teacher knowledge. PCK is not a specific set of practices utilized by expert teachers which can be taught to all novice teachers; ergo, guaranteeing the success of all novice teachers across the world. Modeling the necessary knowledge bases for teaching is a dynamic process, which is influenced by a multitude of factors.

Additionally, the knowledge required to teach will vary depending upon the subject. PCK may refer to the mixture of content knowledge and pedagogical knowledge which is unique to the teacher, but it is also unique to the subject being taught. Hence, the educational research community has adopted the task of outlining subject specific knowledge bases (Ball et al., 2008;

Hill & Ball, 2009; Hill et al., 2005; Magnusson et al., 1999; Zembal et al., 1999). In line with researching pre-service elementary teachers' perspectives on knowledge for teaching science and mathematics, the proposed knowledge bases for science and mathematics are further discussed.

Mathematical knowledge for teaching (MKT).

Mathematical knowledge for teaching (MKT) is a theoretical framework based on the PCK model describing the mathematical knowledge domains and teacher knowledge domains necessary to being a successful mathematics teacher (Ball et al., 2008). Ball et al. (2008) utilized teacher observations as a primary tool for defining the four central domains of MKT. The development of the MKT construct is meant to elaborate on PCK within the frame of mathematics education, not to redefine or replace the existing PCK construct (Ball et al., 2008). Many of the attributes are similar to the definitions of PCK, only designed on a subject specific basis. Certain nuances serve to differentiate MKT and PCK; however, the parallel frameworks and underpinnings are prevalent. In fact, Ball et al. (2008) claim that there are four primary domains in MKT: 1) *common content knowledge (CCK),* 2) *specialized content knowledge (SCK),* 3) *knowledge of content and students (KCS),* and 4) *knowledge of content and teaching (KCT)* (Figure 2). Moreover, common and specialized content knowledge are simply subdivisions of Shulman's (1986, 1987) content knowledge, and knowledge of content and students and knowledge of content and teaching are subdivisions of PCK. Understanding how knowledge for teaching mathematics differs from knowledge for teaching other subjects allows pre-service and in-service teachers to have a greater appreciation of the nature of mathematics. Descriptions of the four primary dimensions of MKT, as defined by Ball et al. (2008) and their comparisons to the PCK construct are as follows.

- **Common content knowledge (CCK) in mathematics:** The domain of CCK refers to mathematical knowledge that is utilized in both teaching and in settings other than teaching, such as: knowledge of appropriate definitions, symbol usages, and mathematical operations that are necessary to adequately teaching mathematics.
- **Specialized content knowledge (SCK) in mathematics:** The domain of SCK describes the mathematical knowledge and skills utilized only within the teaching profession, such as: determining the nature of an error, the ability to determine if new or non-standard approaches to problem solving will still apply to general cases, and selecting and identifying examples with pedagogically strategic intent.
- **Knowledge of content and students (KCS) in mathematics:** KCS involves the interplay of knowledge about mathematics content and students; for example, determining of areas the students find more difficult, identifying common misconceptions, the ability to interpret students' thought processes and predict responses, understanding how content knowledge is constructed in students' minds, and guiding classroom discourse.
- **Knowledge of content and teaching (KCT) in mathematics:** KCT combines knowledge of mathematics with knowledge of teaching; for instance, selecting examples, representations, and activities designed to benefit the most learners, using a variety of problem solving approaches, and adopting a multimodal teaching style.

Figure 2 was created by Ball et al. (2008) to yield a visual representation of the domains included within MKT. In order to better align with PCK, the domain of knowledge of content and curriculum was added to MKT and the domains are divided into two categories: *Subject Matter Knowledge* and *Pedagogical Content Knowledge*.

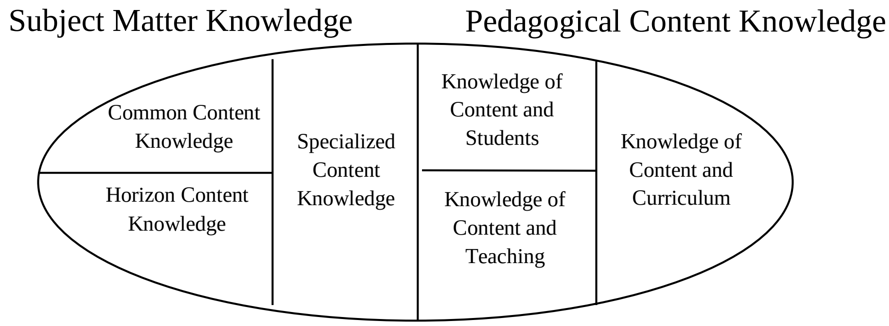


Figure 2. Domains of Mathematical Knowledge for Teaching. Adapted from "Content knowledge for teaching: What makes it special?," by D. L. Ball, M. H. Thames and G. Phelps, 2008, *Journal of Teacher Education, 59*(5), p. 403. Copyright 2012 by Heather Peace. Reprinted without permission.

Teaching requires content knowledge that stretches beyond the normal use of the content and knowledge of the pedagogy required to teach such content. Likewise, possession of science content knowledge is not sufficient for science teaching; thus, there are distinct forms of knowledge necessary for science teaching.

PCK for Science teaching.

Similar to MKT there are domains of pedagogical content knowledge specific to science teaching (Figure 3). Zembal et al. (1999) describe a pre-service science teacher education program that was designed from Shulman's (1986, 1987) concept of PCK. The primary purpose of such a program is to assist pre-service teachers in their ability to integrate knowledge bases as preparation for instruction. Since teacher knowledge is not considered to be a fixed set of information, pre-service teacher educators attempt to give students the skills to develop their own unique PCK base. The domains of knowledge mentioned within the program were: 1) *orientation towards science teaching,* 2) *curricular knowledge of science,* 3) *knowledge of specific science curricular programs,* and 4) *knowledge of instructional strategies*. Magnusson et al. (1999) added to these domains to include *knowledge and beliefs about assessment in* *science* and *knowledge and beliefs about students' understandings of specific science topics*. Moreover, Magnusson et al. (1999) combined *curricular knowledge of science* and *knowledge of a specific science curricular program* into a single knowledge domain: *knowledge and beliefs about science curriculum*. The five knowledge domains are described below as a suggested construct for PCK for Science Teaching.

- **Orientation towards science teaching:** Teachers' orientation to science teaching describes the conceptual map science teachers use to critique, develop, modify and enact teaching and learning activities in the science classroom and the teachers' ideas regarding the purpose or goals of teaching specific science content to specific grade levels (Zembal et al., 1999). Several orientations to science teaching have been suggested: process, academic rigor, didactic, activity driven, discovery, project-based, conceptual change, inquiry, and guided-inquiry (Magnusson et al., 1999; Zembal et al., 1999).
- **Knowledge and beliefs about science curriculum:** Within the domain of knowledge of science curriculum is knowledge of specific science curricular programs, knowledge of the goals and purposes of science education (or curricular knowledge of science) and knowledge of content students will be learning in later classes (Magnusson et al., 1999).
- **Knowledge and beliefs about students' understandings of specific science topics:** The domain pertaining to students' understandings may also be further delineated into knowledge of requirements for learning specific science concepts, variations in learning approaches and areas of science that students find difficult (Magnusson et al., 1999).
- **Knowledge and beliefs about assessment in science:** The domain of knowledge of assessment in science is divided into two categories: knowledge of which dimensions of

science learning are important to assess and knowledge of appropriate methods of assessment.

- **Knowledge of instructional strategies:** Knowledge of subject specific (or general science teaching strategies) and topic specific (or teaching strategies limited to a specific topic) strategies is contained within the domain of knowledge of instructional strategies (Magnusson et al., 1999).

PCK involves transforming subject matter knowledge into pedagogically powerful forms and adapting these forms for various groups of students (Magnusson et al., 1999; Zembal et al., 1999). Using the domains of PCK defined by Grossman (1990), Magnusson et al. (1999) developed a flow chart (Figure 3) to describe their conceptualization of PCK for Science Teaching

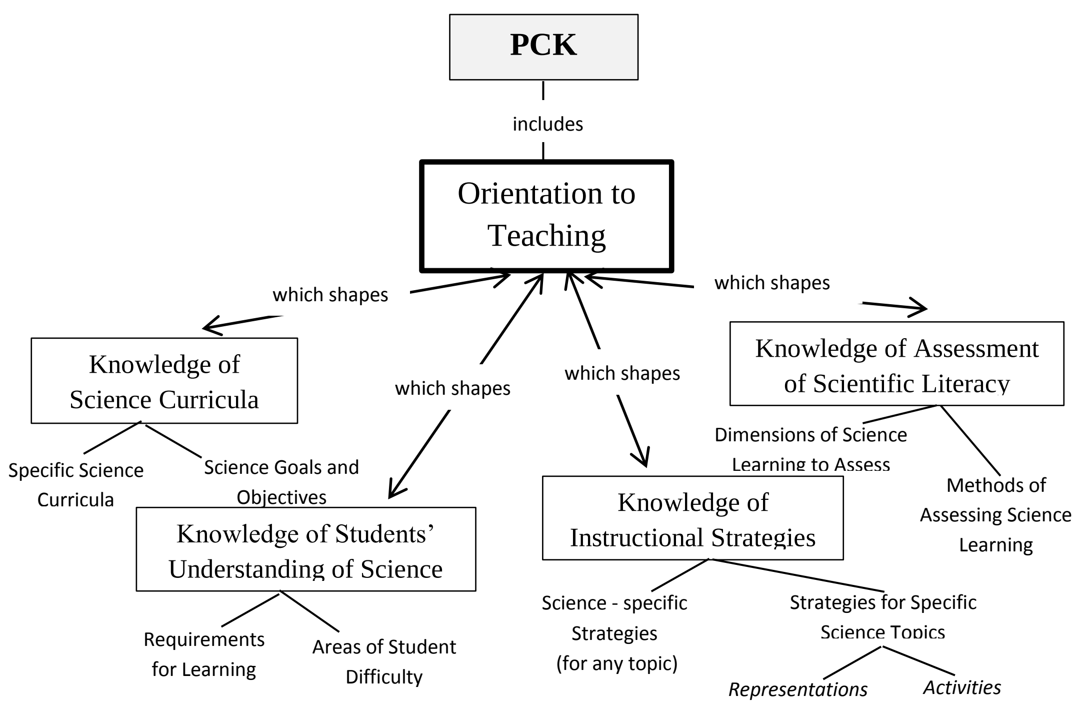


Figure 3. Flow chart of PCK for Science Teaching. "Nature, sources and development of pedagogical content knowledge for science teaching," by S. Magnusson, J. Krajcik, and H. Borko, 1999, in J. Gess-Newsome and N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education*, p. 99. Copyright 2012 by Heather Peace. Reprinted without permission

From Figure 3, all domains of knowledge for science teaching appear to be contained within PCK. Furthermore, *orientation to teaching* science is directly related to all other dimension of science knowledge for teaching. However, none of the other domains appear to share a direct link. Thus, the knowledge base for teaching science appears to be primarily shaped by teachers' orientation to science teaching.

Comparisons between MKT and PCK for Science.

Gaining deeper perspectives of teacher knowledge and the manner in which teacher knowledge domains are developed in mathematics and science for a group of pre-service elementary teachers is one of the focal points of this study. Both MKT and PCK for Science Teaching were constructed using Shulman's (1986, 1987) and Grossman's (1990) conceptions of PCK as a guide; however, certain significant differences are apparent. Firstly, the primary domain within the PCK for Science Teaching knowledge base is orientation to science teaching. Inherent within the construct is the importance of teachers' beliefs regarding science and how science should be approached in the classroom. Conversely, MKT makes no mention of how teachers' beliefs influence teaching strategies. While MKT does discuss knowledge of content and teaching, the implications of teachers' beliefs and philosophies about mathematics education are ignored. Additionally, in MKT, the domain of knowledge of content and curriculum appears to have been included as an afterthought. MKT utilizes *horizon content knowledge* as a parallel for vertical curriculum knowledge, but Ball et al. (2008) does not include an examination of the domain.

On the other hand, PCK for Science Teaching does not define a specific type of scientific knowledge special to teachers. The domain of specialized content knowledge within MKT illustrates a type of mathematical knowledge unique to teachers. Also, MKT shows greater consideration regarding knowledge of students. While PCK for Science Teaching defines a domain dedicated to students' understanding of topics, there is no domain regarding teachers' ability to understand their students. The MKT construct describes knowledge of students as being paramount in stimulating and motivating learning. Hence, the knowledge domains for teaching science and mathematics are related, although not identical.

Teacher knowledge is an elaborate, complex constructive framework that varies not only between disciplines, but between individuals. There is no way to prepare pre-service teachers for every possible scenario they may face in the classroom. However, a strong knowledge base for teaching yields realistic views about what can be completed in the classroom, increases ability to avoid preoccupation with classroom management and focus on learning, assists in the connection of theory with practice, and develops skills for building relationships with students. Additionally, subject-specific knowledge bases, such as MKT and PCK for Science Teaching, illustrate the nuances of teaching within each discipline. As more educational research is completed, greater understandings of subject specific PCK may be achieved. The development of subject-specific knowledge bases for teaching has the potential to lead to increased confidence amongst pre-service and in-service teachers in mathematics and science.

Teaching Efficacy Beliefs

Teacher knowledge is central in forming effective teachers; however, continued success depends greatly upon a teachers' belief in their own ability to influence student outcomes, in other words their teaching efficacy beliefs (Ball, 1988; Ball et al., 2008; Bandura, 1981; Brouwers & Tomic, 2000; Bursal & Paznokas, 2006; Cantrell, Young, & Moore, 2003; Carlsen, 1991; Coladarci, 1992; Grossman, 1989; Grossman, 1990; Hill & Ball, 2009; Hill et al., 2005; Mellado, 1997; Midgley et al., 1989; Morine-Dershimer & Kent, 1999; Shulman, 1986;

Shulman, 1987; Stevens & Wenner, 1996; Swars et al., 2006; Swars, Hart, Smith, Smith, & Tolar, 2007; Tschannen-Moran & Woolfolk-Hoy, 2001; Yilmaz-Tuzun & Topcu, 2008). Efficacy beliefs for teaching are divided into two primary factors, namely: personal teaching efficacy and outcome expectancy. Magnitude, generality and strength are described as three dimensions of efficacy beliefs (Bandura, 1997; Brouwers & Tomic, 2000). Magnitude refers to the level one believes they are capable of performing. Generality is defined as the extent to which changes in self-efficacy beliefs extend to other behaviors and situations. Strength is the resoluteness of conviction that one can perform the behavior in question. With regard to teaching, the dimensions of efficacy beliefs can affect the goals teachers set for themselves and their students, the motivation to continue teaching, and the situations they choose to challenge (Bandura, 1997; Brouwers & Tomic, 2000, Coladarci, 1992, Tschannen-Moran & Woolfolk-Hoy, 2001). Therefore, the development of appropriate teaching efficacy beliefs is an important aspect of becoming an effective teacher. With regard to pre-service elementary teachers, encouraging positive teaching efficacy beliefs associated with mathematics and science can influence future classroom practices such as time dedicated to these subjects and curricular goals (Brouwers & Tomic, 2000). The following section includes a discussion of research regarding the nature of teaching efficacy.

The nature of teaching efficacy.

Teaching efficacy is a simple yet powerful construct. Personal teaching efficacy refers to the teacher's belief in their own ability to successfully plan and execute an action, while outcome expectancy (or general teaching efficacy) refers to the individuals beliefs regarding the likely consequences of performing said action at the given level of competence (Bandura, 1981; Bandura, 1997). Building upon Bandura's (1977) social cognitive theory, researchers in education have spent decades attempting to construct meaningful measures of teaching efficacy beliefs (Bleicher, 2004; Enochs & Riggs, 1990; Enochs, Smith, & Huinker, 2000; Gibson & Dembo, 1984; Kieftenbeld, Natesan, & Eddy, 2011; Riggs & Enochs, 1990; Tschannen-Moran & Woolfolk-Hoy, 2001). However, challenges and questions still arise as to the extent to which efficacy beliefs are stable and/or context specific.

Over time, two primary stands of measuring teacher efficacy beliefs were developed: Rotter's locus of control and Bandura's social cognitive theory. Rotter's locus of control (1966) refers to the extent teachers believe they can control student learning. One of the first efficacy measures was called the RAND measure, which was an extensive questionnaire that included two teaching efficacy beliefs items regarding a teacher's ability to control a student's motivation and performance, stemmed from Rotter's locus of control. Other efficacy measures developed from Rotter's locus of control include: *Responsibility for Student Achievement (RSA), Teacher Locus of Control (TLC)*, and *the Webb Scale*. Meanwhile, Bandura's (1977) cognitive social theory regarding the level of competency an individual believes they will display in a given situation, was also inspiring educational researchers to produce new efficacy measures. Some of the more popular efficacy measures emerging from Bandura's cognitive social theory include: *the Ashton Vignettes, Gibson and Dembo's Teacher Efficacy Scale (TES), Bandura's Teacher Efficacy Scale, Ohio State Teacher Efficacy Scale (OSTES)*, and *the Science Teacher Efficacy Beliefs Instrument (STEBI)*.

Teachers regularly perform a variety of tasks that are regarded as important to teaching. Bandura (1997) suggested that efficacy beliefs might vary given different obstacles. Hence, teacher efficacy beliefs can be measured over an array of contexts and there is no singular agreement as to how efficacy beliefs should be measured. For example, Tschannen-Moran and

Woolfolk-Hoy (2001) developed the OSTES under the assumption that efficacy beliefs are relatively stable across disciplines, however, not across certain teaching tasks, while Riggs and Enochs (1990) developed the STEBI to be specific for science teaching.

Researchers have suggested that teaching efficacy beliefs may vary across disciplines, or even specific content areas (Bandura, 1997; Enochs & Riggs, 1990; Enochs et al., 2000; Riggs & Enochs, 1990). "There are questions about the extent to which teacher efficacy is specific to given contents and to what extent efficacy beliefs are transferable across contents" (Tschannen-Moran & Woolfolk-Hoy, 2001, p. 784). Unfortunately, by keeping teaching efficacy instruments too global the measures of teaching efficacy beliefs are imprecise, and by making the instruments too specific generalizability is lost. A major dilemma in mathematics and science teacher education research is trying to contextually measure teaching efficacy beliefs for mathematics and science without being so specific as to lose generalizability

Teaching efficacy beliefs may fluctuate depending upon the content being taught. Bandura (1997) suggests that self-efficacy beliefs are situational and can vary depending upon the circumstances. Hence teachers require confidence in their ability to perform the tasks associated with teaching in order to develop beneficial teaching efficacy beliefs.

Teaching efficacy beliefs influence teacher burnout, willingness to accept reform, teacher attitudes, and teacher goals (Bandura, 1997; Brouwers & Tomic, 2000; Coladarci, 1992; Midgley et al., 1989; Wheatley, 2002). However, as a construct, understanding and measuring teaching efficacy beliefs is complicated. Teaching efficacy measures must avoid becoming so specific that the instruments lose generalizability; but, diverging levels of teaching efficacy beliefs are likely associated with different tasks. For instance, a teacher with a great deal of subject matter knowledge may believe they lack classroom management skills, or a teacher may have confidence in their ability to engage students but be less confident in their understanding of assessment. As researchers' understandings of efficacy continue to grow, deeper insights regarding the role of teaching efficacy and the factors influencing teaching efficacy will develop.

Pre-service Teachers' Conceptions of Mathematics and Science

One branch of educational research includes the comparison of teachers' conceptions of mathematics and science with reported teaching efficacy beliefs (Bursal & Paznokas, 2006; Lerman, 1990; Swars et al., 2006; Yilmaz-Tuzun & Topcu, 2008). Unfortunately, many pre-service teachers have flawed conceptions regarding the natures of mathematics and science (Abell & Smith, 1994; Ball, 1988; Borko et al., 1992; Carlsen, 1999; Gresham, 2007; Howitt, 2007; Lerman, 1990; Mellado, 1997; Stevens & Wenner, 1996; Szydlik et al., 2003). School science and mathematics is often treated as straight forward processes that must be utilized to solve a given question (Borko et al., 1992; Lowery, 2002). Thus, many teachers fail to convey the explorative natures of mathematics and science. When pre-service teachers do not understand the purpose of these disciplines or the manner in which scientific or mathematical problems are approached, their future students will suffer the consequences (Borko et al., 1992). Furthermore, beliefs as to the natures of science and mathematics influence teacher confidence and efficacy (Bursal & Paznokas, 2006; Lerman, 1990; Swars et al., 2006; Yilmaz-Tuzun & Topcu, 2008). Ergo, the development of appropriate conceptions regarding the natures of mathematics and science is essential for effective teaching.

Developing understandings of mathematics and science.

Pre-service teachers enter methods courses with a variety of conceptions regarding the natures of mathematics and science. Such conceptions are often developed after a lifetime of schooling. However, these conceptions are frequently only shallow understandings of mathematics and science which yield flawed ideas as to the knowledge required to teach mathematics and science (Abell & Smith, 1994; Ball, 1988; Ball et al., 2008; Borko et al., 1992; Brickhouse, 1990; Carlsen, 1999; Hill & Ball, 2009; Howitt, 2007; Lerman, 1990; Magnusson et al., 1999; Zembal et al., 1999). Teacher preparation programs, while focusing on pedagogical strategies, are another opportunity for developing deeper understandings of the natures of mathematics and science; thereby, influencing pre-service teachers' conceptions of teacher knowledge. By creating occasions to question previously held conceptions, methods courses can assist in the development of pre-service teachers' understandings of mathematics and science and the knowledge required for teaching mathematics and science (Abell & Smith, 1994; Szydlik et al., 2003).

A study conducted by Szydlik et al. (2003), determined the mathematical beliefs of a group of pre-service teachers at the beginning and end of their mathematics methods courses. The students were classified as either non-autonomous (taught by an authority figure and memorized), mixed, or autonomous (sense-making rather than memorization). The methods course utilized problem-based learning by giving students complex, involved problems and allowing them to work, as a class, to determine solutions. Significant shifts towards students achieving more autonomous mathematical beliefs were observed. Interestingly, students most frequently attributed the changes in their beliefs to the practice of mathematics as a community (14 of the 24 mentioned working as a community). Thus, the study completed by Szydlik et al. (2003), serves as further evidence of the notion that pre-service teachers often enter teacher education programs with flawed conceptions of the nature of mathematics. In particular, school mathematics is failing to present mathematics as a communal problem-solving approach that requires reflection on the applications of given processes.

Such short-comings have also been seen with regard to the nature of science. Scientific literacy requires not only canonical knowledge of science, but also knowledge of how science works and the role of the sciences in society. Many pre-service teachers have experienced, and understand, science within the school setting; however, they are lacking knowledge of the true nature of science. Abell and Smith (1994) analyzed 140 pre-service elementary teachers' definitions of science and found that many students described science from a realist perspective (i.e., science seeking "truth" within nature); failing to notice the creativity in science, the social aspects of the field, and the ethics involved in science. Furthermore, many of the students in the study lacked an understanding of the nature of scientific knowledge and the manner in which theories are developed or altered (Abell & Smith, 1994). If a teacher believes that science is a body of facts, then they are unlikely to encourage students to seek their own explanations. Hence, methods courses must emphasize science as a physical, cognitive and social activity used to make sense of the world, and not a process of memorizing factual knowledge.

Many pre-service teachers could be considered not scientifically and mathematically literate prior to entering their teacher preparation programs because they do not understand the communal natures of both science and mathematics (Abell & Smith, 1994; Szydlik et al., 2003). Such a lack of understanding is problematic to pre-service teachers who are attempting to develop appropriate knowledge bases for teaching mathematics and science. By researching pre-service elementary teachers' perceptions of the natures of mathematics and science, greater insights will be gained regarding their conceptions of the knowledge domains for teaching mathematics and science. Science and mathematics are not bodies of knowledge meant to be indoctrinated into students. By encouraging constructivist philosophies of learning, pre-service teachers may begin to alter their conceptions of science and mathematics, and realize the importance of explanations and communication in scientific and mathematical thinking. Moreover, through questioning their own perceptions of mathematics and science, pre-service elementary teachers may become more adept at noting the similarities and differences in teaching science and mathematics.

Efficacy beliefs and conceptions of mathematics and science.

Pre-service teachers' teaching efficacy beliefs are related to their conceptions of mathematics and science, both of which can be influenced by a multitude of factors (Bursal & Paznokas, 2006; Swars et al., 2006; Yilmaz-Tuzun & Topcu, 2008). Unfortunately, when pre-service teachers have weak understandings of science and mathematics, such conceptions can lead to inappropriate personal teaching efficacy beliefs. Thus, teacher preparation programs take on the role of providing experiences that inform pre-service teachers' understandings of mathematics and science, and assist pre-service teachers in developing appropriate personal teaching efficacy beliefs.

Yilmaz-Tuzun and Topcu (2008) conducted a study, with 429 pre-service teachers in Turkey, in which they performed a regression analysis on the Schrommer Epistemological Questionnaire (SEQ) to determine which predictor variables (epistemological world views, self-efficacy for science teaching, and outcome expectancy) contributed to the primary factors of the SEQ. They found pre-service teachers with high outcome expectancy scores tended to believe that scientific knowledge was unchanging (Yilmaz-Tuzun & Topcu, 2008). In other words, pre-service teachers who were apt to believe that their students would do well in learning science also appeared to believe that science is a concrete body of knowledge. Unfortunately, these results are paradoxical. While improving teaching efficacy beliefs is a goal of teacher preparation, improving teaching efficacy beliefs through false impressions of the subject matter is unacceptable. Fortunately, Yilmaz-Tuzun and Topcu (2008) also found teachers with high self-efficacy, high outcome expectancy, and a strong believe in student-centered learning approaches (epistemological world views) tended to believe their students learning ability was not fixed (Yilmaz-Tuzun & Topcu, 2008). Neither personal teaching efficacy nor outcome expectancy was found to be significant contributors to the pre-service teachers' conception of science as simple knowledge (single solution problem, no integration) or omniscient authority (the role of authority in science). Yet, as researchers continue to study science teaching efficacy beliefs and conceptions of the nature of science, deeper understandings with regard to their relationship may be obtained.

Another factor found to affect teaching efficacy is subject anxiety. Mathematics teacher efficacy has been shown to have a relationship with mathematics anxiety (Bursal & Paznokas, 2006; Swars et al., 2006). Such results are not surprising because if individuals view mathematics as a threatening discipline, it is unlikely they will have a great deal of confidence in their personal ability to teach the subject. Bursal and Paznokas (2006) divided 65 pre-service elementary teachers into low, medium, and high mathematics anxiety groups, and determined a significant difference in efficacy beliefs between the high and low anxiety groups. Interestingly, the pre-service teachers in the study showed significantly different results in both mathematics and science teaching efficacy beliefs between the two mathematics anxiety groups (Bursal & Paznokas, 2006). Swars et al. (2006) also conducted a study in which a statistically significant negative correlation between mathematics anxiety and mathematics teaching efficacy beliefs was determined. In addition, Swars et al. (2006) included interview data from 28 pre-service teachers to gain greater insights as to their perceived conceptions of mathematics. Interestingly, the interview data did show that pre-service teachers with high mathematics anxiety levels appeared to hold absolutist/realist views of mathematics, while those with low mathematics anxiety described mathematics as requiring reasoning, problem-solving and communication (not memorization).

Inconsistencies within pre-service teachers' perspectives on the natures of mathematics and science can result in unreliable teaching efficacy beliefs (Bursal & Paznokas, 2006; Swars et al., 2006; Yilmaz-Tuzun & Topcu, 2008). While building pre-service teachers' teaching confidence is important, developing accurate understandings of mathematics and science as disciplines holds greater significance. By enhancing perceptions of the natures of mathematics and science, pre-service teachers can improve their understandings of the knowledge necessary for teaching mathematics and science and develop more authentic teaching efficacy beliefs.

Conceptions regarding the natures of mathematics and science can influence both teaching efficacy beliefs and the perceived knowledge domains necessary for teaching. Hence pre-service teacher educators must ask the question: How should mathematics and science be perceived? In other words, consideration must be paid as to which perspectives of the natures of mathematics and science will be most beneficial to pre-service elementary teachers. Conceptions of mathematics and science will also affect what types of knowledge pre-service teachers pursue. Thus, the development of appropriate conceptions of mathematics and science will have a lasting impact on the future careers of pre-service elementary teachers.

Conceptions and Efficacy Beliefs Influencing Teaching

There are a multitude of factors affecting teachers' perceptions of the knowledge necessary for teaching mathematics and science. Factors such as conceptions regarding the natures of mathematics and science and teaching efficacy beliefs impact classroom practices. As pre-service teachers develop their understandings of the role (and types) of knowledge in mathematics and science teaching, perceptions of mathematics and science should also mature. Noting the impact of teachers' notions of mathematics and science and teaching efficacy beliefs on classroom practices is important in encouraging pre-service teachers to cultivate the most beneficial perceptions and beliefs.

The influences of teachers' conceptions of on classroom practices.

Teachers' conceptions of mathematics and science can affect how they choose to present scientific and mathematical objectives in the classroom. Unfortunately, measuring scientific and mathematical philosophies is no simple task. However, personal philosophies and outlooks affect all forms of human behavior. A constructivist may emphasize the importance of students constructing their own understandings, while an absolutist/realist may be more concerned over students obtaining the correct answer by the most efficient means. Methods courses attempt to develop pre-service teachers' understandings of the natures of science and mathematics with the hope that those understandings will translate into action, but determining if (and how) such conceptions influence classroom practices is a challenge.

Lerman (1990) used qualitative methods to compare the viewpoints of two different mathematical philosophies, namely: extreme 'absolutist' (mathematics is the discovery of timeless truths) and extreme 'fallibilists' (mathematics is a socially constructed "language game"). The interviews showed radically different reaction to the same teaching scenario with the absolutists demonstrating concern over allotting too much time for incorrect student responses, and the fallibilists showing more concern for students' understandings (Lerman, 1990). The differing philosophical beliefs resulted in very different perspectives with regards to the same lesson. Thus, having conflicting understandings of the nature of mathematics can result in contradictory conceptions as to how mathematical objectives should be presented.

Brickhouse (1990) found similar results with respect to the influences of nature of science philosophies on classroom practices. The study involved interviewing three in-service teachers and observing their lessons. The results showed that the teachers' philosophies with regard to the nature of science affected their lessons on the nature of science both implicitly and explicitly (Brickhouse, 1990). On the contrary, Mellado (1997) found no significant correspondence between philosophies regarding the nature of science and the classroom practices of four pre-service teachers. However, Mellado (1997) did note: "One of the experts and the novice had similar pictures of scientific knowledge which manifested a positivist and empiricist view of science. This conception conditioned the instructional goals of these two teachers" (Mellado, 1997, p. 335). Ergo, personal philosophies may not always translate into action, but they can still influence the goals set by instructors.

When teachers view science and mathematics as concrete bodies of never changing knowledge that can be memorized, they are unlikely to require students to construct solutions and will likely fail to convey the communal and creative aspects of both disciplines (Abell & Smith, 1994; Lerman, 1990; Mellado, 1997; Szydlik et al., 2003). Furthermore, conceptions of the natures of science and mathematics can influence the instructional goals established by the teacher (Lerman, 1990; Mellado, 1997). However, developing understandings of the natures of mathematics and science may not necessarily influence classroom practices. Long held pedagogical philosophies are not easily swayed. Many pre-service teachers have spent their entire academic careers observing mathematics and science in a traditional lecture environment, and are unfamiliar with any other teaching techniques for science and mathematics. Yet, if pre-service teachers do not develop their understandings of mathematics and science, they will see no reason to change the traditional lecture format.

The influence of efficacy beliefs on in-service teachers.

As conceptions of subject matter knowledge grow and mature, teaching efficacy beliefs also change. Efficacy beliefs are developed through four primary processes: mastery experiences; vicarious experiences; verbal persuasion; and physiological arousal (Bandura, 1997; Brouwers & Tomic, 2000). Mastery experiences are experiences which an individual has that serve as indicators of one's capabilities. Vicarious experiences occur through the observation of other people performing a task. Verbal persuasion affects efficacy beliefs when others guide individuals to believe in their own capabilities. Finally, physiological arousal is the physical effect one experiences when feeling vulnerable. Each of these processes to occur through observations, student teaching, lecturing, discussions, and classroom experiences. As these experiences continue, pre-service teachers begin to develop teaching efficacy beliefs. These beliefs are later carried into the classroom. Teaching efficacy beliefs are a strong indicator for the behavior of in-service teachers.

One factor influenced by self-efficacy is motivation to persist in the face of obstacles (Bandura, 1997; Brouwers &Tomic, 2000). Similarly, teaching efficacy beliefs have been shown to have influence over teacher burnout and commitment to teaching (Brouwers & Tomic, 2000; Coladarci, 1992). Brouwers and Tomic (2000) measured self-efficacy and teacher burnout using two instruments: Self-Efficacy Scale for Classroom Management and Discipline and Maslach Burnout Inventory for Teachers. Using a structural modeling equation, the researchers found that self-efficacy influences personal accomplishment (or the judgment of the consequences of one's performance). Thus, the researchers concluded that teachers with a low teaching self-efficacy did not believe their actions would change student behavior, and as such they did very little to try to change student behavior. Additionally, Coladarci (1992) tested commitment to teaching with one simple question: "Suppose you had it all to do again: In view of your present knowledge, would you become a teacher?" (Coladarci, 1992, p. 323). The question was graded on a five point Likert scale and efficacy was measured on the Gibson and Dembo (1984) instrument. Coladarci (1992) compared teaching commitment with general efficacy, personal efficacy, student-teacher ratio, school climate, and gender. The determination was that general and personal efficacy beliefs were the strongest predictors of commitment to teaching. Ergo, strong teaching efficacy beliefs have been shown to have a positive impact on in-service teachers' willingness to work for change in their students and commitment to teaching.

Conversely, strong teaching efficacy beliefs have been shown to have a negative effect on the adoption of educational reform (Wheatley, 2002). Wheatley (2002) based the conclusion that doubt of one's personal teaching efficacy beliefs can have a positive impact on educational reform on a thorough literature review and discussion of the theoretical framework of self-efficacy. Since self-efficacy beliefs are influenced by physiological arousal, a lack of confidence in teaching may encourage teacher learning (Bandura, 1997; Wheatley, 2002). Teachers who embrace a willingness to learn are more likely to work towards deeper understandings of the material they are expected to teach (e.g., mathematics and science). Furthermore, self-doubt can be an incentive for productive collaboration. While self-doubt has certain beneficial qualities, Wheatley (2002) is not advocating for global self-doubt in teaching. In order for self-doubt to be considered beneficial to school reform, teachers require confidence in their own ability to learn. Thus, pre-service and in-service teachers must proceed with caution to ensure that strong efficacy beliefs do not eventually translate into an unwillingness to change.

In addition to influencing the practices of in-service teachers, evidence has shown teaching efficacy beliefs influence student achievement (Midgley et al., 1989). Over a two-year longitudinal study, Midgley et al. (1989) compared teacher efficacy beliefs with student achievement for a sample of junior high students in mathematics courses. The study determined that teacher efficacy did not have an immediate impact on student achievement. However, as students progressed to different teachers, the impact of efficacy beliefs became more apparent. Specifically, students moving from a teacher with strong efficacy beliefs, to a teacher with low efficacy beliefs suffered the most in terms of attitudinal changes, perceived performance, and perception of task difficulty (Midgley et al., 1989).

Given the influential nature of teaching efficacy beliefs on in-service teachers, teacher preparation programs courses have a unique opportunity to shape the teaching efficacy beliefs of pre-service teacher in a manner which will be most beneficial. By providing experiences and discussions designed to sculpt positive efficacy beliefs, teacher preparation programs impact both the practices and the goals of pre-service teachers (Bandura, 1997; Brouwers & Tomic, 2000). Since teaching efficacy beliefs are of great importance, pre-service teachers must work to cultivate perspectives of mathematics and science that yield the most beneficial teaching efficacy beliefs.

Educational researchers have written a great deal regarding the natures of mathematics and science and teaching efficacy beliefs; however, observing such constructs in practice is the only way to determine the extent of their power. Pre-service teachers' conceptions, beliefs, and philosophies will influence not only their pedagogical approaches, but also the types of knowledge they emphasize to students, their commitment to teaching, and their willingness to adapt lessons and use new techniques. Thus, appropriate perceptions of the natures of mathematics and science and positive teaching efficacy beliefs must be developed to foster an accurate understanding of the complex knowledge domains required for successful science and mathematics teaching.

Conclusions

Pre-service teachers often have shallow understandings of the natures of mathematics and science. To that end, the research proposed in this study is intended to examine a group of pre-service teachers and their understandings of the knowledge required to teach mathematics and science. Specifically, the project involves observing the self-efficacy beliefs of pre-service teachers with regard to specific scientific and mathematical tasks at the beginning and end of their science and mathematics methods courses. By reviewing pre-service teachers' conceptions of the knowledge required to teach mathematics and science, the researcher can make comparisons between disciplines to better understand the perceived differences between mathematics and science teaching.

Furthermore, the interrelation of mathematics and science understandings and self-efficacy beliefs will be studied. Since mathematics and science have so many similarities and are often grouped together in performance related research, this project is also researching the relationships of teaching efficacy beliefs for specific mathematical and scientific tasks as seen by pre-service elementary teachers. Mathematics and science are unique disciplines; yet, they are intrinsically bound. Studying the relationships between mathematical and scientific conceptions and teaching efficacy beliefs for pre-service elementary teachers may be helpful in exploring how to best promote positive understandings of mathematics and science and teaching efficacy beliefs.

Many researchers have discussed the unique knowledge domains required for teaching mathematics and science (Ball, 1988; Ball et al., 2008; Borko et al., 1992; Carlsen, 1991;

Carlsen, 1999; Grossman, 1989; Hill & Ball, 2009; Hill et al., 2005; Lowery, 2002; Magnusson et al, 1999; Morine-Dershimer & Kent, 1999; Shulman, 1986; Shulman, 1987; Stevens & Wenner, 1996; Zembal et al., 1999). Moreover, previous researchers have reviewed the influence of pre-service and in-service teachers' conceptions and efficacy beliefs in mathematics and science on classroom behaviors and educational goals (e.g., Abell & Smith 1994; Bandura, 1997; Brouwers & Tomic, 2000; Bursal & Paznokas, 2006; Buss, 2010; Cantrell et al., 2003; Coladarci, 1992; Gresham, 2007; Howitt, 2007; Mellado, 1997; Swars et al., 2006; Swars et al., 2007; Szydlik et al., 2003; Tschannen-Moran & Woolfolk-Hoy, 2001; Utley, Moseley, & Bryant, 2005; Wheatley, 2002; Yilmaz-Tuzun & Topcu, 2008). The research proposed in this project intends to observe pre-service elementary teachers understandings and self-efficacy beliefs with regards to mathematics and science; and discuss the similarities and differences in the perceived knowledge domains for teaching mathematics and science from the perspective of a cohort of pre-service teachers. Within this project, the pre-service teachers will be given an activity specifically designed to produce doubt in their conceptions of the natures of mathematics and science and the knowledge required to teach mathematics and science. By initiating doubt in previous held conceptions, the development of deeper understandings of the natures of mathematics and science in pre-service teachers may be observed.

Mathematics and science are distinctive disciplines with many similarities. Hence developing appropriate conceptions of mathematics and science within the minds of pre-service teachers can be extremely challenging. When pre-service and in-service teachers fail to understand the true natures of mathematics and science, they can develop erroneous teaching efficacy beliefs. Additionally, weak interpretations of natures of mathematics and science can cause false perceptions of the knowledge required for teaching each discipline. Pre-service teachers must work to develop clear understandings mathematics and science and the knowledge bases necessary for teaching mathematics and science, which will assist in the promotion of beneficial teaching efficacy beliefs for mathematics and science, and give affirmative perspectives about their future science and mathematics curricula.

CHAPTER 3 – METHOD

The researcher utilized a mixed methods approach to study the pre-service teachers' perceptions of knowledge for teaching and teaching efficacy beliefs in mathematics and science. The quantitative analyses were used to compare/relate performance and confidence scores within mathematics and science, performance and confidence scores between mathematics and science, and changes in performance and confidence scores between the initial and final administrations of the PETSMA. The qualitative analyses added depth and expression to the interpretations.

Participants

The participants were pre-service elementary teachers during their first year in the teacher preparation sequence in a college of education, which typically starts during their junior year, at a university in the southwest United States. Prior to being accepted into the College of Education the students enroll in several education courses such as Child Development, Introduction to Educational Technology, and Literacy in Children's Literature. The participants were all female, and with the exception of three students, between 20 and 22 years old. The students proceed through the teacher preparation program as a cohort taking a fixed sequence of courses. When the study was conducted, the students were taking the sequence listed in Table 1.

Table 1
Junior block courses for pre-service elementary teachers

Fall Semester (Junior 1)	Spring Semester (Junior 2)
Study of Exceptional Students	Educational Psychology
Science Methods	Reading Methods
Mathematics Methods I	Mathematics Methods II
Play and Creativity	Social Studies Methods
Teaching Writing	English as a Second Language or Special Education
Field Placement	Field Placement

The sample was based on convenience. All 50 students in the junior 1 block initially participated in the study. Ultimately, a subset of 35 students from the original 50 completed the study. All students consented to participate.

Materials

Pre-Service Elementary Teachers' Science and Mathematics Activity (PETSMA).

The PETSMA was developed prior to this study as an activity for pre-service elementary teachers (Peace, Bloom, & Fuentes, 2012). The activity was designed to examine knowledge, confidence, and confidence in teaching for various science and mathematics topics for grade levels K – 6, with the intention of promoting thought about the types of knowledge necessary for teaching mathematics and science (Appendix A). The PETSMA consists of two mathematics questions and two science questions per grade level. For each set of two questions, the first item is a procedural or factual question and the second item relates to the concepts involved in the first question. For example, the sixth grade mathematics questions involve adding fractions, and an explanation as to why common denominators are necessary for adding fractions. After each question, there are two items designed to measure confidence: *A. This question was easy for me to answer;* and *B. This question will be easy for me to teach.* Confidence-based items were measured on a 0 to 3 scale (0 = Strongly Disagree, 1 = Disagree, 2 = Agree, 3 = Strongly Agree). The responses to the science and mathematics questions were also graded on a 0 to 3 scale based on a rubric (Appendix B).

All factual/procedural mathematics items were collected from grade level, state-approved textbooks (Lappan, Friel, Fey, & Phillips, 2009; Charles et al., 2009). The questions were based on the state content standards, not the process standards for mathematics (Texas Education Agency, 2011). After selecting the factual/procedural items, concept-based questions were designed by the mathematics methods course instructor to parallel each factual/procedural question. The mathematics topics for grade levels K – 6 are as follows: counting, measurement, whole-number addition/subtraction, properties of shapes, data representation and analysis, probability, and addition of fractions. Ergo, all mathematics questions align with appropriate grade level content (Texas Education Agency, 2011).

In a similar fashion, all science questions were selected from, or based upon, state-approved texts (Baptiste et al., 2000; Biggs, Daniel, Feather, Snyder, & Zike, 2002). The science questions are not limited to a single science discipline. The science items for grades K – 6 include: animal classification, plant anatomy, temperature and heat transference, astronomy, human physiology, plant physiology, and physics of objects in motion (Baptiste et al., 2000; Biggs et al., 2002). The PETSMA questions were not designed to measure the process standards of science education, only science content knowledge. Thus, the science items that comprise the PETSMA are appropriate measures of content knowledge for K – 6 grade level science.

Grading rubric for the PETSMA.

The grading rubric developed to assist in scoring the PETSMA is provided in Appendix B. After evaluating a few of the responses on the pre-activity to observe common errors, an assistant professor in mathematics education and an assistant professor in science education generated the grading rubric. Four graders (the two assistant professors and two graduate assistants) worked together in the scoring of the pre-activities. The researcher graded a subset of the activities to ensure inter-rater reliability. The overall inter-rater reliability for scoring the pre-administrations of the PETSMA was 85%. For the post-activity, the researcher was responsible for grading all mathematics and science items. Table 2 summarizes the means calculated for each participant.

Table 2
Chart of means calculated for the quantitative analyses of the PETSMA

Mathematics Means	Science Means
Mathematics Factual/Procedural Items	Science Factual/Procedural Items
Mathematics Conceptual Knowledge Items	Science Conceptual Knowledge Items
Confidence in Answering Factual/Procedural Mathematics Questions	Confidence in Answering Factual/Procedural Science Questions
Confidence in Teaching Factual/Procedural Mathematics Content	Confidence in Teaching Factual/Procedural Science Content
Confidence in Answering Conceptual Mathematics Questions	Confidence in Answering Conceptual Science Questions
Confidence in Teaching Conceptual Mathematics Content	Confidence in Teaching Conceptual Science Content

MTEBI and STEBI-B.

The MTEBI is a validated instrument designed to measure the mathematics teaching efficacy beliefs of pre-service elementary teachers (Bleicher, 2004; Enochs et al., 2000; Kieftenbeld et al., 2011). Similarly, the STEBI-B is a validated instrument designed to measure the science teaching efficacy beliefs of pre-service elementary teachers (Enochs & Riggs, 1990; Riggs & Enochs, 1990). Both instruments are scored using a 5-point Likert scale. Teaching efficacy beliefs, as measured by these instruments, include two factors: personal teaching efficacy beliefs and outcome expectancy beliefs. Both instruments are grounded in Bandura's social learning theory, which postulates that behavior is based upon two factors, namely people's beliefs in their own ability to perform a task (self-efficacy) and on their beliefs that performing the task would lead to desirable outcomes (outcome expectancy) (Bandura, 1977; Bandura, 1981; Bandura, 1997).

Classroom discussions.

The science and mathematics methods instructors facilitated all initial discussions, which consisted of the pre-service teachers' reflections of the activity. A protocol was constructed for the final discussions and given to the science methods instructor who served as the facilitator. For the final discussions, the facilitator was informed of his role as a moderator. The protocol suggested a list of questions to serve as a guide for the classroom discussions (Appendix C). The protocol focused largely on how and if the pre-service teachers changed with respect to their understanding of the knowledge and confidence required for mathematics and science teaching over the progression of the junior block. All classroom discussions were digitally video recorded and transcribed for later analysis.

Procedure

The PETSMA was administered in the two sections of the first semester of the elementary mathematics methods course in August of 2010. Completion of the activity took approximately 35 minutes of class time. Immediately following the completion of the activity, the participants conversed in small groups regarding their initial impressions of the activity. After approximately 15 minutes of small group discussions, an hour-long whole-class discussion was held.

The PETSMA was administered to the pre-service teachers a second time in April of 2011 during the second semester of their elementary mathematics methods course sequence. Again, the cohort was divided into two course sections. The post-administration of the PETSMA took approximately 30 minutes to complete. Immediately following the activity, a whole-class discussion was conducted. During the final classroom discussions, some of the questions on the protocol were referenced (Appendix C). However, discussions were largely driven by the students' reflections on the activity. Each of the two final discussions lasted for approximately one hour.

The mathematics and science methods instructors requested that the pre-service teachers complete the MTEBI and STEBI-B in April of 2011 outside of class time. The instruments were available to the participants using an online survey system.

Data Analysis

The quantitative and qualitative analyses were completed in a parallel fashion.

Analysis of the PETSMA.

A preliminary analysis of the distribution of scores for each item was performed in order to determine the best approach for further analyses. The performance items were then summed and the confidence ratings were averaged to create 12 factors, six pertaining to mathematics and six pertaining to science (Table 2). The item-composites were then submitted to comparisons using the Wilcoxon signed rank test and correlations using Spearman's ρ .

Pre- and post-PETSMA comparisons.

A Freidman's two-way analysis of variance and a chi-square were conducted to compare pre- and post-activity performance item-composites. An additional Friedman's two-way analysis of variance and chi-square were completed to compare all average confidence ratings. Significant differences were detected and a series of post-hoc tests (namely, Wilcoxon signed rank tests) were completed in order to isolate where the significant differences occurred.

The MTEBI, the STEBI-B, and the PETSMA.

MTEBI and STEBI-B scores were correlated with the confidence questions on the PETSMA. Mean scores were computed for each of the confidence factors calculated from the post-administration of the PETSMA (Table 2). For the MTEBI and STEBI-B, the researcher identified items as pertaining to either personal teaching efficacy beliefs or outcome expectancy beliefs before beginning the analyses. Additionally, the researcher adjusted numerical scorings assigned by the computer that pertained to items requiring reverse-scoring. All of the mathematics means were correlated with both the personal efficacy averages and outcome expectancy averages from the MTEBI through a Spearman's ρ correlation. All of the science averages were correlated to the personal efficacy averages and outcome expectancy averages from the STEBI-B, as well. Finally, because the distributions of scores from the MTEBI and STEBI-B were relatively normal, the results were compared and related using a MANOVA, pairwise t-tests, and Pearson's one-tailed correlations.

Analysis of classroom discussions.

The two initial and two final classroom discussions were video recorded, transcribed, and analyzed as a portion of this study. During the course of the transcribing, the researcher assigned pseudonyms to each of the participants. Next, all of the discussions were coded using the constant comparative method. There are four primary stages to the constant comparative method: "(1) comparing incidents applicable to each category, (2) integrating categories and their properties, (3) delimiting the theory, and (4) writing the theory" (Glaser & Strauss, 1999, p. 105). The researcher repeated the following process for coding both the initial and final discussions. First, the researcher reviewed the data by reading the transcribed notes, while watching and listening to the recordings. Student comments were written on index cards to be coded and re-coded until themes emerged. Neither the codes nor the categories were pre-determined; instead they originated from the data. After the first coding, the index cards were shuffled and the process was repeated, collapsing codes as warranted. While the coding process was being completed, memos were written regarding conflicts within categories, relevant observations, and the researcher's theoretical notions, which aided in the later merging of categories. During the third and final sequence of coding, themes emerged.

Trustworthiness and Limitations

Analytical interpretations based upon qualitative data hold certain limitations. As a researcher, one does not want her personal biases to influence the results. However, humans are naturally subjective, and do not enter situations without certain opinions. In an effort to reflect upon personal subjectivities and their possible influences on the data analysis, all discussion data that produced a strong emotional response from the researcher was flagged into a subjectivity file. (Note that the data was not removed from the previously outlined coding process; it was simply copied into a subjectivity file prior to writing the results section.) The researcher had the task of asking why data within the subjectivity file produced a powerful or personal response, and how could that response influence later interpretations. Additionally, peer-debriefing with the methods course instructors who served as facilitators during the discussions took place in order to share personal reactions and discuss alternate perspectives. Thus, by noting personal biases, considering their origins, and discussing them from a variety of perspectives the researcher attempted to account for and understand personal biases.

To enhance trustworthiness, member-checking with the participants and the methods course instructors was completed. The methods instructors were given the opportunity to scrutinize the study. Furthermore, the pre-service teachers were contacted with a list of conclusions drawn from the data analyses. The pre-service teachers were given ample time to review the conclusions and provide feedback to the researcher. In other words, the cohort was also given the opportunity to review the interpretations drawn from the data analysis.

By noting such limitations, the researcher was able to enhance trustworthiness by avoiding conclusions which stretch beyond the scope of the study. Trustworthiness is also strengthened through the use of multiple data sources such as the PETSMA, the MTEBI, the STEBI-B, and the classroom discussions. Therefore, allowing others to assess the interpretations and noting the limitations and biases of the study reinforces the accuracy of the conclusions derived from the analyses.

CHAPTER 4 – RESULTS

This study called for quantitative and qualitative measures to be used in concert to better understand the perspectives held by the cohort of pre-service elementary teachers. The quantitative measures were utilized to notice trends, make comparisons and search for relationships among variables. The qualitative analyses were used to add depth and meaning regarding the thoughts and ideas of the pre-service teachers. Statistical analyses were performed on the pre- and post-result of the PETSMA. Analysis of discussions, paired with the PETSMA results, lend insight into the pre-service teachers' perceptions of the knowledge required for mathematics and science teaching.

Analysis of the PETSMA

A preliminary inspection of pre- versus post-PETSMA results revealed that patterns of performance scores and confidence ratings were markedly similar for both mathematics and science question sets. Therefore, only post-PETSMA results are described in detail, for mathematics and science, and then pre-versus post-comparisons are discussed.

Question 3: How does the cohort's factual/procedural knowledge compare to conceptual knowledge in elementary level mathematics and science?

First, performance scores for both factual/procedural and conceptual mathematics questions were analyzed descriptively for each grade level. Figure 4 displays the minimum, 1st quartile, median, 3rd quartile and maximum scores by grade level for all post-PETSMA mathematics questions.

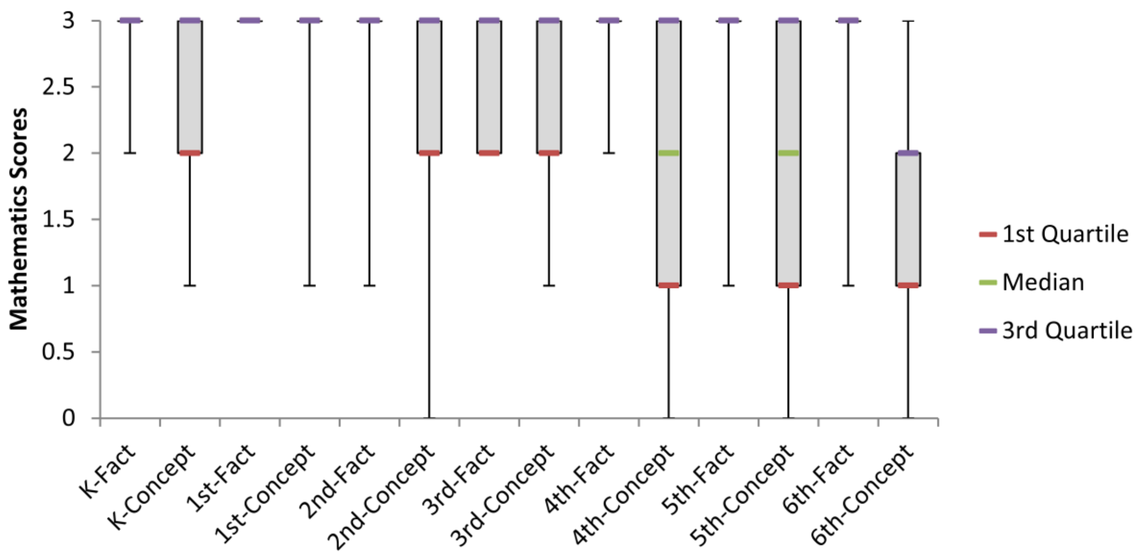


Figure 4. Grade-level scores for mathematics performance on PETSMA. Top possible score = 3.

As can be seen from the boxplots, the pre-service teachers performed well on all mathematics questions. For all questions except the 6th grade conceptual mathematics question, 25% of students received a top score of 3. Additionally, on all factual/procedural mathematics questions 75% of participants earned a top score of 3, except for the third grade question. Scores on the conceptual mathematics questions began to decline around the second grade, but most scores remained near 3; thus the data were not normally distributed. In order to compare overall results pertaining to mathematics performance, factual/procedural and conceptual mathematics scores were separately totaled for each student and subjected to a nonparametric test, namely the Wilcoxon signed rank test (Table 3).

Table 3
Wilcoxon signed rank test for factual/procedural and conceptual mean total mathematics scores

	Factual/Procedural		Conceptual		
	Mean	SD	Mean	SD	Z
Mean total scores	20.26	0.9	15.66	3.3	-5.10*

* $p \leq 0.001$

Overall, the pre-service teachers performed significantly better on the factual/procedural mathematics questions than the conceptual mathematics questions.

Science performance scores were analyzed for the post-PETSMA as well. Figure 5 displays the science scores by grade level for factual/procedural and conceptual questions. Performance on factual/procedural science questions began to decrease around the third grade, with the exception of sixth grade, while scores on conceptual science questions began to decrease around the second grade. Interestingly, the lowest overall performance scores were seen with respect to the fourth and fifth grade factual/procedural science questions; with 75% of the participants scoring 1 or below.

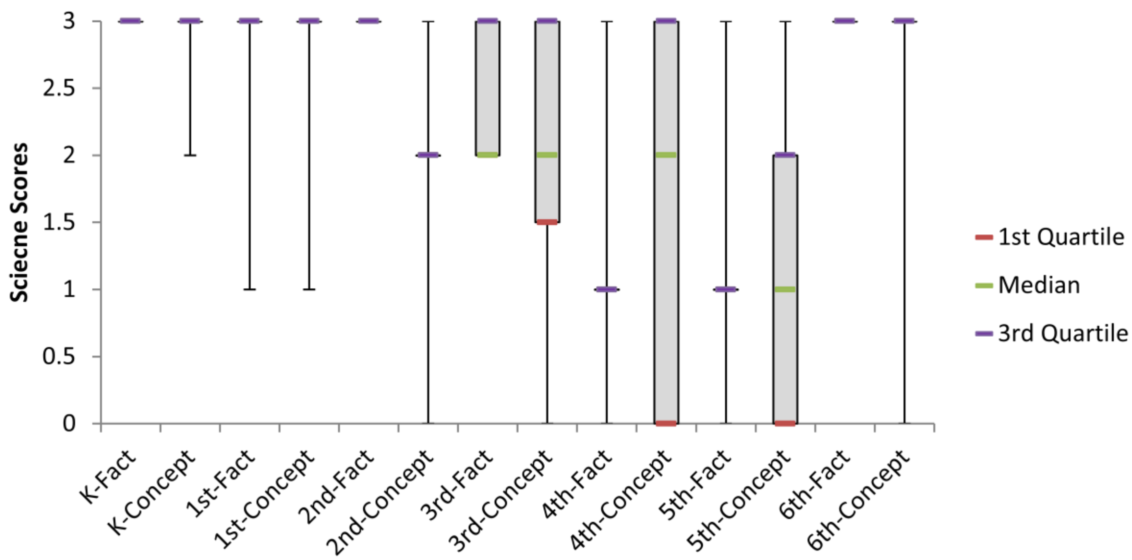


Figure 5. Grade-level scores for science performance on PETSMA. Top possible score = 3.

After reviewing the science performance scores by grade-level, totals were calculated to compare overall performance on factual/procedural questions to performance on conceptual questions (Table 6). As with the mathematics scores, a statistically significant difference was determined between performance on factual/procedural and performance on conceptual science questions (i.e., students performed better on factual/procedural science questions than the related conceptual questions).

Table 4
Wilcoxon signed rank test for factual/procedural and conceptual mean total science scores

	Factual/Procedural		Conceptual		
	Mean	SD	Mean	SD	Z
Mean total scores	16.49	1.4	15.66	2.5	-2.77*

* $p \leq 0.01$

Question 4: How does students' knowledge of elementary mathematics and science change between the beginning and end of their junior year in their teacher preparation program?

Figure 6 displays the initial and final PETSMA performance scores on factual/procedural and conceptual mathematics/science questions.

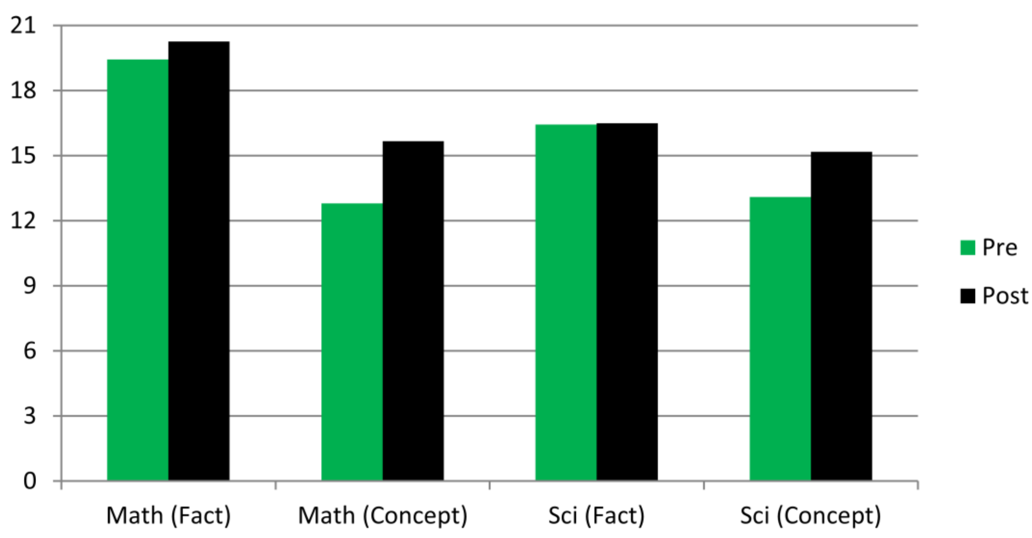


Figure 6. Mean performance scores for pre- and post-PETSMA results. Top possible score = 21. All results pertaining to the initial administration of the PETSMA are in green and all results pertaining to the final administration of the PETSMA are in black.

Since preliminary observations of the data indicated that scores were not normally distributed, non-parametric tests were performed to compare various means for the PETSMA results. The Wilcoxon signed rank test is a non-parametric version of the paired sample t-test. The Friedman F test is a rank order test similar to the repeated measures ANOVA, but designed for multiple variables that are non-parametric. First, totals from the initial and final administrations of the PETSMA were compared using the Friedman F test to study changes over time. Next, performance scores on factual/procedural and conceptual questions for mathematics and science were compared using Wilcoxon signed rank tests.

As shown in Figure 6, the performance scores on factual/procedural questions were higher than performance scores on conceptual questions for both the initial and final administrations of the PETMSA. The Friedman's F test indicated a significant difference between pre- and post-activity performance results $\chi^2(7) = 165.517$; *p = 0.000*. Thus, post-hoc analyses were computed using Wilcoxon signed rank tests to ascertain which factors were responsible for the differences in the pre- and post-PETSMA performance results (Table 5).

Table 5
Wilcoxon signed rank tests of the pre- and post-PETSMA performance results

	Pre-PETSMA		Post-PETSMA		
	Mean	SD	Mean	SD	Z
Performance on factual/procedural mathematics questions	19.43	1.2	20.26	0.9	-3.454*
Performance on conceptual mathematics questions	12.80	3.5	15.66	3.3	-3.931*
Performance on factual/procedural science questions	16.43	1.2	16.49	1.4	0.199
Performance on conceptual science questions	13.09	3.1	15.17	2.5	-3.537*

* $p \leq 0.001$

For mathematics, performance scores on both factual/procedural questions and conceptual questions increased significantly between the initial and final administration of the PETSMA. For science, statistically significant improvements were only seen with respect to performance scores on conceptual questions, not on factual/procedural questions.

Question 5: How confident is the cohort about elementary level mathematics and science?

In addition to measuring performance on various elementary level mathematics/science questions, the PETSMA included items for measuring confidence levels in doing and teaching mathematics/science. Confidence levels in answering factual/procedural questions and conceptual questions from the post-PETSMA data were compared with one another, as well as to confidence in teaching said questions for both science and mathematics.

Question 5a: How confident are the pre-service teachers about their knowledge of elementary level mathematics and science?

Before making statistical comparisons, all confidence ratings related to answering mathematics questions were reviewed for each grade level, as shown in Figure 7.

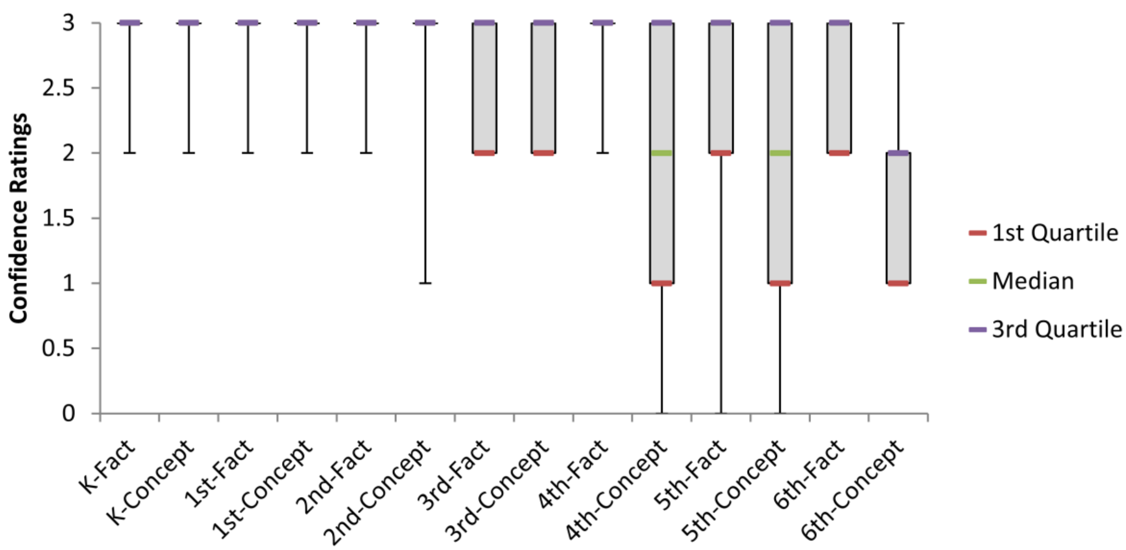


Figure 7. Confidence ratings for answering mathematics questions by grade-level. Top possible rating = 3.

The participants reported high confidence ratings for answering elementary mathematics questions. In fact, for all mathematics questions at least 50% of the pre-service teachers reported confidence ratings of 2 or higher. Confidence ratings decreased slightly starting at the third grade. Since confidence ratings for answering elementary mathematics questions were strongly left-skewed, the data were compared using a Wilcoxon signed rank test as shown in Table 6.

Table 6
Wilcoxon signed rank test for confidence in answering mathematics questions

	Factual/Procedural		Conceptual		
	Mean	SD	Mean	SD	Z
Mean Confidence Ratings for Answering Elementary Mathematics Questions	2.80	0.26	2.45	0.34	-4.32*

* $p \leq 0.001$

Confidence ratings in answering factual/procedural mathematics questions were significantly higher than confidence ratings in answering conceptual questions.

Similarly, confidence ratings pertaining to answering science questions were analyzed. Confidence in answering science questions by grade-level are displayed in Figure 8.

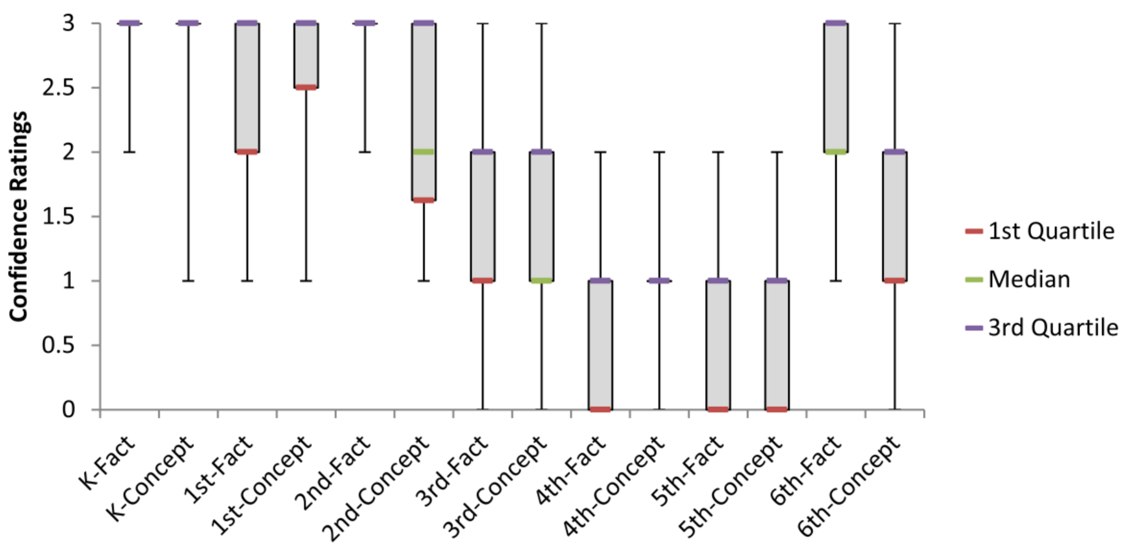


Figure 8. Confidence ratings for answering science questions by grade-level. Top possible rating = 3.

For science, confidence levels began to decrease at the second grade. Additionally, confidence levels appear lower for science than mathematics, with fourth and fifth grade questions receiving maximum confidence levels of 2.

Mean confidence levels for answering factual/procedural science questions and conceptual science questions were compared (Table 7).

Table 7

Wilcoxon signed rank test for confidence in answering science questions

	Factual/Procedural		Conceptual		
	Mean	SD	Mean	SD	Z
Mean Confidence Ratings for Answering Elementary Science Questions	1.95	0.28	1.80	0.33	-2.82*

* $p \leq 0.01$

The students were significantly more confident in their ability to answer the factual/procedural elementary science questions than the conceptual science questions on the PETSMA.

Question 5b: How confident are the pre-service teachers about being able to teach elementary level mathematics and science?

All confidence ratings related to teaching mathematics content were reviewed for each grade-level (Figure 9).

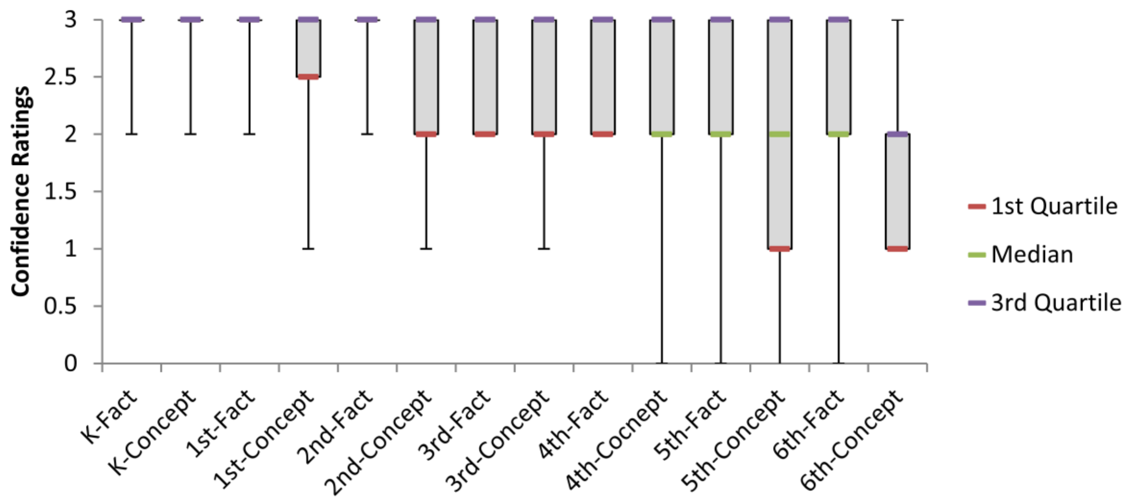


Figure 9. Confidence ratings for teaching mathematics content by grade level. Top possible rating = 3.

The cohort reported high confidence ratings for teaching elementary mathematics content. Similar to the results seen for confidence in answering mathematics questions, 25% of participants reported a confidence rating of 3 for teaching kindergarten through sixth grade factual/procedural content. Teaching confidence ratings decreased starting with the second grade conceptual mathematics content. A Wilcoxon signed rank test was used to compare confidence ratings for teaching factual/procedural versus conceptual mathematics content (Table 8).

Table 8
Wilcoxon signed rank test for confidence in teaching mathematics content

	Factual/Procedural		Conceptual		
	Mean	SD	Mean	SD	Z
Mean Confidence Ratings for Teaching Elementary Mathematics Content	2.67	0.38	2.35	0.45	-4.24*

* $p \leq 0.001$

The confidence ratings for teaching factual/procedural mathematics were significantly higher than for teaching conceptual mathematics.

Teaching confidence ratings pertaining to the science questions were also displayed (Figure 10) and analyzed.

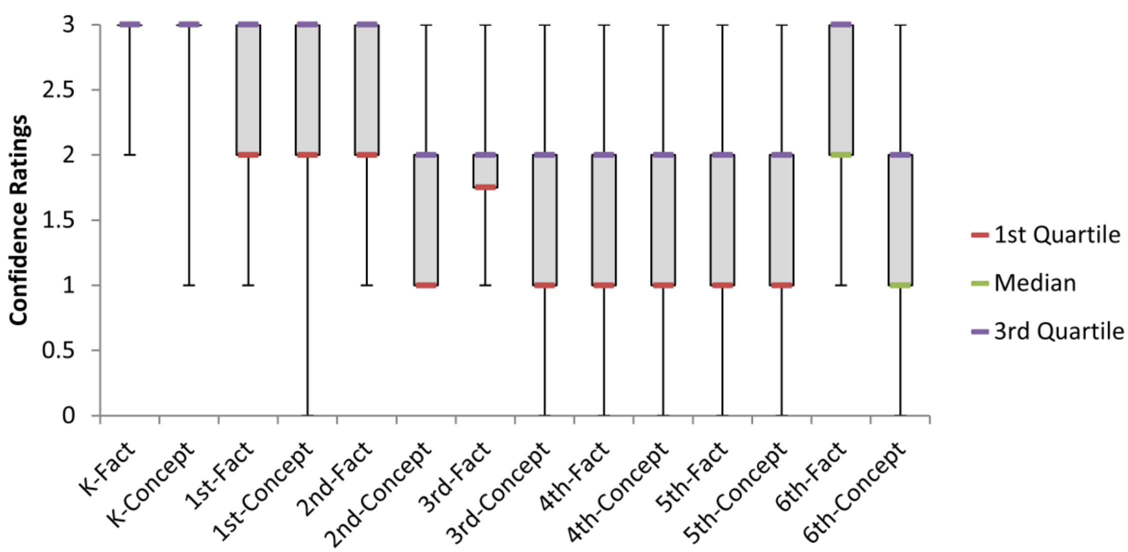


Figure 10. Confidence ratings for teaching science content by grade level. Top possible level = 3.

The science teaching confidence ratings began to decrease around the first grade. Yet, at least 50% of students reported confidence ratings of 2 or higher on answering all elementary science questions, with the exception of the sixth grade conceptual question.

Mean confidence ratings were compared between teaching factual/procedural and conceptual science content (Table 9).

Table 9
Wilcoxon signed rank test for confidence in teaching science content

	Factual/Procedural		Conceptual		
	Mean	SD	Mean	SD	Z
Mean Confidence Ratings for Teaching Elementary Science Content	2.27	0.47	1.94	0.53	-4.41*

* $p \leq 0.001$

The cohort was significantly more confident in their ability to teach the factual/procedural elementary science content than the conceptual science content on the PETSMA.

Question 6: How does students' confidence change between the beginning and end of the junior year in the teacher preparation program?

Confidence levels between the initial and final administrations of the PETSMA were also compared using a Friedman's F test. The analysis involved comparing confidence in answering mathematics/science questions and confidence in teaching mathematics/science content for both factual/procedural questions and conceptual questions. Figure 11 displays the mean confidence ratings reported by the pre-service teachers and shows how the pre- and post- PETSMA results follow similar trends.

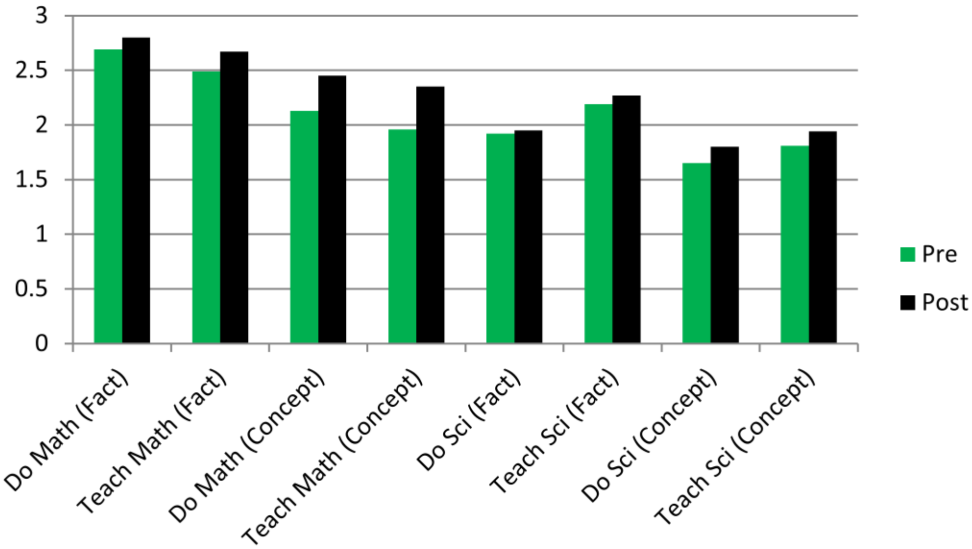


Figure 11. Mean confidence ratings for pre- and post-PETSMA. Top possible rating = 3. All results pertaining to the initial administration of the PETSMA are in green and all results pertaining to the final administration of the PETSMA are in black.

Statistically significant differences were determined $\chi^2(15) = 199.854$; $p = 0.000$. Wilcoxon signed rank tests were utilized to determine which factors produced significantly different confidence ratings between the initial and final administrations of the PETSMA (Table 10).

Table 10
Wilcoxon signed rank tests of the pre- and post-PETSMA confidence ratings

	Pre-PETSMA		Post-PETSMA		
	Mean	SD	Mean	SD	Z
Confidence in answering factual/procedural mathematics questions	2.69	0.27	2.80	0.26	-2.209*
Confidence in teaching factual/procedural mathematics content	2.49	0.40	2.67	0.38	-2.381*
Confidence in answering conceptual mathematics questions	2.13	0.38	2.45	0.34	-3.298***
Confidence in teaching conceptual mathematics content	1.96	0.45	2.35	0.45	-3.092**
Confidence in answering factual/procedural science questions	1.92	0.25	1.95	0.28	-0.807
Confidence in teaching factual/procedural science content	2.19	0.39	2.27	0.47	-1.430
Confidence in answering conceptual science questions	1.65	0.36	1.80	0.33	-1.162
Confidence in teaching conceptual science content	1.81	0.47	1.94	0.53	-1.219

* $p \leq 0.05$
** $p \leq 0.01$
*** $p \leq 0.001$

All confidence ratings relating to mathematics significantly improved between the initial and final administrations of the PETSMA, with the average rating for answering conceptual mathematics questions showing the greatest difference between the pre- and post-PETSMA results. However, none of the confidence ratings relating to science showed a significant difference between the beginning and end of the junior block of the teacher preparation program.

Summary comparisons between mathematics and science.

Since the major purpose of this study involves comparing the cohort's perceptions of, vis-à-vis their performance in and confidence related to, mathematics and science, additional comparisons between science and mathematics were carried out to determine if differences were significant between these domains (Figures 12 through 14).

Knowledge differences.

Figure 12 displays the performance scores on mathematics and science content questions based on the results from the post-PETSMA.

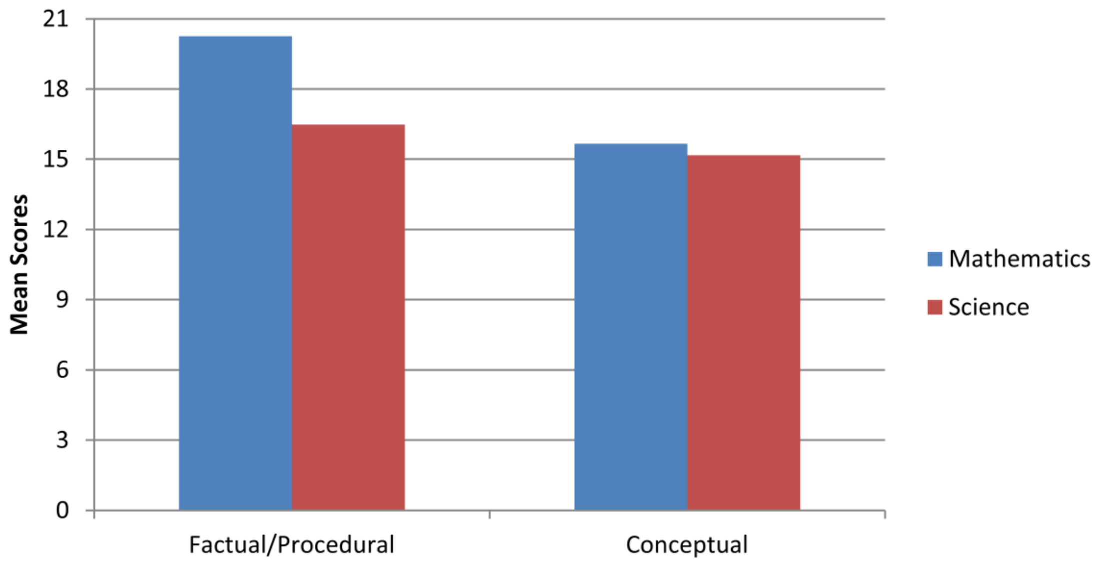


Figure 12. Mean performance scores for mathematics and science on the post-PETSMA. Top possible score = 21. All results pertaining to mathematics are in blue and all results pertaining to science are in red.

Wilcoxon signed rank tests (Table 11) revealed that the pre-service teachers performed significantly better on factual/procedural mathematics questions than the science questions. However, no significant difference was determined between mathematics and science performance on conceptual questions.

Table 11
Wilcoxon signed rank tests for mathematics and science comparisons

	Mathematics		Science		
	Mean	SD	Mean	SD	Z
Performance on factual/procedural questions	20.26	0.9	16.49	1.4	-5.13*
Performance on conceptual questions	15.66	3.3	15.17	2.5	-0.87

* $p \leq 0.001$

Knowledge confidence differences.

Next, mean confidence ratings for answering factual/procedural and conceptual questions were compared between mathematics and science. Figure 13 shows the mean confidence ratings for answering elementary mathematics and science questions, demonstrating that the cohort was more confident in answering mathematics questions than science questions.

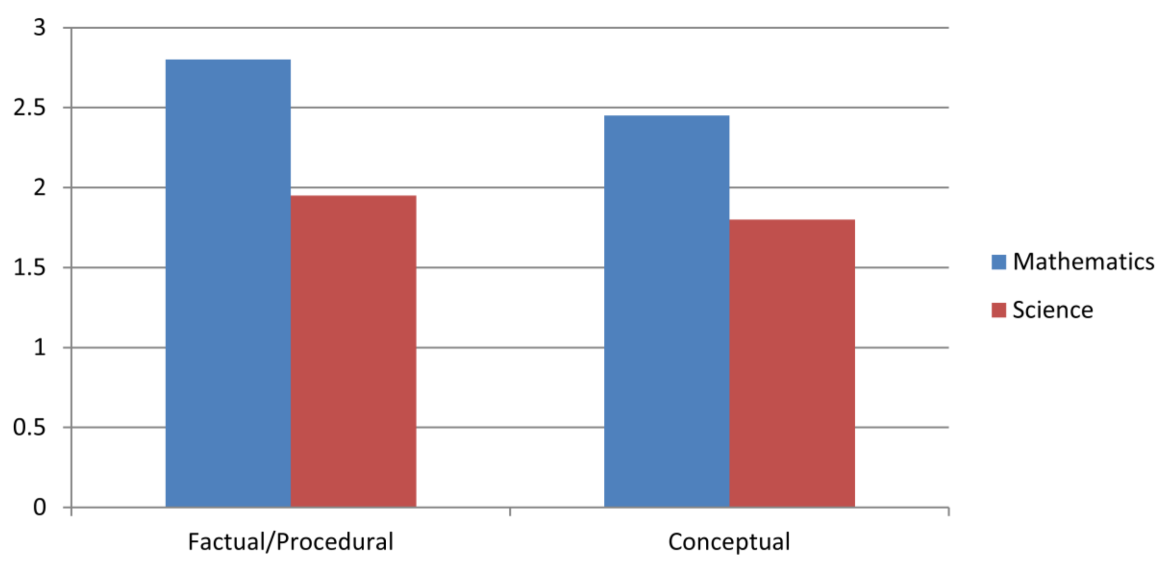


Figure 13. Mean confidence ratings for answering mathematics and science questions. Top possible rating = 3. All results pertaining to mathematics are in blue and all results pertaining to science are in red.

To determine if the differences were statistically significant, Wilcoxon signed rank tests were conducted (Table 12).

Table 12
Wilcoxon signed rank tests for confidence in answering mathematics and science questions

	Mathematics		Science		
	Mean	SD	Mean	SD	Z
Confidence in answering factual/procedural questions	2.80	0.26	1.95	0.28	-5.10*
Confidence in answering conceptual questions	2.45	0.34	1.80	0.33	-4.83*

* $p \leq 0.001$

The cohort's confidence ratings in answering elementary mathematics questions were significantly higher than confidence ratings in answering elementary science questions for both procedural/factual and conceptual types of knowledge.

Teaching confidence differences.

Next, teaching confidence was compared between mathematics and science (Figure 14) and Wilcoxon signed rank tests were conducted to determine statistical significance (Table 13).

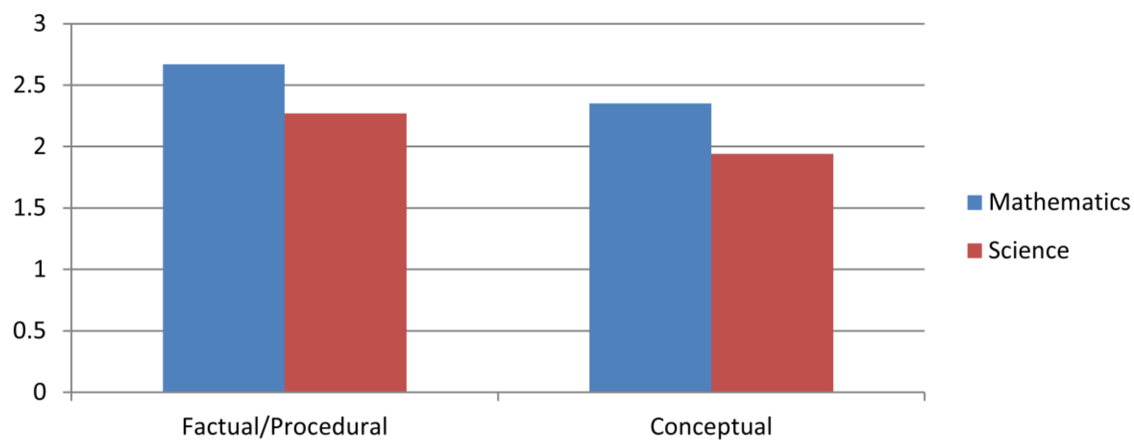


Figure 14. Mean confidence ratings for teaching mathematics and science content. Top possible rating = 3. All results pertaining to mathematics are in blue and all results pertaining to science are in red.

Table 13
Wilcoxon signed rank tests for confidence in teaching mathematics and science content

	Mathematics		Science		
	Mean	SD	Mean	SD	Z
Confidence in teaching factual/procedural content	2.67	0.38	2.27	0.47	-4.04*
Confidence in teaching conceptual content	2.35	0.45	1.94	0.53	-3.76*

* $p \leq 0.001$

The participants were more confident in teaching mathematics than science content for both factual/procedural and conceptual types of knowledge.

Question 7: How does confidence in answering elementary level mathematics and science questions compare to confidence in teaching?

Figure 15 shows the contrast between the reported confidence of the students regarding their ability to answer mathematics and science questions versus their ability to teach the related mathematics and science content.

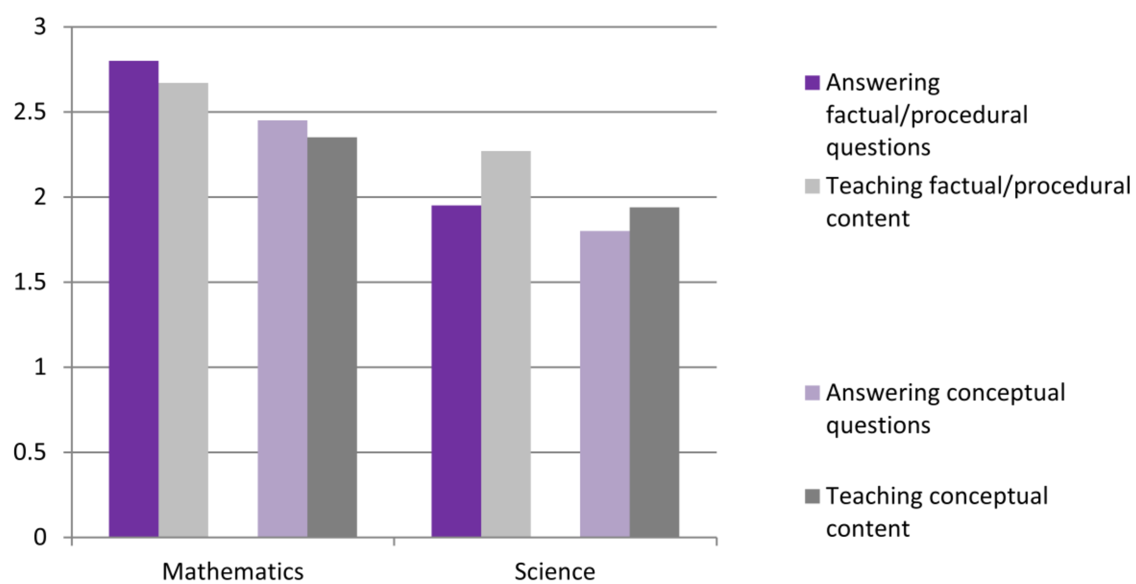


Figure 15. Mean confidence ratings for mathematics and science. Top possible rating = 3. All results pertaining to confidence in answering questions are in shades of purple and all results pertaining to confidence in teaching content are in shades of gray.

The participants reported different confidence ratings with respect to knowing versus teaching elementary level mathematics and science facts/procedures and concepts. Wilcoxon signed rank tests (Table 14) reveal that the pre-service teachers reported significantly higher confidence ratings for answering factual/procedural mathematics questions than teaching. However, no statistically significant difference was determined with respect to conceptual mathematics questions.

Table 14
Wilcoxon signed rank tests for confidence ratings relating to mathematics

	Answering Questions		Teaching		
	Mean	SD	Mean	SD	Z
Mean Confidence Ratings for Factual/Procedural Questions	2.80	0.26	2.67	0.38	-3.07*
Mean Confidence Ratings for Conceptual Questions	2.45	0.34	2.35	0.45	-1.40

* $p \leq 0.01$

The science teaching confidence ratings displayed a curious pattern when compared to confidence in answering questions (i.e., teaching confidence was higher than confidence in answering questions). Inspection of the raw data revealed that this was the case for all third, fourth, and fifth grade questions. To determine if differences were significant, Wilcoxon signed rank tests were conducted (Table 15).

Table 15
Wilcoxon signed rank tests for confidence ratings relating to science

	Answering Questions		Teaching		
	Mean	SD	Mean	SD	Z
Mean Confidence Ratings for Factual/Procedural Questions	1.95	0.28	2.27	0.47	-3.63*
Mean Confidence Ratings for Conceptual Questions	1.80	0.33	1.94	0.53	-1.84

* $p \leq 0.001$

The pre-service teachers reported significantly higher confidence levels for teaching factual/procedural science questions over answering science questions. However, no statistically significant difference was determined with respect to conceptual science questions.

Question 8: What are the relationships among measures of science and mathematics knowledge, confidence, and efficacy?

To better comprehend the pre-service teachers' understandings and confidence levels in elementary mathematics and science, relationships among variables were investigated. To that end, Spearman's ρ one-tailed correlations were computed for PETSMA mathematics questions, science questions, and scores on validated teaching efficacy belief instruments, namely the MTEBI and the STEBI-B, respectively.

Questions 8a and b: How do measures of mathematics teaching efficacy relate to confidence in teaching specific mathematics content? How do mathematics confidence measures relate to knowledge scores?

In order to gain perspective on the relationships between performance on mathematics questions, confidence in answering mathematics questions, and confidence in teaching mathematics content, correlations were calculated. Additionally, the mathematics PETSMA results were compared to the teaching efficacy beliefs reported on the MTEBI. The MTEBI scores were divided into personal teaching efficacy beliefs (PTE) and outcome expectancy beliefs (OE) for each participant. Table 16 displays the Spearman's ρ correlations for the mathematics questions of the PETSMA and the MTEBI.

Table 16

Spearman's ρ correlations for mathematics questions (PETSMA) and efficacy beliefs (MTEBI)

		1	2	3	4	5	6	7	8
1. Performance on factual questions	ρ	1.00	0.11	0.14	-0.04	-0.08	0.02	-0.16	0.01
	n	35	35	35	35	31	32	33	33
2. Performance on conceptual questions	ρ		1.00	0.21	0.12	0.29	0.22	0.16	0.01
	n		35	35	35	31	32	33	33
3. Confidence in answering factual questions	ρ			1.00	0.79***	0.36*	0.41**	-0.02	0.41**
	n			35	35	31	32	33	33
4. Confidence in teaching factual content	ρ				1.00	0.38*	0.55***	0.14	0.32*
	n				35	31	32	33	33
5. Confidence in answering conceptual questions	ρ					1.00	0.71***	-0.24	-0.06
	n					31	31	30	30
6. Confidence in teaching conceptual content	ρ						1.00	-0.20	0.05
	n						32	31	31
7. MTEBI – PTE	ρ							1.00	0.04
	n							33	33
8. MTEBI – OE	ρ								1.00
	n								33

* $p \leq 0.05$

** $p \leq 0.01$

*** $p \leq 0.001$

All mathematics confidence ratings significantly inter-correlated with confidence in answering mathematics questions and confidence in teaching mathematics content showing the strongest relationships. That is, those with high mathematics confidence ratings were confident in doing and teaching both factual/procedural and conceptual mathematics. However, mathematics performance scores did not correlate with confidence ratings. Thus, the pre-service teachers that performed well on the mathematics questions were not necessarily confident in their mathematical abilities (for answering questions and teaching content). Furthermore, personal teaching efficacy beliefs reported on the MTEBI did not correlate at statistically significant levels for any of the mathematics questions on the PETSMA. Confidence in answering factual/procedural mathematics questions and confidence in teaching factual/procedural mathematics content did correlate with the outcome expectancy beliefs reported on the MTEBI, but the correlations were relatively weak. Therefore, the subject specific global teaching efficacy measures for mathematics, from the MTEBI, did not correlate with specific teaching confidence questions from the PETSMA for either factual/procedural or conceptual questions.

Question 8c and d: How do measures of science teaching efficacy relate to confidence in teaching specific science content? How do science confidence measures relate to knowledge scores?

Science performance scores, confidence in answering science questions and confidence in teaching science content were also correlated in a similar fashion to investigate relationships amongst the science variables measured by the PETSMA. Furthermore, the relationships between performance/confidence on specific science content and global science teaching efficacy beliefs were examined using the results from the PETSMA and the STEBI-B. Similar to the MTEBI, STEBI-B scores were divided into personal teaching efficacy beliefs (PTE) and outcome expectancy beliefs (OE) for each participant. Table 17 displays the correlations.

Table 17
Spearman's ρ correlations for science questions (PETSMA) and efficacy beliefs (STEBI-B)

		1	2	3	4	5	6	7	8
1. Performance on factual questions	ρ n	1.00 35	0.29* 35	0.46** 34	0.19 32	0.19 32	0.05 32	0.10 33	0.11 33
2. Performance on conceptual questions	ρ n		1.00 35	0.17 34	0.29 32	0.26 32	0.09 32	-0.10 33	0.07 33
3. Confidence in answering factual questions	ρ n			1.00 34	0.55*** 32	0.63*** 32	0.45** 32	0.07 32	-0.09 32
4. Confidence in teaching factual content	ρ n				1.00 32	0.53*** 31	0.83*** 31	0.36* 30	-0.06 30
5. Confidence in answering conceptual questions	ρ n					1.00 32	0.53*** 32	0.21 31	-0.04 31
6. Confidence in teaching conceptual content	ρ n						1.00 32	0.31* 31	-0.04 31
7. STEBI-B - PTE	ρ n							1.00 33	0.27 33
8. STEBI-B – OE	ρ n								1.00 33

* $p \leq 0.05$
** $p \leq 0.01$
*** $p \leq 0.001$

Similar to mathematics, all science confidence ratings measured by the PETSMA inter-correlated at statistically significant levels. Additionally, performance scores on factual/procedural science questions correlated with confidence in answering factual/procedural science questions, but the correlation was relatively weak. The strongest correlation seen with respect to science was between confidence in teaching factual/procedural content and confidence in teaching conceptual content. Science teaching confidence ratings for specific science content correlated quite strongly. Interestingly, confidence in teaching science content (both factual/procedural and conceptual) correlated with personal teaching efficacy measures on the STEBI-B; but, none of the confidence ratings measured by the PETSMA correlated with the outcome expectancy beliefs measured by the STEBI-B.

Question 9: How do knowledge and confidence ratings relate between mathematics and science?

Spearman's ρ one-tailed correlations were calculated to investigate relationships between mathematics and science measures of factual/procedural knowledge, conceptual knowledge, confidence in answering factual/procedural questions, confidence in answering conceptual questions, confidence in teaching factual/procedural content, and confidence in teaching conceptual content from the PETSMA. Performance on factual/procedural questions did not correlate between mathematics and science. However, performance scores on conceptual questions did correlate at a statistically significant level ($\rho = 0.31, p \leq 0.05$). Additionally, statistically significant correlations were determined between mathematics and science for confidence in teaching factual/procedural content ($\rho = 0.46, p \leq 0.01$) and confidence in teaching conceptual content ($\rho = 0.67, p \leq 0.001$). Moreover, confidence in answering conceptual science questions significantly correlated with confidence in answering conceptual mathematics questions with $\rho = 0.48, p \leq 0.01$. But no significant correlation was determined between confidence in answering factual/procedural questions for science and mathematics. Interestingly, performance scores on factual/procedural questions did not correlate between disciplines, but teaching confidence levels did correlate between mathematics and science for both factual/procedural and conceptual content. Therefore, those participants that were confident in teaching specific mathematics content were also confident in teaching specific science content.

Question 10: How do the teaching efficacy beliefs of the pre-service teachers in this study relate between mathematics and science?

Since teaching confidence ratings significantly correlated between disciplines on the PETSMA, one may question the relationships between subjects of teaching efficacy beliefs. The distribution of scores on the MTEBI and STEBI-B were relatively normal, so the personal teaching efficacy beliefs (PTE) and outcome expectancy beliefs (OE) were analyzed using Pearson's one-tailed correlations (Table 18).

Table 18
Pearson's one-tailed correlations between MTEBI and STEBI-B results

		1	2	3	4
1. MTEBI – PTE	r	1.00	0.01	0.37*	0.18
	n	33	33	33	33
2. MTEBI – OE	r		1.00	0.01	0.68***
	n		33	33	33
3. STEBI-B – PTE	r			1.00	0.25
	n			33	33
4. STEBI-B – OE	r				1.00
	n				33

* $p \leq 0.05$
** $p \leq 0.01$
*** $p \leq 0.001$

A weak, yet significant, correlation was determined between personal teaching efficacy beliefs in mathematics and personal teaching efficacy beliefs in science. A much stronger correlation was determined between disciplines for outcome expectancy beliefs. Such results add credence to the notion of personal teaching efficacy beliefs being subject specific (possibly even situational), and outcome expectancy beliefs being more global across situations (Bandura, 1997).

Question 11: How does the cohort's mathematics teaching efficacy beliefs compare to their science teaching efficacy beliefs?

Given that the PETSMA determined significantly higher confidence ratings related to teaching specific mathematics content over teaching specific science content, one may question how subject specific teaching efficacy beliefs compare between mathematics and science. A generalized MANOVA determined that the results from the MTEBI were significantly different from the results of the STEBI-B ($F(4) = 1702.5; p \leq 0.001$). Figure 16 displays the average personal teaching efficacy and outcome expectancy ratings from both the MTEBI and STEBI-B.

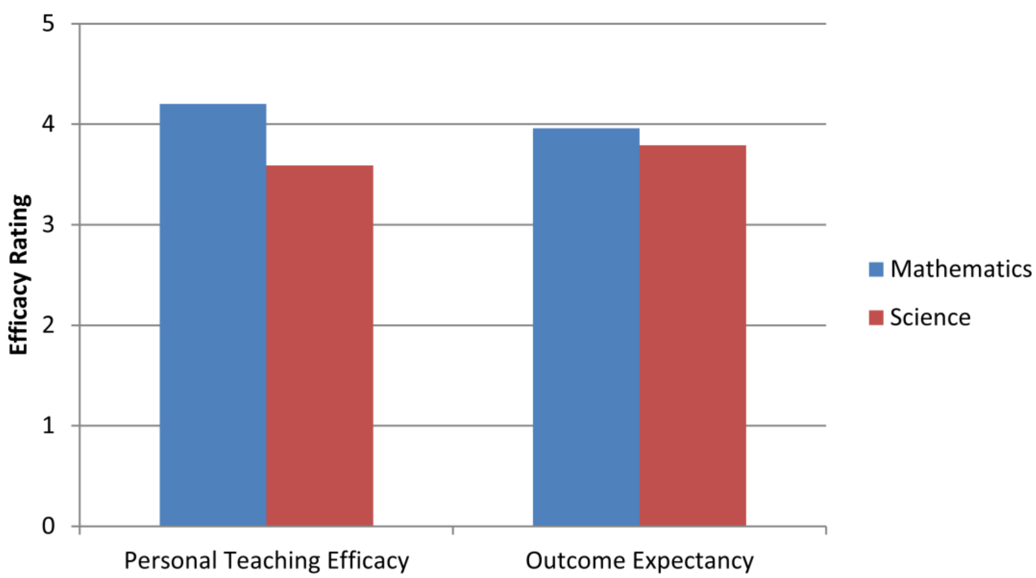


Figure 16. Mean efficacy ratings for mathematics (MTEBI) and science (STEBI-B). Top possible rating = 5. All results pertaining to mathematics are in blue and all results pertaining to science are in red.

Since significant differences were determined by the MANOVA, pairwise t-tests were used to make comparisons between mathematics and science (Table 19).

Table 19
Pairwise t-tests for teaching efficacy beliefs in mathematics and science

	Mathematics		Science		
	Mean	SD	Mean	SD	t
Personal teaching efficacy beliefs	4.20	0.39	3.59	0.62	5.86**
Outcome expectancy beliefs	3.96	0.38	3.79	0.36	3.29*

* $p \leq 0.01$
** $p \leq 0.001$

For both personal teaching efficacy and outcome expectancy, the cohort reported significantly higher mathematics teaching efficacy beliefs than science teaching efficacy beliefs. In mathematics, personal efficacy beliefs were significantly higher than outcome expectancy beliefs ($t(32) = 2.51, p \leq 0.05$). Conversely for science, the participants reported higher outcome expectancy beliefs than personal teaching efficacy beliefs; however, the difference was not statistically significant.

The quantitative results showed some interesting patterns. However, stronger conclusions can be offered regarding the perspectives of the pre-service teachers by including their voices. The PETSMA served a dual purpose of providing the researcher with quantitative results for analysis and stimulating conversations amongst the cohort of pre-service elementary teachers. When paired with the quantitative results, the following analysis of classroom discussions yields deeper understandings of the perceptions of knowledge for teaching mathematics and science held by the participants of this study.

Analysis of Classroom Discussions

A total of four classroom discussions took place as a part of this research project. Two of the discussions occurred in August of 2010 at the beginning of the junior block for the cohort of pre-service elementary teacher. The final two discussions took place in April of 2011 at the end of their junior block. The initial discussions and final discussions were analyzed and coded, separately, using constant comparisons until three major themes for each set of discussions emerged.

Initial Discussions.

The original cohort of fifty pre-service teachers participated in the initial classroom discussions. All discussions were prompted by the completion of the PETSMA, which was intended to stimulate thinking about the types of knowledge necessary for teaching mathematics and science. The analysis of the initial classroom discussions resulted in three major themes: 1) Conceptual Understanding and Reasoning, 2) Knowledge Building from the Learners' Perspective, and 3) Teaching Mathematics and Science.

Conceptual understanding and reasoning.

The first theme, Conceptual Understanding and Reasoning, relates to the participants' perspectives of mathematics and science as disciplines and the role of conceptual understanding and reasoning in each discipline. The pre-service teachers expressed very different ideas about the role of conceptual understanding in science versus mathematics. A comment made by one member of the group illustrates this incongruence.

> Violet: There's a set way to math. Science is more concepts and math…there's more of the details.

The disparity between the perceived roles of conceptual understanding in science versus mathematics was not limited to a single comment. Quite a few comments were made describing mathematics as being procedural and factual. Violet received a great deal of agreement from her peers.

> Mia: I feel like in math, every time you get the answer it's because you had a formula or a step-by-step process.

Other students showed similar impressions of mathematics. They noted that more open-ended questions are used in science, while mathematics is often associated with drill and practice. Such associations lead Sophia to overlook the creative nature of mathematics.

> Sophia: Because I think math is black and white.

Comments like Sophia's are representative of the tendency to simply learn procedures and neglect the development of conceptual understanding in mathematics. Moreover, many of the pre-service teachers expressed frustration with regard to the conceptual mathematics questions.

> Jan: It's hard to explain the thought process in math. The one where…it's just harder to explain the process of how I got to that point.

While they recognized the importance of a teachers' ability to explain topics, the pre-service teachers were less confident in their own ability to explain mathematical concepts at the time of the initial discussions. Thus, many of the pre-service teachers in this study showed confidence in their ability to solve basic factual/procedural mathematics questions, but seemed less confident in their ability to explain the thought process behind such procedures.

> Paige: I think the math questions are easier because we haven't had to really explain how we do that kind of a math problem in ten years, so we know two plus two is four. It's one of those things we take for granted. You have to simplify the denominator because you do, that's just what you do…

The familiarity with mathematical procedures resulted in Paige discounting the concepts behind the formulas. Many of the pre-service teachers in the initial discussions agreed that when given a well-known process, they tend to overlook the explanation of why the procedure works. However, the cohort expressed different sentiments with respect to science.

During the discussions, the pre-service teachers appeared to be more comfortable with the scientific concepts than with the factual/procedural science questions. In fact, many students seemed disappointed by their performance on the factual/procedural science questions.

> Rita: I kind of felt like both the sixth grade science question one and the vocabulary stuff was hard because I didn't remember the vocabulary as much as I remembered concepts. I remembered the concept of this, but I could not tell you the labels at a glance.

In spite of not remembering the vocabulary, the cohort conveyed a certain amount of confidence with regard to their understanding of science. Science vocabulary may not be used in everyday conversations, but science does connect to everyday life.

> Tess: I think the number twos [conceptual science questions] could be easy for some students to answer because its answers that connect to their lives and the number ones [factual/procedural science questions] are more scientific, what are the four vocabulary [alluding to 1st grade factual/procedural science question].

Tess is stating that the conceptual science questions appear easier because one can utilize some basic conceptual knowledge paired with observations to determine rational responses. Some of the pre-service teachers voiced confidence in their conceptual understanding of science; communicating their ability to use logical deductions and reasoning to determine approximate answers to the conceptual science questions. While discussing responses to the fourth grade conceptual science question, which asks "How do muscles and bones work together to help you move?", Zoe discussed her ability to use reasoning in determining a response.

Zoe: If I had been able to review it before, I could come up with a logical reason why that works.

Thus, the confidence in answering conceptual science questions is linked to both everyday experiences with science concepts and the capacity to reason and research.

Sophia: Well I think like with science, a lot of those questions are open-ended on how stuff functions. For a lot of those we know the outcome, so we can go backwards to how it functions and we can guess more. But with math, it might not necessarily be what the outcome is. With science, it was more like you have to guess the function of the muscles or the function of all these things, but we know the outcome is that we can walk. So, we can go backwards and say somehow muscles and bones work together, so…

According to Sophia, science can be very intuitive at times. Given conceptual understanding and an observation of an end result, one can deduce a scientific explanation.

In mathematics, however, many of the pre-service teachers in this study found themselves turning to procedures instead of using conceptual understanding and reasoning. One conversation highlighted the hazards of only focusing on procedural knowledge.

Molly: Well, I think to go with that, because on the fraction problem, if you don't know that you have to get common denominators, you can get two answers. For the adding two-thirds and three-fourths, you could just add three and four on bottom and then add three and two on the top and get five over seven, if you didn't know you have to get the correct denominator.

Facilitator: So five-sevenths is the correct answer?

Molly: Actually, it's a common error. If you don't know the outcome specifically, but if you thought it was five over seven, then you would get a completely different explanation for why people need common denominators.

In the problem Molly was discussing, she mentioned that the logic of common errors may seem appropriate if one does not have an accurate understanding of both the procedures and the concepts. Hence, while the pre-service teachers in the initial discussions in this study seemed to view science as being more conceptual than mathematics, they did note that conceptual understanding assists in avoiding and determining common misconceptions. Moreover, one student pointed out that if a topic, either scientific or mathematical, is truly learned, then one should have a conceptual understanding of said topic.

Jody: But the concepts are something that should be able to actually grasp and understand.

Jody's comment applies to both science and mathematics learning. Both Sophia and Zoe mentioned the ability to use basic conceptual understanding of scientific topics and observations to reason backwards in order to determine sound answers. Additionally, when an individual fully understands a mathematical procedure and has some basic conceptual knowledge, they can reason backwards and determine a logical explanation for the given process. While the pre-service teachers in the initial discussions appeared to utilize their conceptual knowledge of mathematics less than their conceptual knowledge of science, they did recognize that conceptual understanding is fundamentally important to teaching and learning.

Scientific and mathematical learning may occur through a variety of encounters. Prior school experiences led the cohort to perceive science as being a more conceptually based discipline than mathematics. Yet, conceptual understanding was noted as being important to truly grasping content. Furthermore, logic, reasoning and research skill were all cited as being meaningful to developing content knowledge. Thus, the pre-service teachers expressed a willingness to continue to research and build upon their current canons of content knowledge.

Knowledge building from the learners' perspective.

The second prevalent theme is titled Knowledge Building from the Learners' Perspective. The theme references both the pre-service teachers as learners and some conversations regarding their future students. During the initial discussions, the idea of knowledge building on itself frequently arose. Specifically, the participants noted the manner in which mathematical learning involved building upon previously learned topics. While there were discussions of connections across science topics, the pre-service teachers in this study associated knowledge building with mathematical learning.

> Gwen: Science does build on itself, but it's less noticeable, I think. It's more of a stretch. With math you learn how to add and subtract. Then you learn how to multiply, which is adding, basically. I mean, you can write it down that way. Then, when you do fractions, you have to combine all these things. With science, its more information, I guess.

Science content may appear to be distinct pieces of information, but there are connections between certain science content areas. However, determining such connections can prove difficult for learners, and not all science topics are linked. Vera suggested that the science topics may appear to be more separated than mathematics topics because of the numerous branches of science.

> Vera: Yes, it's all kind of related in mathematics, whereas science is kind of different topics under one subject.

Thus, the relations between science topics were less prevalent to the pre-service teachers because grade school science encompasses a multitude of separate disciplines. When studying similar branches of science, connections can easily be made, for example topics in earth science and biology can easily build on each other. Rita suggested that elementary school science does build on itself quite a bit; however, that ceases to be the case in later grades when the science being studied begins to diversify.

> Rita: I think as you get older, they build less. In elementary school, science very much builds on each other. Once you get to high school, you're doing chemistry and you're doing biology. There are some connections, but it's less. That's why you lose a lot of what you had in elementary and middle, because you're not using it as much.

By studying distinct branches of science, learners are not getting the constant reinforcement of content seen in mathematics learning. The pre-service teachers in the initial discussions claimed that their inability to remember science content was attributed to this lack of reinforcement in science learning.

Yet, there were conversations about the broader, overarching concepts in science. The idea of connections between science disciplines and systems was a big area of discussion with regard to science learning.

> Molly: Our body breathes the oxygen that plants make and we stand up straight from the ground because of gravity. I mean, it's true, science is life.

Science learning may not involve continual reinforcement of factual information, but there are larger scientific concepts joining the various branches of science. As science learning occurs connections can be made between different science topics.

> Leila: I was going to say, along with the systems you could talk about how the trees grow and develop and how the bodies grow and develop. The similarities and differences…

However, even given the connections between scientific topics, school science includes many diverse branches. Thus after learning a science topic, the pre-service teachers in this study expressed the tendency to forget because the information is not being built upon and integrated regularly.

> Molly: If I could just review, it's been so long. I mean I'm not nursing, so why on earth would I ever have looked over different types of tissues and muscles in the past ten years.

Molly was noting that information is often remembered based upon whether or not it is considered useful. Since science vocabulary is rarely reinforced once a topic is complete, many of the pre-service teachers considered the factual/procedural science information unnecessary to their daily lives.

> Gwen: We talked about…because for the vocabulary words, honestly, we learn them for the test and then forget about it. So, that's why none of us remember a big vocabulary word because A) it was so long ago and B) [student shrugged her shoulders].

The pre-service teachers in the initial discussions conveyed the idea that since the factual/procedural science information is not revisited regularly; not only are they less likely to retain the information, they are also less likely to want to retain the information.

Conversely, in school factual/procedural mathematics information is regularly integrated into new topics. In fact, basic mathematics topics are reexamined so frequently that factual/procedural mathematics information is perceived as being easier to recall.

> Paige: But we do two plus two all the time.

Furthermore, Jewel noted that since topics in mathematics build from previously learned content, she subconsciously remembered many of the procedures.

> Jewel: I just haven't felt confident in math, but I'm surprised at how much I remember. Like the fraction thing, and that you have to have a common denominator. I just started doing it. Now, it's like, I didn't even know I knew how to do this. I was surprised.

Due to a strong familiarity with procedural mathematics, Jewel was able to recall the information necessary to solve the given problems. Hence the manner in which mathematics topics build upon each other greatly assists learners in remembering content over the long-term. However, when a learner fails to comprehend even a single mathematical procedure, the learning of more advanced topics becomes encumbered. Given that missing basic mathematics content can seriously hinder later learning, Natalie remarked on the importance of reinforcing mathematical topics for young learners.

> Natalie: Well, they can always go over what they've done before, so we need to make sure that we reinforce…that we don't let the kids slip through. We need to make sure everything is in for all kids, not leaving a topic behind, but make sure that all the kids really know what they need to know before they move on to the next level. Because if they don't; they're going to continue to fall behind.

Since mathematics content is frequently integrated into later topics, student learning suffers greatly when there are gaps in knowledge.

The pre-service teachers in the initial discussions associated mathematical learning with knowledge building. Thus, developing a strong understanding of the early content is pivotal to learning later mathematics topics. Science was not perceived as involving knowledge building due to the many distinct branches of science prevalent in early education. However, grasping the overarching connections between science topics aids learners in understanding scientific systems and the inter-relations between the various branches of science. The cohort expressed disparate views of mathematical and scientific learning, but noted the importance of emphasizing connections between topics whenever possible.

Teaching mathematics and science.

Given the perceived contrasts between the natures of and the learning of mathematics and science, it is not surprising that similar distinction were voiced with respect to mathematics and science teaching. Previous educational experiences shaped the perceptions of mathematics and science for each member of the cohort. Furthermore, since mathematics learning is associated with knowledge building and science was described as including many different topics, the pre-service teachers expressed slightly different methods for preparing lessons. However, research skills and conceptual understanding were both noted as being central in the development of mathematics and science lessons.

The final theme, Teaching Mathematics and Science, refers to both the previous experiences the participants had with mathematics and science teachers and their ideas regarding mathematics and science teaching. During the initial discussions, the pre-service teachers were entering their junior block in their teacher preparation program and beginning to consider their own teaching philosophies. Additionally, they were drawing from previous experiences as learners. Rose discussed the manner in which her experiences as a student led her to think of science as more conceptual and mathematics as more factual.

> Rose: I feel like in science, for me personally, the teachers spent more time on trying to get you to understand the concept – this is what photosynthesis is and this is how it happens – instead of focusing on names. In math, it was just – we're not going to explain

> it to you because this is the way you do it and that's it. There is no other way, so do it this way and follow the formula and you'll be fine.

Other pre-service teachers shared this notion of mathematics only having a single approach to solving a given problem.

> Jewel: I think with math…you know that article [Rigelman, 2007]? They were talking about the process and the product. I feel like a lot of times with math it's always the end product. At least that's how I was taught math. You did it to get to the end, you know? Then, it's the answer that matters. I feel like a lot of my teachers emphasized how you have to go about it to understand it, but I feel like in math it was just "you need to find the solution." So maybe that's why I feel in science there is more explanation and you can go about it different ways. In math, I was always taught there is only one way to do it. So, I don't know how to explain it if I'm explaining it differently to myself.

In addition to holding the misconception of mathematics only offering a single procedure to solve a problem, Jewel expressed concern over her ability to explain different procedures in mathematics. Conversely, since these pre-service teachers witnessed science being taught from a more conceptual approach, they voiced the perception that science is more open to different methods and approaches for problem-solving. Such educational backgrounds are consistent with the expressed perception of the nature of science as being more concept-driven with less emphasis on factual knowledge.

When questioned about how they would prepare to teach a science lesson, the pre-service teachers in this study were not overly concerned about a lack of factual/procedural science knowledge.

> Zoe: I was going to say that the one thing we did in our science class that would help is you get those broad topics and you learn how to research them. That's what I would do if I was given – you're teaching about gravity. I would go look online for textbooks and figure out about gravity, because I wouldn't know it before.

Hence the participants stated that a lack of factual/procedural science knowledge should not be considered an impediment to science teaching, provided strong science research skills had been developed.

> Paige: Well, read their textbook, so you know what they have to know, and then do the research yourself. Then they'll ask you questions and you can answer them.

The pre-service teachers in this study emphasized the importance of prep-work and research in developing science lessons.

Unfortunately, in mathematics knowledge builds upon itself, so researching only for the lesson one intends to teach may not be sufficient.

> Molly: But at the same time, I tutored 9th grade TAKS [state exam] and those kids, some of those kids that come in from the previous grades haven't mastered those topics. So you have to be able to teach them, just in case, some kids that I was tutoring in 9th grade didn't know how to multiply. The teacher just passes them along…

Molly expressed the need for mathematics teachers to prepare, not only the expected lesson, but also have a firm enough mathematical understanding to be able to help those students that are missing crucial content. Thus in preparing to teach mathematics, one should both research the topic being discussed and consistently review the underlying concepts. Understanding the concepts that result in a given mathematical procedure greatly aids mathematics teaching; as expressed by Natalie (middle school mathematics major).

> Natalie: Well in our Middle School for Math classes, she taught you all of it and it's in the book. My suggestion is: 1) keep your book for research, to go back to, and 2) she teaches us step-by-step and why we're doing it so that we can teach the kids that.

The cohort articulated the importance of research in both science and mathematics teaching. As students, they noted incongruent experiences between science and mathematics classrooms, but when considering their own teaching philosophies they found significance in researching broad topics for both mathematics and science.

Through the comments made during the initial discussions, insights into the pre-service teacher's perceptions regarding the natures of, the learning of and the teaching of mathematics and science were ascertained. The pre-service teachers described science as being more conceptual in nature and mathematics involving more factual/procedural knowledge. Similarly, in discussing scientific and mathematical learning, mathematics was depicted as involving knowledge building, while science encompassed a variety of distinct topics. When questioned about the practices they intended to employ as they prepared to teach mathematics and science, they stressed the value of continually researching and learning in order to teach. Thus, the analysis of the initial discussion yielded deeper comprehensions of the pre-service teachers' perceptions of the natures of mathematics and science, the learning of mathematics, and the teaching of mathematics and science.

Final discussions.

Thirty-five individuals from the original cohort participated in the final discussions. The final discussions, which took place at the end of the pre-service teachers' junior block in April of 2011. The PETSMA was re-administered prior to the classroom discussions. The final discussions were analyzed in the same fashion as the initial classroom discussions, and again three prevalent themes were noted: 1) Knowledge for Teaching, 2) Confidence in Becoming a Teacher, and 3) Teaching Theories versus Teaching Practices.

Knowledge for teaching.

The theme entitled Knowledge for Teaching describes the participants' considerations of the types of knowledge that would be considered most useful in teaching mathematics and science. The pre-service teachers noted that factual/procedural knowledge, conceptual knowledge, and pedagogical content knowledge all play vital roles in teaching; however, there was some debate within the groups as to which types of knowledge should be the focus of teacher preparation programs.

> Barbara: Yes, generally everything. Like, and of course it's good to get different perspectives and different tools and stuff like that, but I just feel like as a teacher you; this is just me guys, please don't walk away with anything that I'm saying, but just for me as a teacher, you should be able to teach your students. You see what I'm saying? So, that's how I feel, so for me I needed more content than methods, for me personally.

Barbara was expressing her desire to have learned more content information from her teacher preparation program. Although she noted the importance of learning different teaching methodologies, she conveyed some self-assurance in her ability, as a teacher, to reach her future students, but held less certainty about obtaining the necessary content knowledge. One of Barbara's classmates stated a different philosophy about the role of content knowledge in teacher preparation.

> Ginger: I would rather walk away knowing how to research and how to teach it, than to know the content and to not know how to teach it. Because now I know, just like for your class [Science for Elementary Teachers], we had to research some of the material

> and learn it in order to be able to tell you about it, but we also learned through the methods class and your class how to teach it and how to prepare for it. So, when we go to that point in time, we have the tools to be ready.

Thus, Ginger conveyed the opposite belief of Barbara. Ginger was more concerned with obtaining pedagogical content knowledge and tools for research from her teacher preparation program, rather than focusing on content knowledge. However, content knowledge is necessary to teaching.

> Rita: I really wish we had another science class. I feel like I didn't get as much as I should have from the last ones, because I do not feel as confident as I know I should in the science stuff. I know I feel like in almost every science topic I'll have to teach, I'm going to have to look it up and, I don't know, I just wish we had another science class before we had to take the [certification] test on science stuff.

In Rita's case, the concern over the lack of science content knowledge was related to both the amount of future research required to teach effectively and her own performance on her certification exam.

Both similar and differing sentiments were expressed with regard to mathematics. When discussing factual/procedural versus conceptual learning in methods courses, Helen mentioned the desire for someone to simply tell her the mathematical concepts behind operations and not require her to discover the reasons on her own; however, this view did not transfer over to learning science content.

> Facilitator: So, did the science class drive you crazy then?

> Helen: No, because that's different. Math is different because I have never been confident in math, so like when I didn't understand something in science I was more like 'oh well, I'll get it eventually.'

Helen's comment implies that the different opinions about the roles of factual/procedural knowledge, conceptual knowledge and pedagogical content knowledge in teacher preparation relate to the individuals confidence in each subject area. However, regardless of the confidence levels in various subjects, many of the pre-service teachers emphasized the importance of conceptual understanding in teaching.

> Vera: I feel it's good to know the concepts all the time, because you can look up the vocabulary and the details and thing like that right before you teach it, but concepts it's good to have a solid grasp on it so you can explain.

The cohort strongly recognized the value of teachers' conceptual understanding of content in both mathematics and science.

Possession of conceptual knowledge allows teachers to more thoroughly explain topics to students and construct activities/environments that encourage conceptual learning. Yet, there are occurrences of in-service teachers who do not hold strong conceptual understandings of topics.

> Shanna: …Actually, while I was taking this I was thinking about this. You can kind of see where the cycle is and I think that especially in science, in my science teachers in high school, I don't think they understood the why. Because I can even remember when you're learning like physics stuff, like elementary physics, and stuff like that sixth grade question, I kind of remember a lot of textbooks when it came to that stuff. I remember like experiments with plants that you can teach, but I think that stuff even made them uncomfortable, that they didn't really understand the why and then they went to 'this is

> just this because of this' and you don't have the physics experience because I think they feel uncomfortable with it. So like, I think it's comforting to know that we are trying to break the cycle to some degree.

Shanna described both frustration over prior experiences with her science teachers' excessively relying on textbooks for teaching, and reassurance due to her own teacher preparation program emphasizing the importance of conceptual understanding in science. Tools, such as textbooks and scripted curricula, allow teachers to conduct class without a strong grasp of the topics being taught; however, having a conceptual understanding of content allows the teacher to create richer learning opportunities.

> Paige: I think understanding the 'why' makes it easier to teach, but even if we don't understand the 'why' as well, we can do it, but it's a lot harder for us to teach.

Paige was comparing the ability to complete a task to the ability to teach a task. While she may have stated confidence in her ability to answer a scientific/mathematical question, she recognized the benefit of conceptually understanding the task for teaching purposes. By developing skills for identifying the underlying concepts in mathematics and science, teachers are better able to note the connections between different topics, explain scientific and mathematical ideas, and construct learning environments that focus on conceptual understanding.

> Molly: They [mathematics and science] both have a lot of big broad concepts that have vocabulary underneath them you can learn, but you need to understand the broad idea things.

Mathematics and science are both detail oriented subjects; however, learning details, such as vocabulary, is easier if one already understands the associated concepts. Elementary teachers cover a variety of scientific and mathematical ideas throughout their teaching careers. Molly implied that one can memorize facts, but having a strong comprehension of the underlying concepts is of greater importance.

If one does not feel secure in their conceptual understanding of the content, then they will face uncertainty in their ability to teach science and mathematics topics.

> Shanna: And that's why I'm so unsure of it all, because I don't really know the why. I was never really taught the why and I just know that that's what gravity is and…you know what I mean?

Shanna's stated insecurities in teaching broad topics such as gravity are linked to her previous educational experiences. Without a memorable example or prior experience being taught conceptually, Shanna was puzzled about how to approach teaching such an abstract scientific topic. A lack of confidence related to teaching scientific concepts was shared by many of her peers.

> Colleen: It's kind of like 'what is gravity?' I don't know. It's cool. We go down. We stay on the ground, but like what…
>
> Facilitator: How do you explain it?

Colleen expressed an operational understanding of gravity, but an inability to teach the concept. Teaching involves not only imparting the content, but conveying the concepts in a manner that is appropriate to the audience. Thus, teachers must develop thorough enough conceptual understanding to tailor lessons for each level of student.

> Claire: …okay, I was thinking for the first grade one for the oxygen, for the 'why should we save trees?' I could answer that one, but it would be almost harder to teach because like beyond the basic of 'we should save trees', but teaching a first grader that trees create oxygen so we can breathe, it's really hard to do that.

Claire communicated concern regarding teaching children a topic that is considered basic to adults; namely, the reasoning behind preserving trees. As an adult, Claire has a strong understanding of the role of trees within our eco-system; however, scientific processes such as photosynthesis would be difficult to rationalize to a first grader.

Confusion over ways to explain abstract topics was not limited to science. Nancy expressed uncertainty about describing mathematical operations.

> Nancy: And it's so hard to, like you know, there's a reason and I know how to say it in my head, but I don't know how to say it out loud because I've just never really heard it.

In the case of mathematics, learning is often related to ability to perform operations. Yet, being able to vocalize the operations in a manner that accounts for each procedure can be far more cumbersome. Nancy stated that the difficulty in defining operations was directly linked to a lack of memorable examples and not being taught using conceptual approaches. Carol, on the other hand, expressed a belief that her mathematics methods course experiences prepared her to explain mathematical reasoning.

> Carol: It's because that's what we've been doing all year in both classes for math. When we solve a problem, half of what we have to do is describing it and how we got to that point and found our solutions.

Being required to explain the reasoning behind solution processes gave the pre-service teachers in this study practice for their future classrooms. Learning to reword scientific and mathematical explanations in terms appropriate for children is a difficult task. A strong conceptual understanding is valuable to teaching.

A thorough understanding of content allows teachers to recognize the nature of students' mistakes. When facing common misconceptions, teachers must take care in correcting students' erroneous beliefs.

> Trudy: Yeah, we talked about on site, how kids think they know the answer and are like 'I'm going to get it.' But you have to work a little harder to make sure you change their thoughts, I guess….

Rectifying false impressions can be particularly difficult for subjects such as mathematics and science. Many of the topics, such as adding fractions and explaining the concept of gravity, seem to contradict common sense. Teachers require a deep conceptual understanding of all topics they are expected to teach if they intend to appropriately convey the subject matter to young learners. Factual/procedural knowledge is also necessary for teaching, but the participants in this study noted that obtaining factual knowledge, such as vocabulary, is a simple task provided one already understands the underlying concepts.

Knowledge for teaching is a complex and dynamic area of study that includes many domains. Factual/procedural knowledge, conceptual understanding and pedagogical content knowledge all play important roles in teacher knowledge (Ball et al., 2008; Carlsen, 1999; Grossman, 1990; Hill & Ball, 2009; Hill et al., 2005; Magnusson et al., 1999; Shulman, 1986, 1987; Zembal et al., 1999). As the pre-service teachers prepared to enter the classroom, they emphasized the significance in conceptual knowledge for teaching mathematics and science and expressed faith in their ability to research/develop all domains of teacher knowledge over time.

Confidence in becoming a teacher.

Many of the pre-service teachers expressed self-assurance with regard to their ability to learn the content necessary for teaching prior to a given lesson. This self-assurance relates to a confidence in their learning/teaching aptitudes. The second theme to emerge from the final discussions was Confidence in Becoming a Teacher. Many factors influence ones confidence in teaching; including the perception of what knowledge is necessary for teaching.

> Shanna: I think, too, at the beginning of the year when we took this, I was kind of like, 'oh, I feel bad that I don't know all of these things.' But should I know all of these things? Do I need to know all of these things to become a teacher? And through taking like science and math I've realized that you don't…I mean you have to be equipped to know how students think about them and how students are going to learn them. That's the, what you were saying earlier, like I feel comfortable with the fact that I can learn from this and how to best teach it to my students, but I don't have to like know…I mean I need to eventually, but I don't need to know all the plants and their systems right now in order to be a good teacher. You know?

Shanna communicated her perception of knowledge for teaching, while also expressing a certain amount of confidence in her-self as a teacher. She recognized the need to eventually learn the topics she intends to teach, but places more emphasis on the need to understand and best teach her future students. Thus, Shanna conveyed confidence in her own teaching abilities even without extensive science content knowledge. Many of her peers shared the sentiment.

> Sophia: I said in science and I wrote down that once I know the answers, I'll be able to teach it.

Sophia's statement implies that she does not allow a lack of science content knowledge to hamper her global confidence in science teaching. However, her opinion is predicated on the idea that she will obtain the necessary content knowledge prior to teaching a lesson and that having the knowledge implies an ability to teach the content. Evelyn shared a first-hand experience related to Sophia's comment.

> Evelyn: …I just feel like if I know information about science, I can teach it. Because I'm tutoring a little boy right now about the brain, and I was sitting there and I had no idea what to do until I read over it.

Evelyn was asked to tutor over a scientific topic with which she was unfamiliar. But after a brief preparation period, she was able to assist the student. Evelyn's ability to quickly learn the subject matter bolstered her confidence in her future teaching of unknown science topics. Elementary teachers teach various scientific content areas, so the cohort placed more emphasis on their ability to learn than on their current cannons of science content knowledge.

> Colleen: I mean hopefully the night before we teach osteoclast we'll do what you taught us and do a content course, and then the next day hopefully a child doesn't ask a question we didn't research.

Colleen articulated confidence in herself as a science teacher because her teacher preparation program has taught her to research topics efficiently; however, she also voiced lingering concerns about facing questions she would be unable to answer. The idea of being unable to answer a student's question is intimidating to many teachers. But, many of the pre-service teachers noted that teachers are also life-time learners.

> Vera: Yeah, I feel like whether we know it right now or not, we just have to be able to teach ourselves pretty easily.

Several of the pre-service teachers in this study suggested a confidence in teaching science, even when unversed in science content, due to their ability to effectively research scientific topics.

In mathematics, however, knowledge of content was expressed as elevating their confidence as teachers. Many of the pre-service teachers claimed mathematics would be easier to teach because of their familiarity with procedures.

> Sierra: Math is just easier because you have a lot of formulas. Like before you teach the method, you know how to solve it already. I know we don't teach the formula way first, but we have it and we have a way to solve it, so in science it's like I learned this ten years ago and I don't remember any of it. You know?

Although they have been taught conceptual teaching approaches for mathematics that do not involve initially giving the formulas to students, Sierra stated that knowing the formulas and the correct final results gave her more confidence in teaching mathematics conceptually. Since she has the formulas in her cannon of knowledge, she can use those formulas to confirm the accuracy of her solutions before proceeding with problem-based teaching.

> Yvonne: If you see an algorithm, like how it's set up, you're able to figure out how you got that answer with the algorithm.
>
> Colleen: Whereas science it's all; not all of it but like, what is a photon, and I mean its mind boggling sometimes. It's just…

The pre-service teachers noted that the presence of a familiar algorithm and some basic mathematical reasoning skills assist greatly in understanding mathematical problems. But science does not have familiar algorithms teachers can utilize to confirm solutions to scientific questions. The ability to easily determine accuracy reinforced the pre-service teachers' confidence in teaching mathematics. While there is no algorithm for checking the accuracy of scientific solutions, appropriate preparation and research were mentioned as being necessary for confidence in science teaching.

In both science and mathematics, the participants expressed a great deal of confidence in teaching provided they were secure in their accuracy of the content. When questioned about developing this security, the pre-service teachers cited teaching experience as a key factor in learning elementary science and mathematics content.

> Facilitator: What would you need to get it to a point where you feel 'now I can teach it?' Because you're finishing your second semester of mathematics, you're not bad anymore.
>
> Paige: A lot of practice.
>
> Claire: Repetition.
>
> Facilitator: I mean have the two math methods courses you've had planted a seed enough so that while you go through your teaching it will keep growing until you become that 'I get it.'
>
> Vera: I think it's going to come with experience.

Many of the pre-service teachers in this study recognized knowledge for teaching and confidence in teaching as dynamic elements. Furthermore, numerous participants in the discussion took onus on themselves for such professional developments.

> Barbara: By observing other teachers, by doing my own research; because I'm also the type of person, I like to self-improve, so if there is something I see my child is not getting I'll be like 'well, what's another way I can help you figure it out.' I probably would have figured it out on my own because that's just the type of person that I am. So, I feel like I wanted more content and methods more so than one or the other.

Barbara remarked on the desire to learn both content information and pedagogy together, rather than focusing on one or the other because she perceives self-improvement in teaching techniques as a teacher's duty. For Barbara, confidence in teaching is linked to her drive to better herself as a teacher. Teachers are perpetually learning, both methods and content, as they teach. Helen shared a specific example of her improved knowledge in mathematics after obtaining some teaching experience.

> Helen: I found myself, with the fractions and stuff, like because I'm tutoring sixth grade and seventh grade math right now, and those were just so much easier for me because of the experience with just teaching math this semester, as opposed to last semester. I mean when would you ever do fractions?

Helen expressed increased confidence in performing the addition of fractions problem, which stemmed from the recent experience with the topic. The group recognized that familiarity with topics will likely come with teaching experience. Yet, certain members of the cohort were still apprehensive about a lack of science content knowledge as they prepared to enter their teaching careers. The final science methods course focused on pedagogy and science pedagogical content knowledge, which lead to some trepidation for the pre-service teachers with respect to their science content knowledge.

> Barbara: What I'm about to say is going to sound rude, and I don't mean it to be, this is just the way my brain thinks, but I feel like yes we got the methods course and we are learning different ways to teach things; but I also feel like at the same time as a teacher, if it is in you to teach, you're going to figure out a way to teach your students. Period. But that's just me, as a teacher. I don't really necessarily need a methods course to be a good teacher.

Barbara vocalized her concerns because from her perspective the science methods course concentrated on pedagogy instead of content or pedagogical content knowledge. Given Barbara's previously mentioned drive to self-improve, she considered the learning of content information and pedagogical content knowledge, over strict pedagogy, to be more influential to her confidence in teaching. However, having tools for research and an understanding of students were both mentioned by other pre-service teachers as being advantageous in developing their confidence in teaching.

Of the many factors that influence teaching confidence, self-assurance in the accuracy of content information when teaching was predominantly mentioned in the final discussions. Whether such self-assurances occur through preparation and research, the presence of familiar algorithms, or learning by experience, a thorough understanding of topics was viewed as central in giving teacher the confidence they need to teach effectively and allow students to question freely.

Teaching theories versus teaching practices.

The teacher preparation program advocated inquiry and problem-based learning, which encourages student discourse and questioning. However, field experiences, in a district with highly scripted curricula, often did not align with the practices promoted by their teacher education program. As such, the pre-service teachers deliberated greatly about the ability to implement such *best practices* in their future classrooms. The final theme, Teaching Theories versus Teaching Practices, includes discussions of classroom observations, considerations of constraints in implementing certain teaching theories, and memorable learning experiences expressed by the pre-service teachers. As a portion of their teacher education program, the group watched various videos displaying examples of inquiry and problem-based learning in mathematics. Nancy found these videos particularly helpful in determining her own teaching approaches.

> Nancy: I really liked watching the videos, because I'm always like 'okay, I want to teach this a certain way, but I feel like it's going to take a really long time,' and those videos showed how to compress it into a short math concept in all the different places. In Starpoint, I'm teaching a girl…I was teaching her multiplication, and that's what she started off learning in her class…and I went through every single step, and I was like 'this is going to take a really long time' because first I had to start out with groups of M&Ms so I could show her a concrete thing, and then I drew pictures with groups and she counted them, and then I said this is the same as taking two plus two plus two, and then I did it every single way we were taught, and she learned really fast. I just thought that was really interesting because I was expecting, I really wanted her to understand it and I was covering all the different ways we did it in class, that it was going to take a really long time, but she actually caught on faster than I thought she would.

Nancy recognized the importance of time-management in teaching, but still attempted to adopt the best practices she saw in the teacher preparation program. Initially she was concerned that the techniques would require too much time, but she was surprised by how quickly her student learned the material. In this case, by concentrating on developing a strong understanding of multiplication, Nancy's student was better able to master related topics. While Nancy had a positive experience related to the videos, not all of the pre-service teachers were convinced in the effectiveness of inquiry/problem-based learning.

> Paige: I had a really hard time with the videos because I look at that ten minutes of instruction and I feel like that's great for that ten minutes, but I don't see how she can do that over a period of time and across more than one subject. So, I think that's where the videos lose me, but I feel like if I was in field work with teachers who are doing that, and

> maybe that means finding teachers from this program who are placed in the area who have been taught this way, but watching that progression and then watching how the kids…you know, the next day if they come back and still understand it, I think that would make a big difference. I don't know. I haven't really had time to do this.

The available videos only offered a brief view into various classrooms, so Paige was curious about the extent to which students retained their knowledge. She did not necessarily deny the benefits of inquiry/problem-based learning, but she did state a desire to see long term learning results. Furthermore, Paige wanted to observe a classroom that adopted the 'best practices' promoted by her teacher preparation program.

Unfortunately, many of the pre-service teachers in this study noted the difficulty in finding such a classroom.

> Rose: I was thinking about choosing a TCU teacher in the Fort Worth area. Well, last year in the fall Donna and I were in Westfield Elementary and there was a teacher who graduated from our program in 2008, and she's not doing any of the things we learned because of time-management. I mean she's skipping straight from the enVision.

enVisionMATH is an interactive digital mathematics curriculum covering a variety of topics. Pre-packaged curricula can be dangerous for many teachers. While the vast majority of curricula are designed to be flexible, many teachers begin to view the outlines as scripts and do not allow for freedom or student questioning. Rose perceived that the teacher was disregarding the best practices she had learned and reading directly from the pre-made enVisionMATH lectures in order to save class time. However, Rose did not follow this model.

> Rose: I mean I just think you can teach lessons with enVision and still make it your own. Like, whenever I do my lessons from enVision I take them and I change them up a lot,

> and I just feel maybe it's like the way her classroom is or whatever, but I don't feel like the stuff that we're learning in here we're necessarily going to have time for or a portion of it we're not going to have time for especially her example of: okay, if she learned something like we learned it then why is she not using it.

Rose depicted her own situation in which she used a pre-packaged curriculum, but was still able to make alterations and take ownership of her classroom. Rose, like many other teachers, is still required to confront time-management issues but she did not allow those issues to prevent her from utilizing some of the techniques she learned in her teacher preparation program. Rose's story emphasizes the idea that using pre-made curricula does not control the classroom environment.

> Sandra: That's what I saw in my classes I did last semester. I was in two third grade classes and they were about math, and at one of the schools the teacher was just focused on like…and she'd give them worksheets, and if the kids had a wrong answer or they got out of the bubble she screamed at them and get right in their faces. Those kids were so intimidated, they didn't talk about the math problems; they talked about how scared they were of the TAKS [state test] test. I know it was the saddest day of my life. And at the other school, the teacher was like, they were in the third grade and when I was there they could do subtraction problems and addition problems, but they did it in ways that we learned here in our math class, so I thought that was cool. And then, one of the days I went, she taught them how to add and subtract using the traditional method and I was like 'they're in third grade, how do they not know this?' But like they were faster than I was, and one of the little kids there used algebra to solve a math problem. Seriously, I didn't know what he was doing. So like, it was the exact same problems, it was the exact same

everything, it's just the way they taught it was completely different and it made a difference.

Sandra confirmed Rose's notion that the teacher can greatly impact learning even when restricted by pre-packaged lessons. Sandra observed two third grade mathematics classes in the same district with the same expectations and the same required worksheets, but witnessed two very different classroom environments.

In order to create positive learning environments, the teacher requires a certain amount of control and flexibility with regard to the lessons. The pre-service teachers noted that their ability to implement the best practices may depend upon the school or classroom in which they are placed.

> Colleen: Well, it's also the Texas and this school and how much they want you to teach and TAKS [state exam] and all of that. Nell and I were in a third grade class and we got kicked out because they were stressed out about TAKS, so we couldn't watch them anymore. There's so much that a teacher needs to do that…It would be nice if we could teach the way we've been taught here, but in reality we may not be able to.
>
> Facilitator: Do you…that's provocative…how many of you think that you will be able to teach the way that "we" have said you ought to?
>
> Colleen: I would like to in certain situations, but it depends on the school, and the principal, and what we're asked to do, and…

Although Colleen expressed a desire to adopt the 'best practices' she learned in her teacher preparation program, she recognized the difficulty of utilizing such techniques without support from her administration. High stakes testing has been particularly detrimental to the use of inquiry/problem-based learning approaches. Direct teach methods and drill sessions, which involve telling students the algorithms and solutions, appear far less time consuming and allow teachers to cover a broader array of topics quickly; however, simply because a teacher discussed a topic does not imply that the students understood the content. Yet, in the environment of high stakes testing, teachers often return to the direct teach model in an effort to meet the demands of such standardized exams.

> Alice: I was going to say for one of my math lessons, because we were supposed to ask what the kids were learning and the teacher asked if we could just do TAKS [state exam] and drills and go over the questions with them. That's what she wanted me to do as a lesson, so that's what we had to do. She was just like 'Give them a worksheet with TAKS questions. You can pick which ever ones you want but they need to be from these TAKS and give them to the kids.'

For their field experience, the pre-service teachers are supposed to prepare and teach two grade-level appropriate lessons. Unfortunately for Alice, her opportunity to design a lesson was circumvented in favor of drill as preparation for a standardized test.

Throughout the discussions of teacher knowledge, the participants noted the importance of conceptual understanding over factual/procedural knowledge; claiming that vocabulary and other factual information can be learned quickly provided the teachers have a strong research skills and some understanding of the concepts. However, when questioned as to the types of knowledge that should be the learning goals for their students, Vera observed:

> Vera: Number two [conceptual questions], but realistically, they're tested over number one [factual/procedural questions].
>
> Facilitator: Oh, you hurt me bad just then.
>
> Vera: I mean, like, they're tested over…

Vera remarked on the reality of high stakes testing. While there is an expressed desire to teach their students about the broad scientific and mathematical concepts, there is the realization that they will be judged based on their students' abilities to answer factual/procedural questions. Such judgments quickly overthrow the desire to adopt the more time-consuming inquiry/problem-based teaching practices. Further hindering the use of best practices is a lack of available classrooms where pre-service teachers may observe inquiry learning in action.

> Pamela: Getting back to…I think it would be good to kind of see the way we've been taught to teach in the actual classroom. I haven't seen any classrooms that follow what we've learned to teach in science or math, so…

At the end of her junior block, Pamela developed a thorough understanding of the theories supporting the suggested teaching practices, but yearned for a real-world example of the best practices in action.

Without being able to observe a classroom utilizing the techniques they learned in the teacher preparation program, many of the pre-service teachers had difficulty visualizing how such practices could be successfully employed within the constraints faced by in-service teachers.

> Helen: Just like when we see…you know we talk a lot about the summer camps they do here and Dr. Jones talks about how her and Dr. Smith they like…it just seems like they have so much time to ask those deep questions and really get kids thinking, but I feel like when you're an actual teacher, you have to be so conscious with your time management, so it's like 'yeah, they can spend two whole weeks getting that one answer', but that's not affecting a school day or like…

Helen cited an example of the successful implementation of inquiry-based learning in a summer program sponsored by the university, but expressed concern about translating such practices into a classroom facing time-management issues. Classroom learning does have constraints and expectations not present in summer programs, but practices such as inquiry-based learning can be adapted for the classroom environment during the regular school year.

> Vera: I don't know. I'm in Seaside Elementary and went to teach with Ms. Conner and she is a fifth grade science teacher and she just amazes me. Because by the fifth grade I didn't really like science because it had become more about reading and things like that, but she chooses a topic, and she just comes up with all of these crafts and she does so many hands-on games. I mean they made fossils from play-dough and let it harden and they got to paint it and things like that. Then they got to play archeologist and it was just so cool, and I don't know. When I see teachers like that I'm like 'okay, it can be done.' There can be, if there is a way to incorporate it and make it not just like 'read the textbook and do the worksheets.' So, when I see teachers like her it makes me excited to think I can use what I'm learning, I can make it hands-on, and fun like that.

Vera's observation of inquiry-based learning in a fifth grade science classroom enticed her desire to adopt the best practices she learned in her teacher preparation program. As a student, Vera claimed science was boring by the fifth grade because it centered on reading, but the techniques she observed as a pre-service teacher made fifth grade science appear *cool* and *fun*. Thus, Vera noted the benefit of utilizing teaching techniques different from those seen when she was a student. However, not all of Vera's peers shared this perspective.

> Evelyn: I mean science is obviously a little bit harder for me at least, because in math we've learned; I don't know how to explain it but, like sometimes the little borrow carry

> thing. That just makes me angry, because that's what I learned and that's what I want to teach, but apparently that's not…

Evelyn stated a desire to utilize the same teaching approaches she witnessed in her youth. Specifically, she refers to the desire to teach an algorithm for subtraction utilizing the word *borrowing,* rather than a term that truly represents the procedure such as *exchanging*. In addition, throughout the teacher preparation program, the pre-service teachers were told to avoid teaching basic algorithms until after students had the opportunity to develop their own problem solving approaches. The logic behind the practice is that by compelling students to construct their own understanding of mathematical concepts, students then develop stronger mathematical reasoning skills, which supports comprehension of the algorithm.

Requiring students to reason and seek solutions is an integral aspect of inquiry/problem-based learning in both mathematics and science.

> Facilitator: There's a rule you said that has been burned into your brain somewhere that 'there's a rule for getting the answer but we don't teach that way.' And I've seen that in your class. "Don't teach with the algorithm. Don't!" Is there a parallel to that in science?
>
> Quinn: Yeah, you don't just give them an answer. You make them seek it out.

The pre-service teachers learned best practices for teaching science and mathematics of inquiry and problem-based learning that requires students to seek solutions. Unfortunately, many in-service teachers do not implement such practices. Inquiry/problem-based teaching is difficult for teachers to adopt because the techniques require more creativity and greater conceptual understanding than the direct teach method. When implemented appropriately, inquiry/problem-based instruction can be both memorable and enjoyable for students. In fact, many of the pre-service teachers complimented the facilitator on the manner in which he taught science, stating that they learned a great deal of content throughout the semester.

Facilitator: Because I didn't lecture you in my class. You talked about all the content that you learned in my class.

Quinn: Well, we taught ourselves the content.

Colleen: The way you taught it is…we taught ourselves.

Sophia: We had to reason.

Facilitator: That's the big punch line folks. I didn't prepare for your class. I didn't know the answers to my own questions. I swear to God, I was like 'how does a volcano form?' That sounds like a good question 'how does a volcano form?' And I would come to class and I would say I'm going to learn how volcanoes form.

Colleen: But that made it interesting because that made it feel like we were teaching you.

The facilitator adopted inquiry-based techniques for science teaching, in which he would ask the class a broad question and expect them to obtain scientific explanations. This practice allowed the pre-service teachers to not only learn the content, but to also develop scientific research skills. Moreover, the cohort stated that the teaching practices made the topics more memorable. Although many of the pre-service teachers claimed they preferred learning via inquiry-based approaches, they still doubted their ability to adopt such practices.

Teaching with inquiry/problem-based techniques requires creativity, conceptual understanding, self-assurance, and patience on the part of the teacher. The majority of the pre-service teachers expressed confidence in their teaching abilities, provided they were knowledgeable of the topics they were expected to teach. Moreover, they stated that factual/procedural knowledge was of lesser importance to teaching than conceptual understanding, because with a strong conceptual understanding and appropriate tools for research they would be able to learn topics prior to teaching. Interestingly, the participants associated the need to research with science, stating that the presence of familiar algorithms in mathematics alleviated the need for such investigations. Even though inquiry/problem-based learning specifies that teachers should not initially teach the algorithm to students, the existence of such algorithms increased their confidence by giving a simple avenue for checking the accuracy of various solutions. Therefore, inquiry teaching in science was expressed as being more daunting because teachers have no algorithm for testing the accuracy of a student's scientific explanation. Regardless of the dilemmas with respect to inquiry/problem-based instruction, the pre-service teachers related such teaching techniques to their more enjoyable and memorable experiences with school science and mathematics, even though they expressed challenges with teaching this way in the current climate of standardized testing.

Conclusions

There are numerous approaches for teaching mathematics and science. Perceptions as to the knowledge required for teaching mathematics and science influences which teaching practices are adopted. Furthermore, teaching efficacy beliefs and confidence in the subject matter knowledge impacts how teachers approach student questions, attrition, and teaching approaches (Bandura, 1997; Brouwers & Tomic, 2000; Bursal & Paznokas, 2006; Coladarci, 1992; Midgley et al., 1989; Swars et al., 2006; Wheatley. 2002). The pre-service teachers in this study held disparate views of the knowledge required to teach mathematics and science. As seen in both the quantitative and qualitative results, the cohort had very different perspectives regarding the role of factual/procedural knowledge in teaching mathematics versus teaching science.

Additionally, certain attributes of the nature of mathematical learning resulted in the pre-service teachers expressing increased confidence in both teaching and performing mathematical tasks, over scientific tasks. Conceptual understanding was emphasized as being essential to teaching both mathematics and science. The various domains of knowledge for teaching differ between mathematics and science disciplines to some extent. Yet, overarching similarities only emphasize the commonalities of these two subjects. The results from this study yield fascinating ideas regarding the pre-service teachers' perceptions of the knowledge required for teaching mathematics and science.

CHAPTER 5 - DISCUSSION

The aim of this study was to compare the perceptions of the cohort of pre-service elementary teachers with respect to the knowledge required for mathematics teaching versus science teaching, and to compare their teaching efficacy beliefs between mathematics and science. The manner in which mathematics and science are perceived influences how knowledge for teaching is viewed. Teachers' understanding of the nature of subject matter shapes the topics they emphasize and the methods they use to convey such content to their students (Borko et al., 1992; Brickhouse, 1990; Cantrell et al., 2003; Grossman, 1989, 1990; Hill & Ball, 2009; Hill et al., 2005; Lerman, 1990; Mellado, 1997; Shulman, 1986, 1987; Stevens & Wenner, 1996; Swars et al., 2007; Yilmaz-Tuzun & Topcu, 2008). Additionally, teaching efficacy beliefs affect the techniques teachers are likely to employ in the classroom (Bandura, 1997; Brouwers & Tomic, 2000; Bursal & Paznokas, 2006; Coladarci, 1992; Midgley et al., 1989; Swars et al., 2006; Wheatley, 2002). A multitude of dynamic factors coincide to sculpt the pedagogical philosophies adopted by each individual teacher. Principal among these factors are perceptions of the nature of content, perceptions of knowledge for teaching and teaching efficacy beliefs. However, these factors are not global across disciplines. Hence the following discussions focus on the comparisons of knowledge for teaching and teaching efficacy beliefs between mathematics and science from the perspectives of the pre-service teachers in this study.

Knowledge for Teaching

Knowledge for teaching is a dynamic area of study. Shulman (1986, 1987) initially defined teacher knowledge as a type of professional understanding that stretched beyond classroom management and content knowledge. Central within teacher knowledge is pedagogical content knowledge (PCK), or the special mixture in which knowledge of content interacts with pedagogical knowledge to create the teachers professional understandings. Teachers require thorough understandings of content and pedagogy in order to appropriately convey topics to young learners. While science and mathematics are both detail oriented subjects that center on the use of rigorous methodologies, they remain distinctive disciplines with separate constructs for teacher knowledge. The pre-service teachers in this study noted that the precise roles of factual/procedural knowledge and conceptual knowledge vary between disciplines.

As a profession, teaching requires complex understandings of content, pedagogy, assessment, politics, and students. While certain attributes of knowledge for teaching stretch globally across disciplines, other aspects are unique to each subject. The pre-service teachers in this study were in the process of developing their own understandings of teacher knowledge. Through the analysis of the PETSMA results and classroom discussions, conclusions were drawn with respect to their perceptions of the knowledge required for teaching mathematics and science. In what follows, the cohort's perspectives of mathematics and science are discussed separately, and then the perspectives are compared between disciplines. Additionally, considerations of the perceived role of factual/procedural knowledge and the role of conceptual knowledge in teaching each subject are reviewed. Finally, comparisons are made between the data from the initial and final administrations of the PETSMA and the initial and final discussions.

Pre-Service teachers' perspectives of mathematics.

Mathematics is a rigorous discipline founded in logic and reasoning. Yet, mathematics can also be very abstract and creative. Teachers' perceptions of mathematics sculpt the manner in which they approach mathematics content in the classroom. Furthermore, ideas regarding the knowledge required for teaching mathematics impact teachers' professional understanding of content, assessment, and pedagogical approaches (Ball et al., 2008; Shulman, 1986, 1987). The pre-service teachers in this study expressed many viewpoints regarding the nature of mathematics and the knowledge require for teaching mathematics.

Pre-service teacher' perspectives on the nature of mathematics.

Prior to discussing the cohorts' perceptions of the knowledge required for teaching mathematics, relevant observations regarding their beliefs about the nature of mathematics are considered. How mathematics is perceived greatly influences beliefs about mathematics teaching (Aiken, 1963; Ball, 1988; Ball et al., 2008; Borko et al., 1992; Hill & Ball, 2009; Hill et al., 2005; Lerman, 1990; Swars et al., 2007; Szydlik et al., 2003). During the initial discussions, the pre-service teachers described mathematics as being largely composed of factual/procedural knowledge, relying heavily on algorithms, and focusing on correct end results over problem-solving processes; however, this outlook modulated by the final discussions.

Based on the analyses of the pre- and post-PETSMA data, the participants performed significantly better on factual/procedural mathematics items than on the conceptual mathematics items. Additionally, they were more confident in performing and teaching factual/procedural mathematics tasks over conceptual mathematics tasks as shown by the initial and final PETSMA results. Such findings align with the notion that factual/procedural mathematics problems can be solved without a thorough understanding of the underlying concepts, when a familiar algorithm or process is given. Furthermore, prior school experiences with mathematics led many of the pre-service teachers to believe that, as a discipline, mathematics is only concerned with end results and not conceptual understanding.

During the initial discussions, knowledge of mathematics content was frequently associated with the ability to obtain the correct answers to various mathematics problems. Mathematics was described as being "black and white" and focusing largely on the accuracy of solutions rather than understanding mathematical concepts. However, by the final discussions, the cohort recognized the importance of understanding mathematical concepts in teaching. Algorithms may allow one to obtain a correct solution, but memorization of algorithms/procedures does not necessarily imply understanding. Yet, the presence of familiar algorithms and the ability to be self-assured in the accuracy of mathematics solutions were mentioned as being important to improving confidence in performing mathematics tasks and in mathematics teaching.

The pre-service teachers largely associated mathematics with understanding factual/procedural knowledge. In the final discussions, the cohort recognized that mathematics content stretches beyond the ability to simply utilize appropriate algorithms. They saw that understanding mathematics concepts would greatly aid in teaching, but still expressed a desire to rely on procedural operations to ensure accuracy of their solutions. Thus, while many of the participants discussed wanting to teach mathematics from a more conceptual perspective, they also expressed a desire to continue practicing mathematics by using familiar algorithms and procedures.

Pre-service teachers' perspectives on the knowledge for teaching mathematics.

Ball et al. (2008) described the domains of knowledge that unite to form the theoretical construct of Mathematical Knowledge for Teaching (MKT). Teaching mathematics requires not only knowledge of how to perform a given procedure, but also conceptual knowledge to determine the exact nature of a student's mistake and which procedures are appropriate for a problem. For example, a student may have an inaccurate result after attempting to solve a quadratic equation, so the teacher must be able to determine if the error occurred from misusing the formula, inappropriately simplifying the radical, or inappropriately reducing the final fraction. According to the Ball et al. (2008) there are six domains that comprise the MKT construct: 1) *common content knowledge (CCK),* 2) *specialized content knowledge (SCK),* 3) *horizon content knowledge,* 4) *knowledge of content and students (KCS),* 5) *knowledge of content and teaching (KCT),* and 6) *knowledge of content and curriculum.* The domain of specialized content knowledge (SCK) is one that is unique to mathematics teaching and involves the mathematical skills utilized only by individuals in the teaching profession.

With respect to mathematics, there was no debate among the pre-service teachers about the importance of factual/procedural knowledge. The cohort performed very well and expressed a great deal of confidence in their ability to both perform and teach factual/procedural mathematics problems. *Common content knowledge*, one of the domains of MKT, refers to the mathematical knowledge that any individual, who is considered educated in mathematics, should know. The pre-service teachers agreed that a mathematics teacher should be able to solve any mathematics problem they are expected to teach.

Additionally, the pre-service teachers described mathematics as focusing more on factual/procedural knowledge over conceptual knowledge. Performance scores were significantly higher on the factual/procedural mathematics questions than the related conceptual mathematics questions. When citing their own educational experiences, they noted the tendency for teachers to only be interested in their students' abilities to get the correct answer. Stemming from such experiences is the misconception that the ability to solve a mathematical problem translates into being able to teach the content related to that problem. However, as teachers, the participants did note that a lack of conceptual understanding would hinder their ability to teach mathematics, because they understood that knowledge for teaching mathematics stretches beyond *common content knowledge*.

The participants noted that being able to solve a mathematics problem does not give one the skills to explain the process, and the reasoning behind the process, to a group of students. Learning procedures without understanding why the procedure works can be detrimental to students at a later date. For example, the pre-service teachers discussed common misconceptions with regard to addition of fractions. Frequently, when adding fractions, students will simply add the numerators and add the denominator, without noting the need to first find a common denominator then add the numerators while keeping the common denominator. If students do not understand the purpose of first obtaining the common denominator they may use an inappropriate, although seemingly logical, procedure. The participants noted that memorization of algorithms allows students to pass standardized tests. But, when the students do not know the logic or reason behind a procedure, they are not prepared for the more advanced mathematical topics they will face later on in their academic careers, such as combining like terms with variables which relates to common denominators in adding fractions (*Horizon Knowledge*). Thus, the cohort acknowledged that teachers must thoroughly understand and convey the concepts that underlie the mathematical procedures and algorithms.

In mathematics, numerous underlying concepts often come together to be implemented in new topics. The pre-service teachers noted the importance of *horizon content knowledge*; in particular, the importance of understanding the previous concepts on which the topic they are teaching were built. The participants stated the unfortunate truth that many students are passed to the next level of education without a strong grasp of the mathematics content they were expected to learn in previous grades. The pre-service teachers noted the manner in which mathematics learning builds on previous topics, so when faced with a student that does not have the foundational understanding necessary to learn the new topic, the teacher must go back and reteach the fundamental concepts. Thus, the participants felt it necessary to be prepared to teach not only their grade level curricula, but the curricula of any lower grade level in order to properly assist those students that were 'passed along'. The pre-service teachers expressed frustration regarding students who are sent to the next grade level because they were able to pass some exam by temporarily memorizing an algorithm without actually learning the underlying concepts of the content covered on the test, because such practices only cause problems for students as the content becomes more advanced.

For both students and teachers, the familiar algorithms and procedures linked to mathematical learning are more easily understood than the associated mathematics concepts. The results from the analysis of the PETSMA indicated that the participants were more confident in performing and teaching the content related to the factual/procedural mathematics questions than the related conceptual mathematics questions. Additionally, for the factual/procedural questions, the cohort was significantly more confident in their ability to answer a given question than their ability to teach the content. These results are not surprising given that teaching mathematics involves deep conceptual understanding and the knowledge/skills to verbalize abstract mathematical ideas in ways that assist student learning. In fact, during the discussions, many of the pre-service teachers expressed frustrations about explaining mathematics concepts. Several members of the cohort articulated being taught mathematics by memorization of algorithms and practice drills. However, as pre-service teachers, they were encouraged not to begin by teaching these algorithms and instead to have students develop problem-solving skills by approaching problems without an algorithm. Many of the pre-service teachers came to realize that such algorithms can become a crutch and do not aid in the development of strong mathematical understandings.

Interestingly, the results of the PETSMA showed that the participants were significantly more confident in their ability to answer factual/procedural mathematics questions than teaching factual/procedural content, but the difference was not significant with respect to conceptual mathematics content. These trends further emphasize the notion that the pre-service teachers recognized that knowledge required for teaching mathematics is more conceptual in nature. In other words, being able to answer factual/procedural questions is not sufficient for mathematical teaching. Instead, knowledge for teaching mathematics includes deep conceptual understanding of the topics, how the content develops and builds over time, and the different ways in which the concepts may be approached or explained. In other words, knowing that the square root of four is two (factual/procedural knowledge) does not imply an understanding of the meaning of square roots (conceptual knowledge). Moreover, translating mathematical procedures into clear, accurate, and age-appropriate explanations requires deep understanding of both the mathematical content and the manner in which students learn mathematics (Ball, 1988; Ball et al, 2008; Hill & Ball, 2009; Hill et al., 2005). While the pre-service teachers rarely cited mathematics as being conceptual in nature, they did note that holding a conceptual understanding of mathematics topics would aid teachers in explaining the content.

Furthermore during the post-discussions, the cohort mentioned the role of curricula and the expectations of the institution as influencing mathematical teaching practices. The PETSMA did not include any mention of curricula or institutional goals; yet, *knowledge of content and curricula* is a stated knowledge domain of MKT. The pre-service teachers discussed the issue of time-management when trying to create a deep conceptual understanding on the part of their future students. They believe that standardized curricula can impede teachers from dedicating more time to areas that are a source of misconceptions for a given group of students. While there was an expressed desire to give future students a conceptual understanding of mathematics topics, the reality of time-management, standardized testing expectations, and pre-made rigid curricula was a source of concern for many of the participants. However, after gaining a certain amount of student-teacher experience a few of the pre-service teachers were able to convey experiences regarding the impact of teaching mathematics using problem-based approaches versus traditional drill sessions.

One participant, in particular, shared her experience in teaching multiplication. Nancy incorporated a multitude of techniques when initially teaching multiplication to a student she was tutoring. Utilizing objects as concrete exemplars, pictures for visual models, and examples with mathematical notation, she revisited multiplication from a plethora of perspectives. At first, Nancy expressed concern regarding the amount of time required to cover so many different techniques. In a classroom, time-management issues could easily prohibit a teacher from using so many different methods. However, by utilizing numerous approaches the student was able to better understand the concept of multiplication and learn more quickly after developing a conceptual understanding. Since the student did not rely on the memorization of multiplication facts and instead learned using a conceptual approach, the student was able to use that conceptual understanding when attempting more complex problems. Thus, Nancy's experience displayed the manner in which taking time in the beginning to give students a strong conceptual understanding allows them to excel as the content becomes more advanced. This practice of implementing numerous techniques and appreciating the role of conceptual understanding to aid in later learning is an example of *horizon content knowledge, knowledge of content and teaching*, and *knowledge of content and curriculum* in MKT.

Pre-Service teachers' perspectives of science.

The pre-service teachers recognized that knowledge of science content includes both factual/procedural knowledge and a conceptual understanding of topics. Similar to mathematics, science is a discipline defined by rigorous methodologies and reproducibility of results (Abell & Smith, 1994; Lakatos, 1977; Wolpert, 1992). However, science is based on observations and is therefore grounded in reality, while mathematics can be more abstract (Devlin, 1994; Devlin, 1998a; Ogilvy, 1956). Yet, science frequently appears counter-intuitive (Wolpert, 1992). For teachers, approaching science in the classroom, with limited time and resources, can be difficult. Moreover, teachers' orientations to science content impact the manner in which science is approached and assessed in the classroom (Carlsen, 1999; Magnusson et al., 1999; Zembal et al. 1999). In this study, the pre-service teachers discussed orientations to science content which differed from those expressed with respect to mathematics content.

Pre-service teachers' perspective on the nature of science.

Noting the manner in which the cohort perceived science is germane to understanding their perceptions of the knowledge required for science teaching. Perspectives of the nature of science and the knowledge for teaching science impact both classroom practices and student outcomes (Brickhouse, 1990; Carlsen, 1991, 1999; Magnusson et al., 1999; Mellado, 1997; Yilmaz-Tuzun & Topcu, 2008; Zembal et al., 1999). The participants expressed the view that science is conceptual in nature. From their perspective, science learning was associated with open-ended questions and logical reasoning based on observations.

The pre-service teachers recalled their experiences with school science as involving open-ended questions and experimentation. However, results from the PETSMA display significantly higher performance and confidence scores related to factual/procedural science questions than conceptual science questions. The PETSMA results, when paired with the discussions, showed that the cohort described factual/procedural science information as being easier to learn and understand than the underlying science concepts, but placed greater importance on the understanding of science concepts. Moreover, basic factual science information, such as definitions, was described as being inconsequential to their daily lives.

The participants associated science learning, not with recalling vocabulary, but instead with the ability to research and reason scientifically. Research, reasoning and observational skill were all discussed as being pertinent to preparing science lessons. Since science is grounded in observations, science comprehension was described as understanding how things function versus knowing proper scientific names. Thus, in science, the cohort noted that the ability to achieve the correct responses on factual/procedural science questions did not imply an understanding of the related science concepts. However, confidence ratings related to factual/procedural science questions were still higher than those related to conceptual science questions for both answering questions and teaching content.

The cohort described science content as being more conceptual in nature as opposed to focusing on factual/procedural information. Furthermore, the participants expressed a certain amount of confidence in their ability to learn factual science content, such as vocabulary, provided they were given time to research the topics. However, when discussing conceptual science content, the pre-service teachers did communicate some concerns regarding their ability to grasp some of the more counter-intuitive science topics. In the classroom, teachers are expected to not only understand science content, but also to be able to appropriately convey the topics to young learners. Since factual/procedural science information was described as being easier to understand and teach, many of the participants stated trepidations regarding their ability to teach using pedagogical approaches that highlight the conceptual nature of science content.

Pre-service teachers' perspectives on the knowledge for teaching science.

Science teaching entails certain domains of knowledge not used in the teaching of other subjects. The construct of PCK for Science Teaching has been considered by the educational research community (Magnusson et al., 1999; Zembal et al., 1999). The five domains of knowledge that form PCK for Science Teaching are: 1) *orientation to teaching science,* 2) *knowledge of science curricula,* 3) *knowledge of students' understanding of science,* 4) *knowledge of instructional strategies*, and 5) *knowledge of assessment of scientific literacy.* The domain of *orientation to teaching science* is described as including the teachers' ideas of the purposes or goals of teaching specific science topics and as being the central domain of PCK for Science Teaching. Interestingly, the philosophies of the individual teacher are not noted in the MKT construct.

Similar to mathematics, science teaching requires intricate understandings of content, students, assessment, and curricula. Yet, the pre-service teachers in this study expressed very different perspectives of the knowledge required for science teaching. Science content was described as being more conceptually oriented than mathematics. The pre-service teachers expressed that school mathematics focused more on the end result of problems, while science learning was associated with open-ended questioning. The participants noted previous experiences of school science in which teachers tended to focus on students' conceptual understandings as opposed to factual/procedural science knowledge. Such experiences and perspectives regarding the nature of science served to shape these pre-service teachers' views of the knowledge required for science teaching.

The analysis of the PETSMA showed that the pre-service teachers were more confident in teaching factual/procedural science content than in their own ability to answer the factual/procedural science questions. When viewed without any other context, these results seem disturbing because one would assume that a teacher needs to know the topic they are expected to teach. However, in light of the classroom discussions, the results have a logical justification. The pre-service teachers recognized that they will need to know all of the topics prior to teaching, but given strong research skills and appropriate preparation time they do not need to memorize all scientific facts, such as vocabulary words. Furthermore, learning factual science information is relatively simple, provided the individual has a strong conceptual understanding of the topic. For instance, one may understand the process of photosynthesis, but need to review the difference between the xylem and the cortex. Thus, the participants expressed that factual/procedural knowledge of science was less important to science teaching provided that the teacher had a strong conceptual understanding of scientific topics and sound research strategies.

Furthermore, many of the pre-service teachers noted that science vocabulary is not a part of their daily lives. Since the participants did not have perpetual reinforcement of the factual/procedural science content, they tended to describe a perception of science as discrete pieces of information. Additionally, they noted that school science encompasses many diverse branches of study, so connecting information between topics is not always a possibility. Yet, connections in science were discussed because science involves the study of our-selves and our surroundings. Since scientific phenomena are witnessed daily, many of the pre-service teachers stated having the ability to reason backwards in an attempt to determine explanations to open-ended conceptual science questions. For example, one may not know how muscles and bones work together to help people move, but they are aware of their own muscles ability to tense and contract which aids in walking; so they may be able to determine that muscles pull on bones simply by observing their own movements. This ability to observe phenomena and determine scientific explanations is an example of science literacy. The pre-service teachers were able to make the distinction between knowing all science facts (such as vocabulary terms) and being scientifically literate (being able to reason scientifically).

Conceptual understanding of broad scientific topics is necessary to science literacy and was expressed as being crucial to science teaching. The analyses of the PETSMA results showed that the pre-service teachers were significantly more confident in their ability to teach factual/procedural science content than in their ability to answer factual/procedural science questions. However, there was not a statistically significant difference with respect to the conceptual science questions between the participants' confidence in their ability answer questions and their ability to teach content. In other words, the pre-service teachers' perspectives differed between factual/procedural science questions and conceptual questions. They recognized that in order to be confident in teaching science concepts, they first must be self-assured in their ability to conceptually understand the topics. Researching science vocabulary is simple, when given the aid of a textbook; but deep conceptual science knowledge requires time and understanding. During the discussions, a few of the pre-service teachers did express concern regarding the amount of research they would need to do to prepare for science lessons and worry that a student may ask a question they are unprepared to answer. The participants noted that many scientific concepts are counter-intuitive, which only makes teaching more difficult. However, when faced with questions they are unprepared to answer, the pre-service teachers noted the many resources available to determine answers. Evelyn conveyed her experience in tutoring a student about the human brain. She arrived at the tutoring session being unaware of what she was expected to teach. But after reviewing the textbook for a few minutes, she was able to assist the student. Basic research skills, reasoning skills, and scientific literacy allowed Evelyn to quickly glean the information necessary to assist in her student's learning. Thus, while factual/procedural knowledge is important to teaching science, the pre-service teachers placed greater emphasis on science literacy and research skills. Developing a conceptual understanding of scientific theories and laws was described as being of superior importance in science teaching. However, the pre-service teachers noted that forming appropriate comprehensions of theoretical constructs is more difficult than memorizing vocabulary. The analysis of the PETSMA revealed significantly higher confidence on factual/procedural science questions over the related science conceptual questions for both answering questions and teaching content. Although the participants noted the necessity of teachers understanding science concepts, when faced with specific science questions, they felt more comfortable with answering/teaching science facts/procedures. One explanation provided during the discussions was that science concepts can be very abstract. For example, a child may ask a seemly basic question of 'what is light?' Yet, explaining how light is made up of photons and can simultaneously behave like a particle and a wave could easily lead to greater confusion. Additionally, the pre-service teachers noted the difference between understanding a topic and explaining the topic to a child. One may know that plant life plays a pivotal role of our ecosystem and is responsible for creating oxygen, but a child may have difficulty understanding that the tree in their yard is producing oxygen. From the perspective of the cohort, teaching factual/procedural items, such as vocabulary and simple rules, is easier because there is little explanation required. However, teaching in a manner that develops a strong conceptual understanding of scientific topics and increases science literacy is more difficult for the teacher.

Different teaching techniques accentuate different types of knowledge (Adams & Hamm, 1998; Howitt, 2007; Mellado, 1997; Morine-Dershimer & Kent, 1999; NCTM, 2000; NRC, 1995; NSF, 1999; NSTA, 2008). For example, requiring students to read a section of the textbook, find all of the bold printed words, and locate/write those definitions from the glossary emphasizes factual knowledge; while requiring students to create their own experiments to answer a question posed in class stress scientific reasoning. Teachers' perceptions of how science teaching should be approached in the classroom, or *orientation to teaching science*, was defined as the central domain for PCK for Science Teaching (Magnusson et al., 1999; Zembal et al., 1999). The pre-service teachers in this study noted that embracing techniques designed for conceptual learning is more difficult than implementing direct teach methods to convey basic factual/procedural information. Again, time-management was identified as a primary obstacle against the use of inquiry-teaching methods. In elementary school, the class-time dedicated to science was described as being extremely limited, so having students develop and construct their own experiment can be a challenge. However, the use of such methodologies is not impossible. Vera described a classroom observation experience in which the teacher considered a different broad scientific topic each week, and allowed for related experiments or demonstrations to occur throughout the week's progression. For instance, when the students learned about dinosaurs, they made clay fossils and were able to play archeologist. The pre-service teachers mentioned that such techniques are time consuming and require a great deal more effort on the part of the teacher. However, Vera noted that such activities made the learning experience more enjoyable for the students. While constructing a learning environment that will guide students to scientific discoveries is very difficult, the participants described such environments as being more fun and exciting than the traditional lecture classroom they observed. Thus, the students recognized that the teachers' extra efforts in constructing such experiments aid in students' comprehensions and enjoyment of science.

The participants noted that teaching factual/procedural knowledge, such as vocabulary, is easier than trying to build deep a conceptual understanding of science. When faced with a question they are unprepared to answer, the participants cited science textbooks as useful, quick reference tools for determining factual/procedural information. However, they recognized that developing an understanding of scientific concepts requires more time and effort. When teachers do not have a strong understanding of the broad concepts underlying scientific phenomena, there is an impulse to focus on only teaching factual/procedural knowledge from the textbook in order to avoid facing questions they are ill-equipped to answer (Carlsen, 1991). However, the participants remarked on the importance of having a conceptual understanding of science topics because memorization of vocabulary does not equate to being scientifically literate. From their stated perspectives, conceptual understanding of science content is of more significance when teaching science than factual/procedural knowledge of science. Although the pre-service teachers noted that scientific phenomena are often difficult to explain to children, they also recognized that teaching from an approach that emphasizes concepts, over factual information, makes learning science more enjoyable. While many of the pre-service teachers expressed concern over the amount of preparation and research they would require prior to teaching a science lesson, they did note a willingness to self-improve in order to generate meaningful learning experiences in science.

Comparison of knowledge for teaching mathematics and science.

Deep understandings of underlying concepts were noted as being important to both mathematics and science teaching. Yet, the perspectives of the pre-service elementary teachers regarding the knowledge for teaching mathematics and science were not identical. In particular, the role of factual/procedural knowledge was expressed as one of the greatest differences between subjects. While certain aspects of knowledge for teaching vary between mathematics and science, the pre-service teachers did note commonalities linking teacher knowledge for each discipline.

Conceptual knowledge was emphasized as being important to both mathematics and science teaching. Interestingly, the pre-service teachers noted that conceptual understandings were not necessary for answering K – 6 level factual/procedural mathematics questions; however, having a strong conceptual grasp of topics was helpful in teaching mathematics. Conversely, conceptual understandings of science topics were expressed as being of more importance than factual/procedural knowledge in science. Since the cohort associated school science with open-ended questions, they developed a perspective of assessment in science focusing on scientific literacy and understandings of the scientific process. In their school experiences, assessment of mathematical understandings tended to focus on students' ability to determine the correct final solution, which does not necessarily display conceptual understanding. For example, when asked to explain photosynthesis students could give any number of responses that would be considered accurate, provided the response shows an understanding of photosynthesis; however, when asked to add 279 + 318 a student can determine the correct answer without a strong understanding of the concept of place-value. Thus, the cohort noted that teachers require strong conceptual understandings of scientific topics in order to accurately assess student work, whereas in mathematics student work can be assessed as correct or incorrect even if the teacher does not have an appreciation for the underlying concepts.

Conceptual understandings may appear less important to mathematics teaching; however, without comprehending the underlying concepts of mathematics a teacher would have difficulty determining the nature of student errors (Ball, 1988; Ball et al., 2008; Hill & Ball, 2009; Hill et al., 2005). Ball et al. (2008) described this type of conceptual mathematical knowledge utilized only by mathematics teachers as the domain of *specialized content knowledge.* Assessment has a principal role in education, and a strong conceptual understanding of mathematical topics allows teachers to better utilize assessment as a learning opportunity (Ball, 1988; Ball et al., 2008; Hill et al. 2005). Similarly, PCK for Science Teaching notes *assessment of scientific literacy* as an important domain of teacher knowledge, but assessment in science may take many forms (Carlsen, 1999; Magnusson et al., 1999; Zembal et al., 1999). The participants noted the manner in which standardized testing has impacted assessment in mathematics and science. Given the pressures related to standardized testing, many teachers have turned attention away from utilizing assessment to aid in teaching concepts and instead focused on accuracy of content, such as vocabulary and ability to complete algorithms. Hence the pre-service teachers defined standardized testing and the philosophies of their future administrators to be the greatest hindrance in teaching conceptually, and an impetus for focusing on factual/procedural knowledge.

The types of knowledge (factual/procedural or conceptual) a teacher views to be most significant greatly impacts the pedagogical philosophies adopted in the classroom. Pedagogical philosophies were described as being in the domain of *orientation to science teaching*, the central domain of PCK for Science Teaching; however, Ball et al. (2008) did not discuss the manner in which personal teaching philosophies influenced Mathematical Knowledge for Teaching. Yet, the participants observed the effects of differing teaching philosophies in both mathematics and science classrooms. A few of the pre-service teachers described the tendency for mathematics teachers to focus on standardized testing drills or pre-made curricula. Observations such as these were remembered in a negative context where the classroom environment was described as more stressful and the teachers seemed overly concerned with accuracy instead of learning. Conversely, classrooms that encouraged problem-based learning and student discourse were viewed as a more positive setting. Similarly in science, learning was expressed as being more enjoyable in classrooms where teachers constructed avenues for student discovery instead of direct lecturing. Even in the presence of pre-made curricula and standardized drills, the participants noted the manner in which teachers' pedagogical philosophies emerge. Moreover, the cohort discussed how when teachers take ownership of a lesson, they become more invested in the success of the lesson and the students' learning. While not mentioned in MKT, the cohort perceived the pedagogical philosophies of the teacher as being a significant domain of knowledge for both mathematics and science teaching.

Teachers have unique professional understandings of the knowledge required by their career (Shulman, 1986; Shulman, 1987). These professional understandings vary between grade level being taught, subject, and individual. For mathematics and science, teachers' understandings of underlying concepts aid in explanation of phenomena, correcting misconceptions, and providing valuable feedback on assessments (Brickhouse, 1990; Grossman, 1989; Hill & Ball, 2009; Lerman, 1990; Mellado, 1997). Mathematics and science are disciplines focused on process and rigor. When teaching these disciplines, teachers must consider the topic being taught, the concepts that underlie the topic, how the topic will influence later content, and the perspectives of the students. A teacher's perception of the role of content greatly influences the techniques they adopt (Carlsen, 1999; Magnusson et al., 1999; Zembal et al. 1999). As the pre-service teachers in this study prepared to enter the classroom, they developed their own perceptions of the similarities and differences in knowledge for teaching mathematics and science.

Pre-Service teachers' perspectives of factual/procedural versus conceptual knowledge.

Knowledge for teaching involves a professional understanding of pedagogy, assessment, educational policies, and content (Shulman, 1986, 1987). The domain of understanding of content includes the different types of knowledge associated with various topics. The PETSMA focused on factual/procedural and conceptual knowledge. Two of the secondary questions (namely, questions 3 and 5) in this study relate to the pre-service teachers' understanding with respect to the different types of knowledge and how confidence ratings compare across the different types of knowledge.

For both science and mathematics, the participants scored significantly better on factual/procedural questions over conceptual questions. Additionally, scores on the factual/procedural mathematics questions were significantly higher than those on the factual/procedural science questions for the final administrations of the PETSMA. During the discussions, the students often associated mathematics content with factual/procedural knowledge and science content with conceptual knowledge. Ergo, the trend of higher scores on factual/procedural mathematics questions, over science questions, is not surprising. However, performance scores between mathematics and science did not differ significantly with respect to the conceptual questions. Although the pre-service teachers were better able to successfully complete factual/procedural mathematics tasks over science tasks, they did not have an improved conceptual understanding of mathematics over science. In other words, having a stronger factual/procedural understanding of a discipline does not necessarily translate into having a stronger conceptual understanding of said discipline.

The pre-service teachers noted that factual/procedural information requires less reflection and explanation than conceptual content. Moreover, teaching factual/procedural information does not require the same amount of fore-thought as teaching approaches that emphasize conceptual information. As such, higher confidence ratings were associated with factual/procedural questions for both science and mathematics. In the final discussions, the pre-service teachers described observations of conceptually based classroom settings as being "fun" and "interesting"; but, also noted inquiry and problem-based lessons are more time consuming, require more work on the part of the teacher, and do not align with standardized curricula they had seen during their student observations. Furthermore, the cohort expressed apprehension about not being able to accurately answer students' questions. When a teacher is anxious about his/her ability to provide correct responses to student questions, he/she is less likely to allow students to question freely (Borko et al., 1992; Carlsen, 1991; Grossman, 1989, 1990).

Interestingly, all confidence ratings related to mathematics were higher than those related to science for both factual/procedural and conceptual questions. While the participants performed similarly on conceptual mathematics and science questions, they expressed higher confidence ratings related to answering conceptual mathematics questions and teaching conceptual mathematics topics over science. Even though many of the students had doubts regarding their conceptual understanding of mathematics, they cited the presence of familiar algorithms, which allowed them to be certain of the accuracy of their solutions, as being responsible for bolstering their confidence in answering mathematics question and teaching mathematics content.

The cohort noted that when teaching using techniques that emphasize conceptual knowledge, teachers require deep understanding and forethought in order to construct environments that will lead to student discoveries. In constructing such environments, the pre-service teachers discussed the importance of developing an understanding of content that stretches beyond the basic factual/procedural information provided by textbooks. For mathematics, the content was initially described as involving more factual/procedural knowledge because familiar algorithms yield an avenue for determining accurate solutions. Conversely, science content was depicted as being more conceptual in nature. Since science topics rarely provide a simple way to determine the accuracy of solutions to given problems, the pre-service teachers expressed less confidence in their ability to allow for student questioning in science. Thus, the participants' perceptions of the types of knowledge associated with the different content areas influenced their confidence in teaching.

Changes in the pre-service teachers' perspectives over time.

Knowledge for teaching is not a static construct. Teachers are perpetually developing and changing their understandings of the teaching profession. This study reviewed the perspectives of knowledge for teaching mathematics and science for a group of pre-service elementary teachers at the beginning and end of the junior block of their teacher preparation program. While this study was not designed to determine the cause of changes, there were noted differences between the views expressed during the initial discussions and those mentioned in the final discussions. Perspectives of the natures of mathematics and science changed, along with ideas about themselves as teachers. At the time of the initial discussions, most of the participants expressed viewpoints that stemmed from their perspectives as students. By the time the final discussions took place, the group had begun to consider the philosophies and strategies they would utilize as teachers. Such queries helped to mature their understandings of knowledge for teaching mathematics and science.

At the time of the initial discussions, the pre-service teachers stated understandings of the natures of science and mathematics that had been acquired from their previous learning experiences. Many of the participants described mathematics as being largely procedural, and devoid of freedom and creativity. They expressed difficulty in explaining the reasoning behind mathematical processes. However, they did note a certain amount of confidence in performing mathematical procedures because of the manner in which mathematical learning builds upon itself. The confidence did not transfer to answering factual/procedural science questions. Science learning does not involve constantly revisiting earlier topics, so the cohort expressed frustration over their inability to answer all of the factual/procedural science questions. Primarily, they were frustrated over their inability to recall vocabulary words. As students, they had learned science content (such as vocabulary), but their teachers had also emphasized conceptual understanding in science. Conversely, in mathematics their teachers had concentrated on students obtaining the correct solutions. When questioned about how they would approach mathematics and science teaching, the pre-service teachers expressed little concern about teaching mathematics topics and stated that they could use textbooks and research science topics to prepare for science teaching.

By the end of their junior block in the teacher preparation program, the pre-service teachers' perceptions of knowledge for teaching mathematics and science had changed in many respects. Firstly, the majority of comments in the final discussions concentrated on their own teaching philosophies, teacher observations, or teaching experiences. While the initial discussions included more remarks regarding the natures of mathematics and science, in the final discussions the participants appeared to truly be considering themselves as teachers. In mathematics, greater understandings of mathematical concepts were expressed. Furthermore, the results of the PETSMA found that the pre-service teachers had significantly increased their reported confidence ratings in answering conceptual mathematics questions and teaching conceptual mathematics content. The participants discussed the numerous teaching approaches they had learned for mathematics and how these approaches had aided in their conceptual understandings of mathematical topics and mathematical reasoning. Additionally, the role of factual/procedural knowledge in science teaching transformed for many of the pre-service teachers. While there was an expressed frustration for not being able to answer the factual/procedural science questions during the initial administrations of the PETSMA, during the final discussions the pre-service teachers noted that basic factual science content could easily be learned. However, the reality of the amount of preparation involved in creating science lessons was a source of some concern. At the time of the final discussions, the pre-service teachers were one year away from preparing to enter the classroom, and many were beginning to note the difference between theory and reality in teaching. For example, in theory reviewing science topics before a lesson sounds easy; in reality this may entail time-consuming research and extra work on the part of the teacher. Additionally, the cohort noted that their ability to implement the *best practices* learned in their teacher preparation program would depend greatly on the institution and administration of their future schools. Thus, in the post-discussions the pre-service teachers had developed an understanding of knowledge for teaching that included not only ideas of content knowledge, but also considered the role of administration and policies in education.

Teachers' professional understandings include subject matter knowledge, knowledge of curricula, knowledge of assessment, knowledge of students, knowledge of pedagogy, and knowledge of policies/administration. All of these aspects and more build together to form knowledge for teaching. Moreover, knowledge for teaching differs between disciplines. The pre-service teachers in this study were developing their own unique understandings of the knowledge required for teaching mathematics and science.

Teaching Efficacy Beliefs in Science and Mathematics

Teachers require strong understandings of knowledge for teaching, but they also need confidence in their ability to teach and positive attitudes regarding learning outcomes. Self-efficacy is a construct originally proposed by Bandura (1977) that refers to one's confidence in their ability to successfully complete a task. The MTEBI and STEBI-B were used to measure teaching efficacy in this study (Enochs & Riggs, 1990; Enochs et al., 2000). The MTEBI and STEBI-B divide teaching efficacy measures into two factors, namely personal teaching efficacy and outcome expectancy. Personal teaching efficacy beliefs refer to the belief one has in their own ability to successfully complete a task. Outcome expectancy refers the beliefs one has regarding the likely outcomes once a task has been successfully completed. Bandura (1997) even noted that self-efficacy beliefs could easily vary given different situations. In general, outcome expectancy beliefs have been described as more global across subject areas, while personal teaching efficacy beliefs depend more upon the content being taught. Teaching efficacy beliefs have been found to influence commitment to teaching, classroom behavior, adoption of reform, and student performance outcomes (Brouwers & Tomic, 2000; Bursal & Paznokas, 2006; Coladarci, 1992; Midgley et al., 1989; Swars et al., 2006; Wheatley, 2002). Given the importance of efficacy beliefs with respect to in-service teachers, the teaching efficacy beliefs of the pre-service teachers in this study were also considered. MTEBI and STEBI-B results were correlated with teaching confidence ratings from the PETSMA in order to determine the extent to which teaching efficacy beliefs are task specific.

Teaching efficacy and confidence in teaching mathematics.

For mathematics, the results from the MTEBI regarding personal teaching efficacy beliefs did not correlate with the mathematics teaching confidence ratings reported in the PETSMA. This means the pre-service teachers that reported high personal teaching efficacy beliefs on the MTEBI did not necessarily report a high confidence level when questioned about teaching specific mathematics content. However, there was a weak, although significant, correlation between confidence in teaching factual/procedural mathematics content and outcome expectancy beliefs as measured by the MTEBI. Confidence ratings in teaching conceptual mathematics did not correlate with either personal teaching efficacy beliefs or outcome expectancy beliefs. These results imply that mathematics teaching efficacy may be situation specific. For instance, pre-service teachers may claim they are confident in teaching mathematics, but when questioned about teaching addition of fractions they express lower confidence ratings. However, the confidence in answering mathematics questions did significantly correlate with confidence in teaching. Hence those individuals that expressed high confidence ratings in answering mathematics questions were also more confident in teaching the mathematic content.

When teachers are confident in their ability to complete a task, they can be more open to students' questions because they are secure in the accuracy of their responses (Carlsen, 1991).

The participants described mathematics as involving knowledge building and being highly procedural. Since mathematical learning does build on itself (e.g., learning addition plays a part in learning multiplication), mathematical topics are often reviewed throughout one's academic career. The pre-service teachers noted this practice and attributed an increased confidence in both answering and teaching factual/procedural mathematics questions to the phenomenon. In fact, the cohort directly stated that the presence of familiar procedures and algorithms increased their confidence in mathematics teaching because, even if they do not teach the algorithm, they are able to insure the accuracy of their solutions by checking the work with the algorithm.

Yet, when students ask conceptual mathematics questions, teachers' responses cannot be confirmed with an algorithm. For example, if a student inquires as to why common denominators are necessary in adding fractions, repeating the algorithm does not justify the procedure. The pre-service teachers reported significantly lower confidence ratings with respect to teaching mathematical concepts, as opposed to teaching factual/procedural mathematics content (such as algorithms). The participants expressed that teaching mathematical concepts requires strong reasoning skills and an ability to explain topics in a manner that young learners can understand. However, there was a statistically significant increase between the initial PETSMA administration and the final PETSMA administration in reported confidence ratings for teaching mathematical concepts. Thus, while the pre-service teachers were still more confident in teaching factual/procedural mathematics, there was an improvement over time in confidence for teaching mathematical concepts.

Teaching efficacy beliefs in mathematics appear to be more task specific, instead of subject specific for this cohort of students. Additionally, their confidence in teaching varied depending upon the type of mathematical information being taught. Familiar algorithms were cited as being helpful to reinforce mathematics teaching confidence because the accuracy of a response could easily be tested. When facing mathematical questions that did not have an algorithm to confirm and reassure the pre-service teachers, their stated teaching confidence diminished. However, the participants maintained a hopeful outlook, and expressed faith in their ability to learn by experience.

Teaching efficacy and confidence in teaching science.

The outcome expectancy beliefs measured on the STEBI-B did not correlate at a statistically significant level with the science teaching confidence results from the post-PETSMA. Thus, outcome expectancy beliefs appear to be situation specific for both mathematics and science teaching. For the personal teaching efficacy beliefs, significant correlations were determined for both teaching factual/procedural science content and teaching conceptual science content. Yet, both correlations were extremely weak. Confidence in answering science questions did correlate with confidence in teaching said science content at a statistically significant level; however the correlation was not as strong as the ones seen with respect to mathematics. The pre-service teachers held very different ideas between mathematics and science about the role of subject matter knowledge in teaching. These different ideas could account for the lower correlation between confidence in answering questions and confidence in teaching science content.

Factual/procedural knowledge was viewed as less important in the knowledge required for teaching science than the knowledge required for teaching mathematics. The participants reported significantly higher scores in confidence for teaching factual/procedural science topics, over their own ability to answer factual/procedural science questions. The reasoning was that basic factual science content can be reviewed prior to teaching a science lesson. For instance, they may not be able to state the difference between a comet and an asteroid, but they believed that given a textbook and some time to prepare, they would be able to teach an elementary lesson on astronomy. In school, factual/procedural science is not perpetually reinforced, so often factual/procedural science knowledge is forgotten. However, if one has strong conceptual understanding of science topics, then relearning basic factual science content, such as vocabulary, is simple. Science concepts are more difficult to relearn. Finding definitions to words such as asteroid and comet is easy, but having to reteach oneself why we have seasons is more challenging. The pre-service teachers noted this distinction in types of scientific knowledge. Thus, there was no significant difference between confidence in answering conceptual science questions and confidence in teaching science concepts for the post-PETSMA results. Conceptual understanding of science is more involved than factual/procedural knowledge of science; but conceptual understanding was stated as being more important to science teaching.

While science was noted as involving more conceptual learning, the pre-service teachers had significantly higher confidence scores regarding teaching factual/procedural science content. Similar to mathematics, the participants perceived teaching factual/procedural topics as being easier for a variety of reasons: accuracy can be determined by reviewing textbooks, students are less likely to ask questions they are ill-equipped to answer, teaching factual/procedural information involves fewer open-ended questions, etc. While the pre-service teachers reported a preference to teaching factual/procedural topics over conceptual ones, there was a significant improvement in their performance on conceptual science questions between the initial and final administrations of the PETSMA. However, there was no marked increase in confidence in answering conceptual science questions or confidence in teaching science content from a conceptual perspective. Thus, while the pre-service teachers showed improvement in answering conceptual science questions, their confidence in teaching said content did not significantly increase.

Teaching efficacy and confidence in teaching mathematics versus science.

Teaching efficacy beliefs are a powerful construct, which appear to be relatively task specific (Bandura, 1997; Gibson & Dembo, 1984; Rotter, 1966). Since teaching efficacy beliefs fluctuate depending on the situation, determining meaningful measures of teaching efficacy beliefs is difficult (Tschannen-Moran et al., 1998; Tschannen-Moran & Woolfolk-Hoy, 2001). Instruments such as the MTEBI and STEBI-B have been shown to be validated and reliable instruments for measuring teaching efficacy beliefs (Bleicher, 2004; Enochs & Riggs, 1990; Enochs et al., 2000; Kieftenbeld et al., 2010; Riggs & Enochs, 1990). The results of this study showed that mathematics and science teaching efficacy beliefs varied when asked about teaching specific mathematical and scientific topics. The PETSMA allows for consideration of personal teaching efficacy beliefs with respect to specific content questions, yet the MTEBI and STEBI-B were designed to study efficacy beliefs for the entire discipline. Thus, to examine the relationship of teaching efficacy beliefs between disciplines for the given cohort of pre-service teachers, the MTEBI and STEBI-B results were correlated and compared.

The participants in this study reported interesting results regarding teaching efficacy beliefs and confidence in teaching for science and mathematics. MTEBI and STEBI-B results did not display strong correlations with confidence ratings in teaching mathematics content and teaching science content, respectively. Thus, simply because pre-service teachers have high teaching efficacy beliefs for a given subject does not mean they will be confident in teaching a specific topic within that subject area. Additionally, personal teaching efficacy beliefs showed a weak correlation between the MTEBI and STEBI-B results. These results further exemplify the notion that personal teaching efficacy beliefs are not global across disciplines, or even specific situations. However, the outcome expectancy results from the MTEBI and STEBI-B displayed a stronger correlation. Outcome expectancy beliefs have been described as being more general than personal teaching efficacy beliefs (Bandura, 1997). This conjecture is confirmed by the results of this study. Thus for the participants, the personal teaching efficacy beliefs did not strongly correlate between mathematics and science; however, the outcome expectancy beliefs were found to relate between mathematics and science teaching.

One similarity between mathematics and science determined from the PETSMA was that the pre-service teachers were more confident in their ability to teach factual/procedural topics over conceptual topics in both subjects. There was a moderate correlation between science and mathematics with respect to confidence in teaching factual/procedural content. In other words, those participants that reported high confidence ratings with respect to teaching factual/procedural mathematics content were more likely to report high confidence ratings with respect to teaching factual/procedural science content. As pre-service teachers, they had an expressed desire to be assured of the accuracy of the information before having to teach the topics to young children. Moreover, the participants stated some concern over facing students' questions they would be unable to answer. Such concerns are less substantial when dealing with factual/procedural questions, where the accuracy of a response can easily be verified. Conceptual questions, on the other hand, are more challenging for the pre-service teachers. Many of the participants stated that even if they were confident in their own understanding of an underlying concept, teaching said concept may still seem daunting.

Conceptual understandings are more involved than memorization of basic factual content information. Interestingly, confidence in answering conceptual mathematics questions did moderately correlate with confidence ratings for answering conceptual science questions. Moreover, confidence in teaching conceptual content strongly correlated between disciplines. While the pre-service elementary teachers identified increased confidence related to mathematics teaching over science teaching, a clear relationship existed between disciplines with respect to teaching conceptual information. Similar to the results from the PETSMA, the participants reported significantly higher ratings with respect to mathematics (MTEBI) over science (STEBI-B) for both personal teaching efficacy beliefs and outcome expectancy beliefs.

While this study found little evidence to assume that personal teaching efficacy beliefs related between mathematics and science, outcome expectancy beliefs were determined to be more consistent across subjects. Additionally, the participants reported significantly higher ratings with respect to mathematics (MTEBI) over science (STEBI-B) for both personal teaching efficacy beliefs and outcome expectancy beliefs. These results were similar to those observed with respect to the PETSMA. In the discussions, the nature of mathematics was described as being more factual/procedural than science; and, factual/procedural content was described as being easier to teach than conceptual content. Ergo, the perception that teaching broad conceptual topics is complex than teaching factual/procedural information was consistent across disciplines.

Summations

Shulman (1986, 1987) described the numerous professional domains of knowledge entailed in teaching. A thorough understanding of subject matter is necessary, but not sufficient, for becoming a teacher. Teacher knowledge also includes pedagogical knowledge, knowledge of students, knowledge of assessment, knowledge of curricula, and knowledge of administration and educational policies. The pre-service elementary teachers noted some of the similarities and differences between knowledge for teaching mathematics and science. In particular, science was mentioned as being more conceptual in nature, while mathematics education focused on the end product rather than understanding the reasons for the underlying processes. Thus, the cohort emphasized the importance of conceptually understanding the broad underlying topics in science, placing less stress on basic factual/procedural knowledge. Conversely in mathematics, conceptual knowledge was viewed as being helpful to teaching, but not crucial in determining solutions to mathematical problems. The participants described their experiences with school mathematics as focusing on algorithms and procedures, which only teaches students to practice mathematics without understanding the underlying concepts. However, they noted that teaching from a conceptual approach helps to build foundations of mathematical understanding that can be carried into more advanced mathematics topics. Similarly, the pre-service teachers mentioned that encouraging conceptual understanding of science topics allows students to note connections between systems when observing their surroundings. Thus, the participants expressed that teachers must develop appreciations for the underlying concepts in science and mathematics to better aid in science and mathematics education.

Furthermore, confidence in subject matter knowledge matter yields more confidence in teaching. The pre-service teachers in this study reported higher confidence in teaching mathematics over science because familiar algorithms allowed for self-assurance in the accuracy of their answers. Additionally, confidence in answering science/mathematics questions correlated significantly with confidence in teaching science/mathematics content for both factual/procedural and conceptual questions. When teachers are secure of their understanding of subject matter, they are more confident and willing to allow for student questioning (Carlsen, 1991). Confidence ratings tended to fluctuate depending on the individual's self-assurance with respect to each topic. Consequently, personal teaching efficacy beliefs did not align well with task specific confidence ratings in either mathematics or science. Additionally, personal teaching efficacy beliefs varied between mathematics and science. However, outcome expectancy beliefs were more consistent across disciplines.

Despite the various ways in which mathematics and science overlap, they remain distinctive disciplines. As the pre-service teachers prepared to enter the classroom, they were developing their own understandings of mathematics and science teaching. Such understandings are not static, but continue to grow throughout one's teaching career. The cohort noted that mathematics and science teaching require deep conceptual understanding of topics in order to better address students' questions, prepare meaningful learning experiences, recognize when different approaches apply to various problems, etc.. The participants stated that when they are confident in their own ability to answer such questions, they are more likely to cultivate a classroom environment that encourages student reasoning and discovery. By encouraging students to question scientifically and reason mathematically, teachers are promoting positive impressions of science and mathematics and developing strong foundations for future learning (Adams & Hamm, 1998; NCTM, 2000; NRC, 1995; NSF, 1999; NSTA, 2008).

Limitations of the Study

Mathematics and science are fundamentally important to our nation's continued development in this technologically rich world. Mathematics and science educators have a pivotal role in the development of students' understandings and appreciations of these disciplines. Hence continued research regarding pre-service teachers' perceptions of knowledge for teaching mathematics and science are imperative to cultivating quality teachers. Yet, every research project has limitations. For example, this research project involved studying a group of pre-service teachers at the beginning and end of their junior block in a teacher preparation program, but the program itself was not evaluated. The experiences the participants underwent as a result of their teacher preparation program greatly impacted their perspectives on knowledge for teaching and a different cohort may have very different results. However, this project was not designed to examine why or how the perspectives were developed, simply to investigate their perspectives. Furthermore, many interesting changes between the beginning and end of the junior block were discussed, but the factors which caused such changes were not investigated.

Avenues of Future Research

As with any research project, more questions have arisen throughout the investigations. The following questions are proposed avenues for future research projects.

- How would the domains of PCK for Science Teaching operate within a specific science lesson? Or would a different theoretical construct of Science Knowledge for Teaching better align with the practice of science teaching?
- How will this cohort's perceptions of knowledge for teaching mathematics and science change after their first year of teaching? After their fifth?
- How will the cohort's teaching efficacy beliefs and confidence in teaching change after their first year of teaching? After their fifth?
- How do in-service teachers' perceptions of knowledge for teaching mathematics and science influence classroom behaviors?

References

Abell, S. & Smith, D. (1994). What is science?: Preservice elementary teachers' conceptions of the nature of science. *International Journal of Science Education, 16*(4), 475 – 487.

Adams, D. & Hamm, M. (1998). *Collaborative inquiry in science, math and technology*. Portsmouth, NH: Heinemann.

Aiken, L. R. (1963). Personality correlates of attitude toward mathematics. *The Journal of Educational Research, 56*(9), 476 – 480.

Ball, D. L. (1988). Unlearning to teach mathematics. *For the Learning of Mathematics, 8*(1), 40 – 48.

Ball, D. L., Thames, M. H. & Phelps, G. (2008). Content knowledge for teaching: What makes it special? *Journal of Teacher Education, 59*(5), 389 – 407.

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review, 84*(2), 191 – 215. doi: 10.1037/0033-295X.84.2.191

Bandura, A. (1981). Self-referent thought: A developmental analysis of self-efficacy. In J.H. Flavell & L. Ross (Eds.), *Social cognitive development: Frontiers and possible futures*. (pp. 200 – 239). Cambridge, NY: Cambridge University Press.

Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York, NY: W. H. Freeman and Company.

Baptiste, P., Daniel, L., Hackett, J., Moyer, R., Stryker, P., & Vasquez, J. (2000). *McGraw-Hill science*. New York, NY: McGraw-Hill School Division.

Biggs, A., Daniel, L., Feather, R. M., Snyder, S., & Zike, D. (2002). *Texas science: Grade 6*. New York, NY: McGraw-Hill Companies.

Bleicher, R. E. (2004). Revisiting the STEBI – B: Measuring self-efficacy in preservice elementary teachers. *School Science and Mathematics, 104*(8), 383 – 391.

Borko, H., Eisenhart, M., Brown, C. A., Underhill, R. G., Jones, D. & Agard, P. C. (1992). Learning to teach hard mathematics: Do novice teachers and their instructors give up too easily? *Journal for Research in Mathematics Education, 23*(3), 194 – 222.

Bosse, M. J., Lee, T. D., Swinson, M., & Faulconer, J. (2010). The NCTM process standards and the five Es of science: Connecting math and science. *School Science and Mathematics*, *110*(5), 262 – 276.

Brickhouse, N. W. (1990). Teachers' beliefs about the nature of science and their relationship to classroom practice. *Journal of Teacher Education, 41*(3), 53 – 62.

Brouwers, A. & Tomic, W. (2000). A longitudinal study of teacher burnout and perceived self-efficacy in classroom management. *Teaching and Teacher Education*, *16*(2), 239 – 253.

Bursal, M. & Paznokas, L. (2006). Mathematics anxiety and preservice teachers' confidence to teach mathematics and science. *School Science and Mathematics*, *106*(4), 173 – 180.

Buss, R. R. (2010). Efficacy for teaching elementary science and mathematics compared to other content. *School Science and Mathematics, 110*(6), 290 – 297.

Cantrell, P., Young, S., & Moore, A. (2003). Factors affecting science teaching efficacy of pre-service elementary teachers. *Journal of Science Teacher Education*, *14*(3), 177 – 192.

Carlsen, W. S. (1991). Effects of new biology teachers' subject-matter knowledge on curricular planning. *Science Education*, *75*(6), 631 – 647.

Carlsen, W. S. (1999). Domains of teacher knowledge. In J. Gess-Newsome and N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its* *implications for science education*. (pp. 133 – 144). Dordrecht, Netherlands: Kluwer Academic Publishers.

Charles, R., Fennell, F., Caldwell, J., Sammons, K., Cavanagh, M., Schielack, J., Chancellor, D., Tate, W., Copley, J., Van de Walle, J., Crown, W. (2009). *Envision math Texas Grade K -5*. Glenview, IL: Pearson Education, Inc.

Cobb, P., Boufi, A., McClain, K., & Whitenack, J. (1997). Reflective discourse and collective reflection. *Journal of Research in Mathematics Education, 28*(3), 258 – 277.

Coladarci, T. (1992). Teachers' sense of efficacy and commitment to teaching. *Journal of Experimental Education*, *60*(4), 323 – 337.

Devlin, K. (1994). *Mathematics, the science of patterns: The search for order in life, mind, and the universe*. New York, NY: Scientific American Library.

Devlin, K. (1998a). *The language of mathematics: Making the invisible visible*. New York, NY: W. H. Freeman and Company.

Devlin, K. (1998b). *Life by the numbers*. New York, NY: John Wiley & Sons, Inc.

Enochs, L. G. & Riggs, I. M. (1990). Further development of an elementary science teaching efficacy belief instrument: A preservice elementary scale. *School Science and Mathematics*, *90*(8), 694 – 706.

Enochs, L. G., Smith, P. L. & Huinker, D. (2000). Establishing factorial validity of the mathematics teaching efficacy beliefs instrument. *School Science and Mathematics, 100*(4), 194 – 202.

Furner, J. M. & Kumar, D. D. (2007). The mathematics and science integration argument: A stand for teacher education. *Eurasia Journal of Mathematics, Science & Technology Education*, *3*(3), 185 – 189.

Gibson, S. & Dembo, M. H. (1984). Teacher efficacy: A construct validation. *Journal of Educational Psychology, 76*(4), 569 – 582. doi: 10.1037/0022-0663.76.4.569

Gieryn, T. F. (1983). Boundary-work and the demarcation of science from non-science: Strains and interests in professional ideologies of scientists. *American Sociological Review, 48*(6), 781 – 795.

Glaser, B. & Strauss, A. (1999). *The discovery of grounded theory: Strategies for qualitative research.* Hawthorne, NY: Aldine de Gruyter.

Gresham, G. (2007). A study of mathematics anxiety in pre-service teachers. *Early Childhood Education Journal, 35*(2), 181 -188.

Grossman, P. L. (1989). Teachers of substance: Subject matter knowledge for teaching. In M. Reynolds (Ed.), *Knowledge Base for the Beginning Teacher* (pp. 23 – 36). Oxford, NY: American Association of Colleges for Teacher Education by Pergamon Press.

Grossman, P. L. (1990). *The making of a teacher: Teacher knowledge and teacher education*. New York: Teachers College Press.

Hill, H. & Ball, D. L. (2009). The curious - and crucial – case of mathematical knowledge for teaching. *Kappan, 91*(2), 68 – 71.

Hill, H., Rowan, B., & Ball, D. L. (2005). Effects of teachers' mathematical knowledge for teaching on student achievement. *American Educational Research Journal*, *42*(2), 371 – 406.

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

Kieftenbeld, V., Natesan, P. & Eddy, C. (2011). An item response theory analysis of the mathematics teaching efficacy beliefs instrument. *Journal of Psychoeducational Assessment, 29*(5), 443 – 454.

King, J. P. (1992). *The art of mathematics*. New York, NY: Plenum Press.

Lakatos, I. (1977). *Philosophical papers* (Vol. I). Cambridge, MA: Cambridge University Press.

Lappan, G., Friel, S., Fey, J. & Phillips, E. D. (2009). *Connected mathematics 2: Grade 6*. Boston, MA: Pearson/Prentice Hall.

Lerman, S. (1990). Alternative perspectives of the nature of mathematics and their influence on the teaching of mathematics. *British Educational Research Journal, 16*(1), 53 – 61.

Lindberg, D. C. (1992). *The beginnings of western science: The European scientific tradition in philosophical, religious and institutional context, 600 B.C. to A.D. 1450.* Chicago, IL: University of Chicago Press.

Lowery, N. V. (2002). Construction of teacher knowledge in context: Preparing elementary teachers to teach mathematics and science. *School Science and Mathematics, 102*(2), 68 – 83.

Magnusson, S., Krajcik, J. & Borko, H. (1999). Nature, sources and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome and N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 95 – 132). Dordrecht, Netherlands: Kluwer Academic Publishers.

Mellado, V. (1997). Preservice teachers' classroom practice and their conceptions of the nature of science. *Science & Education, 6*(4), 331 – 354.

Midgley C., Feldlaufer, H., & Eccles, J. (1989). Change in teacher efficacy and student self- and task-related beliefs in mathematics during the transition to junior high school. *Journal of Educational Psychology, 81*(2), 247 – 258.

Morine-Dershimer, G. & Kent, T. (1999). The complex nature and source of teachers' pedagogical knowledge. In J. Gess-Newsome and N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 21 – 50). Dordrecht, Netherlands: Kluwer Academic Publishers.

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: Observe, interact, change, learn*. Washington, DC: National Academic Press.

National Science Foundation (NSF). (1999). Inquiry*: Thoughts, views, and strategies for the K – 5 classroom.* Volume 2 of Foundations: A Monograph for Professionals in Science, Mathematics, and Technology Education. Washington DC: National Science Foundation.

National Science Teachers Association (NSTA). (2008). *Science as inquiry in the secondary setting*. Arlington, VA: NSTA Press

Niess, M. L. (2005). Preparing teachers to teach science and mathematics with technology: Developing a technology pedagogical content knowledge. *Teaching and Teacher Education, 21*(5), 509 – 523.

Ogilvy, C. S. (1956). *Through the mathescope*. New York, NY: Oxford University Press.

Peace, H., Bloom, M. & Quebec Fuentes, S. (2012). *Do you know it? Can you teach it? An activity for pre-service elementary teachers*. Manuscript submitted for publication. Texas Christian University, Fort Worth, TX.

Richards, S. (1983). *Philosophy and sociology of science: An introduction.* Oxford, England: Basil Blackwell.

Rigelman, N. R. (2007). Fostering mathematical thinking and problem solving: The teacher's role. *Teaching Children Mathematics, 13*(6), 308 – 314.

Riggs, I. M. & Enochs, L. G. (1990). Toward the development of an elementary teacher's science teaching efficacy belief instrument. *Science Education, 74*(6), 625 – 637. doi: 10.1002/sce.3730740605

Rotter, J. B. (1966). Generalized expectancies for internal versus external control of reinforcement. *Psychological Monographs: General and Applied, 80*(1), 1 – 28.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4 – 14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, *57*(1), 1 – 23.

Stevens, C. & Wenner, G. (1996). Elementary preservice teachers' knowledge and beliefs regarding science and mathematics. *School Science and Mathematics*, *96*(1), 2 – 9.

Swars, S., Daane, C. J., & Giesen, J. (2006). Mathematics anxiety and mathematics teacher efficacy: What is the relationship in elementary preservice teachers? *School Science and Mathematics, 106*(7), 306 – 315.

Swars, S., Hart, L., Smith, S., Smith, M. & Tolar, T. (2007). A longitudinal study of elementary pre-service teachers' mathematics beliefs and content knowledge. *School Science and Mathematics, 107*(8), 325 – 335.

Szydlik, J., Szydlik, S., & Benson, S. (2003). Exploring changes in pre-service elementary teachers' mathematical beliefs. *Journal of Mathematics Teacher Education, 6*(3), 253 – 279.

Texas Education Agency. (2011). *TEKS standards.* Retrieved from http://www.tea.state.tx.us/

Tschannen-Moran, M., Woolfolk-Hoy, A. & Hoy, W. K. (1998). Teacher efficacy: Its meaning and measure. *Review of Educational Research, 68*(2), 202 – 248. Retrieved from http://www.jstor.org/stable/1170754

Tschannen-Moran, M. & Woolfolk-Hoy, A. (2001). Teacher efficacy: Capturing an elusive construct. *Teaching and Teacher Education, 17*(7), 783 – 805.

Utley, J., Moseley, C. & Bryant, R. (2005). Relationship between science and mathematics teaching efficacy of preservice elementary teachers. *School Science and Mathematics, 105*(2), 82 – 87.

Wheatley, K. F. (2002). The potential benefits of teacher efficacy doubts for educational reform. *Teaching and Teacher Education, 18*(1), 5 – 22.

Wolpert, L. (1992). *The unnatural nature of science: Why science does not make (common) sense*. Cambridge, MA: Harvard University Press.

Yilmaz-Tuzun, O. & Topcu, M. S. (2008). Relationships among preservice science teachers' epistemological beliefs, epistemological world views, and self-efficacy beliefs. *International Journal of Science Education, 30*(1), 65 – 85.

Zembal, C., Starr, M. & Krajcik, J. (1999). Constructing a framework for elementary science teaching using pedagogical content knowledge. In J. Gess-Newsome and N. G. Lederman (Eds.), *Examining Pedagogical Content Knowledge: The Construct and Its Implications for Science Education* (pp. 237 – 256). Dordrecht, Netherlands: Kluwer Academic Publishers.

Appendix A – Pre-service Elementary Teachers' Science and Mathematics Activity

Kindergarten Mathematics

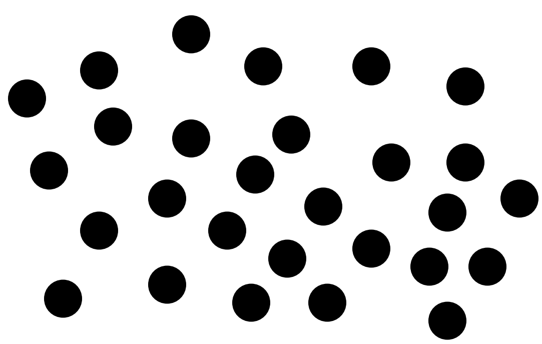
1. Count the umbrellas and write the number.

Teacher Questions – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
Strongly Agree Agree Disagree Strongly Disagree

B. This question will be easy for me to teach.
Strongly Agree Agree Disagree Strongly Disagree

2. How many circles are there below? How did you count the circles?



Teacher Questions – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
Strongly Agree Agree Disagree Strongly Disagree

B. This question will be easy for me to teach.
Strongly Agree Agree Disagree Strongly Disagree

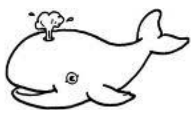
Kindergarten Science

1. Draw a circle around the animals below that move by swimming.

BUTTERFLY

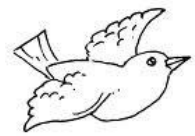
FISH

HORSE



WHALE

TIGER



BIRD

Teacher Questions – Circle the answer that best matches your opinion

C. This question was easy for me to answer.
Strongly Agree   Agree   Disagree   Strongly Disagree

D. This question will be easy for me to teach.
Strongly Agree   Agree   Disagree   Strongly Disagree

2. Sort the animals above into two groups by writing their names into one of the two boxes below. Explain how you chose to sort them.

Group 1   **Group 2**

Explanation of how you sorted them - ____

____

____

Teacher Questions – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
Strongly Agree   Agree   Disagree   Strongly Disagree

B. This question will be easy for me to teach.
Strongly Agree   Agree   Disagree   Strongly Disagree

First Grade Mathematics

1. (Multiple Choice) About how many paper clips long is the key?

- **a.** 8
- **b.** 6
- **c.** 4
- **d.** 2

Teacher Questions – Circle the answer that best matches your opinion
A. This question was easy for me to answer.
Strongly Agree Agree Disagree Strongly Disagree

B. This question will be easy for me to teach.
Strongly Agree Agree Disagree Strongly Disagree

2. Adam measured the length of the shorter edge of this piece of paper with the paper clip (pictured above). He estimated that the length is about 7 paper clips. Julia also measured the length of the shorter edge of the paper. She used the key (pictured above) and estimated the length to be about 4 keys. Can Adam and Julia both be correct? Explain.

Teacher Questions – Circle the answer that best matches your opinion
A. This question was easy for me to answer.
Strongly Agree Agree Disagree Strongly Disagree

B. This question will be easy for me to teach.
Strongly Agree Agree Disagree Strongly Disagree

First Grade Science

1. Name the four main parts of a tree.

______________________________ ______________________________

______________________________ ______________________________

Teacher Questions – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
Strongly Agree Agree Disagree Strongly Disagree

B. This question will be easy for me to teach.
Strongly Agree Agree Disagree Strongly Disagree

2. Why should we try to save trees?

Teacher Questions – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
Strongly Agree Agree Disagree Strongly Disagree

B. This question will be easy for me to teach.
Strongly Agree Agree Disagree Strongly Disagree

Second Grade Mathematics

1.

$$\begin{array}{r} 36 \\ \underline{+\ 48} \end{array}$$

Teacher Questions – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
Strongly Agree Agree Disagree Strongly Disagree

B. This question will be easy for me to teach.
Strongly Agree Agree Disagree Strongly Disagree

2. To perform the subtraction below, you can "borrow" from the tens place of the top number. Why does this move not alter the answer?

$$\begin{array}{r} 32 \\ \underline{-\ 17} \end{array}$$

Teacher Questions – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
Strongly Agree Agree Disagree Strongly Disagree

B. This question will be easy for me to teach.
Strongly Agree Agree Disagree Strongly Disagree

Second Grade Science

1. Draw a line to match each word with its meaning.

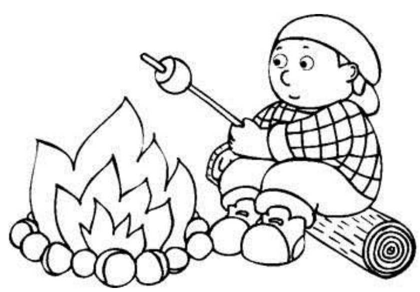
heat	find the size or amount of something
temperature	energy that can make things change
measure	how warm or cool something is
fuels	a tool to measure temperature
thermometer	things that give off heat when they burn

Teacher Questions – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
Strongly Agree Agree Disagree Strongly Disagree

B. This question will be easy for me to teach.
Strongly Agree Agree Disagree Strongly Disagree

2. A man warms a marshmallow over a fire. How does the heat get from the fire to the marshmallow?



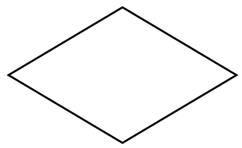
Teacher Questions – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
Strongly Agree Agree Disagree Strongly Disagree

B. This question will be easy for me to teach.
Strongly Agree Agree Disagree Strongly Disagree

Third Grade Mathematics

1. Write two special names for this figure.



____

Teacher Questions – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
Strongly Agree Agree Disagree Strongly Disagree

B. This question will be easy for me to teach.
Strongly Agree Agree Disagree Strongly Disagree

2. Is a square a rectangle? Why or why not?

Teacher Questions – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
Strongly Agree Agree Disagree Strongly Disagree

B. This question will be easy for me to teach.
Strongly Agree Agree Disagree Strongly Disagree

Third Grade Science

1. Use the following words to complete the sentences.

Asteroid	Atmosphere	Comet	Corona	Fuel
Planet	Solar System	Star	Sunspot	Telescope

A dark area on the Sun's surface is called a _______________.

A small chunk of rock or metal that orbits the sun is a(n) _______________.

A satellite of the Sun is called a _______________.

Something burned to provide heat or power is a _______________.

A tool that gathers light to make faraway objects appear larger, closer, and clearer is a _______________.

Teacher Questions – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
Strongly Agree   Agree   Disagree   Strongly Disagree

B. This question will be easy for me to teach.
Strongly Agree   Agree   Disagree   Strongly Disagree

2. What would be different about summer and winter if Earth's axis were straight up and down instead of tilted?

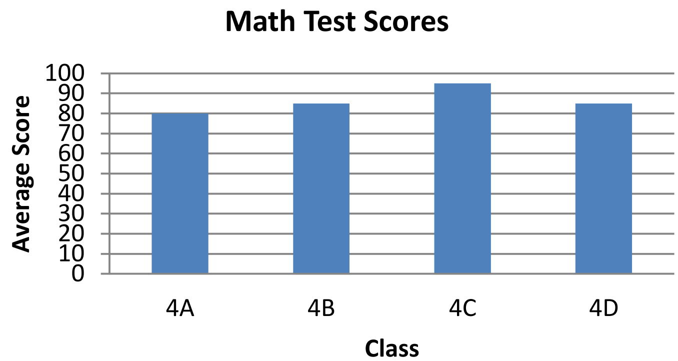
Teacher Questions – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
Strongly Agree   Agree   Disagree   Strongly Disagree

B. This question will be easy for me to teach.
Strongly Agree   Agree   Disagree   Strongly Disagree

<u>Fourth Grade Mathematics</u>

1. For a through d, use the bar graph below.



a. Which class has the highest average math test scores? ____________

b. Which two classes have the same average math test scores? ____________

c. What is the average math test score for 4A? ____________

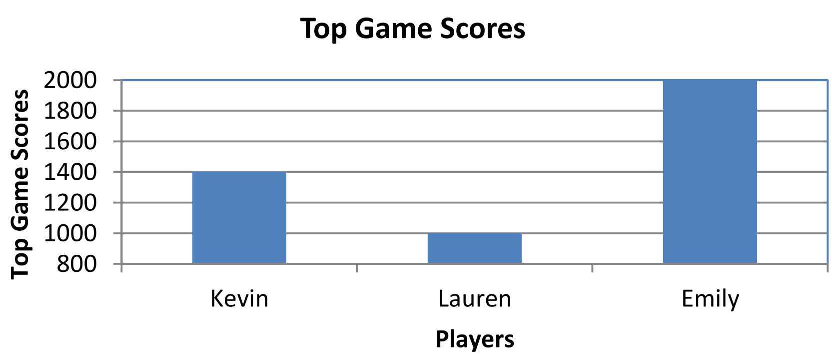
d. How many more points would 4A need to have the same average test scores as 4C?

<u>Teacher Questions</u> – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
Strongly Agree   Agree   Disagree   Strongly Disagree

B. This question will be easy for me to teach.
Strongly Agree   Agree   Disagree   Strongly Disagree

2. Explain why the graph below is misleading and how it should be changed so that it is less misleading.



<u>Teacher Questions</u> – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
Strongly Agree   Agree   Disagree   Strongly Disagree

B. This question will be easy for me to teach.
Strongly Agree   Agree   Disagree   Strongly Disagree

Fourth Grade Science

1. Use the following words to complete the sentences.

Cardiac Muscle	Cartilage	Fracture	Involuntary Muscle
Joint	Ligament	Marrow	Skeletal Muscle
Smooth Muscle	Sprain	Tendon	Voluntary Muscle

A tough band of tissue that holds two bones together where they meet is a(n) _______________.

The supporting frame that gives the body its shape and protects many organs is called the _______________.

A muscle that is attached to a bone and allows movement is a(n) _______________.

A strong band of tissue that connects a muscle to bone is a(n) _______________.

A smooth muscle is classified as a(n) _______________.

Teacher Questions – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
Strongly Agree Agree Disagree Strongly Disagree

B. This question will be easy for me to teach.
Strongly Agree Agree Disagree Strongly Disagree

2. How do muscles and bones work together to help you move?

Teacher Questions – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
Strongly Agree Agree Disagree Strongly Disagree

B. This question will be easy for me to teach.
Strongly Agree Agree Disagree Strongly Disagree

Fifth Grade Mathematics

1. A bag contains 13 purple marbles, 9 green marbles, 6 blue marbles, 5 yellow marbles, and 12 red marbles. What is the probability of pulling out a yellow marble?

____

<u>Teacher Questions</u> – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
   Strongly Agree   Agree   Disagree   Strongly Disagree

B. This question will be easy for me to teach.
   Strongly Agree   Agree   Disagree   Strongly Disagree

2. A fair coin is tossed six times and for all six tosses the result was heads. What is the probability of the seventh tosses being heads? Explain your answer.

<u>Teacher Questions</u> – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
   Strongly Agree   Agree   Disagree   Strongly Disagree

B. This question will be easy for me to teach.
   Strongly Agree   Agree   Disagree   Strongly Disagree

Fifth Grade Science

1. Use the following words to complete the sentences.

Cambium	Chlorophyll	Chloroplast	Cortex
Epidermis	Fungus	Nonvascular	Phloem
Photosynthesis	Respiration	Root Cap	Xylem

The outer layer of a root is the _______________.

Water and minerals flow up through the _______________.

Foods flow down from the leaves through the _______________.

Water and minerals then pass through the root's _______________ to the xylem.

A green chemical called _______________ allows plants to use the Sun's energy to make their own food.

Teacher Questions – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
   Strongly Agree   Agree   Disagree   Strongly Disagree

B. This question will be easy for me to teach.
   Strongly Agree   Agree   Disagree   Strongly Disagree

2. What is the difference between the way plants make food and the way plants use food?

Teacher Questions – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
   Strongly Agree   Agree   Disagree   Strongly Disagree

B. This question will be easy for me to teach.
   Strongly Agree   Agree   Disagree   Strongly Disagree

Sixth Grade Mathematics

1. Find the value for N that makes the number sentence correct.

$$\frac{2}{3} + \frac{3}{4} = \mathrm{N}$$

Teacher Questions – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
Strongly Agree Agree Disagree Strongly Disagree

B. This question will be easy for me to teach.
Strongly Agree Agree Disagree Strongly Disagree

2. Why are common denominators necessary when adding fractions?

Teacher Questions – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
Strongly Agree Agree Disagree Strongly Disagree

B. This question will be easy for me to teach.
Strongly Agree Agree Disagree Strongly Disagree

Sixth Grade Science

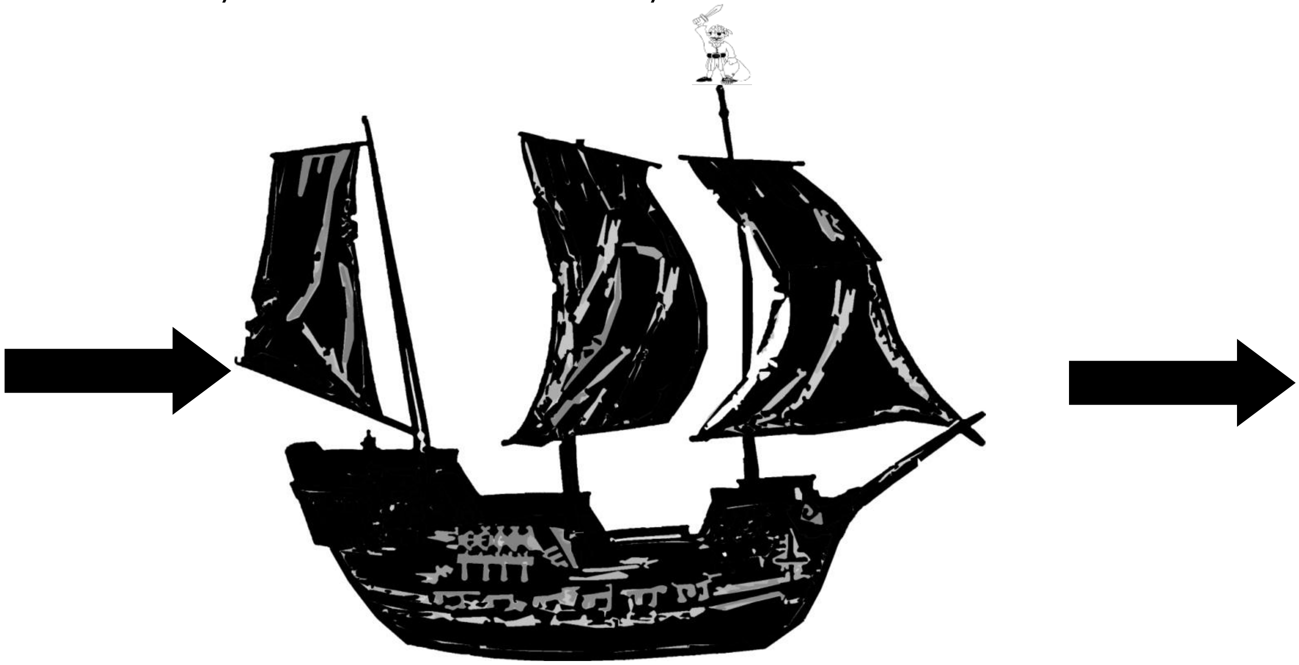
1. What causes a dropped coin to fall?
   a. Inertia
   b. Velocity
   c. Gravity
   d. friction

Teacher Questions – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
   Strongly Agree   Agree   Disagree   Strongly Disagree

B. This question will be easy for me to teach.
   Strongly Agree   Agree   Disagree   Strongly Disagree

2. The pirate ship below is sailing in the direction indicated and is moving at 50 miles per hour. A pirate who was sitting 100 feet above the boat on the top of the highest mast accidentally fell. Where would he most likely land?



   A. Directly below where he fell (at the base of the mast)
   B. Somewhere in between the mast and the back of the ship
   C. He would miss the boat entirely and land in the ocean

Teacher Questions – Circle the answer that best matches your opinion

A. This question was easy for me to answer.
   Strongly Agree   Agree   Disagree   Strongly Disagree

B. This question will be easy for me to teach.
   Strongly Agree   Agree   Disagree   Strongly Disagree

Appendix B – Grading Rubric for the PETSMA

Kindergarten Mathematics

Question 1	
0	No response
1	Incorrect
2	Incomplete
3	Correct

Question 2	
0	No response
1	Just number (27 or 28)
2	Poor explanation (27 or28) OR Demonstrates how without words
3	Correct Explanation (27 or 28)

Kindergarten Science

Question 1	
0	No response
1	NA
2	NA
3	Correct (fish and whale)

Question 2	
0	No response
1	Sorts but no explanation
2	Explanation with errors
3	Correct explanation

First Grade Mathematics

Question 1	
0	Incorrect OR No response
1	NA
2	NA
3	Correct

Question 2	
0	No response OR Just "No"
1	No with explanation OR Yes but cannot understand explanation
2	Yes with poor explanation
3	Yes with correct explanation

First Grade Science

Question 1	
0	0 correct
1	1 or 2 correct
2	3 correct
3	4 correct

Question 2	
0	No response
1	Not a valid reason
2	At least 1 valid reason with no elaboration (e.g., oxygen) OR elaboration with no reason
3	At least 1 valid reason with elaboration (even if minor factual issue)

Second Grade Mathematics

Question 1	
0	No response
1	Mathematical error
2	NA
3	Correct

Question 2	
0	No explanation
1	Explanation that demonstrates no understanding
2	Explanation indicates an understanding of the need to borrow but cannot address why borrowing "works" OR explanation not articulated well
3	Valid explanation

Second Grade Science

Question 1	
0	No response OR 0 correct
1	1 correct
2	2 or 3 correct
3	4 correct

Question 2	
0	No response
1	Incorrect explanation
2	Incomplete explanation (e.g., heat rises)
3	Correct explanation (e.g., heat waves move through air)

Third Grade Mathematics

Question 1	
0	No response or 0 correct
1	1 correct
2	1 correct and diamond OR 1 correct and one incorrect
3	2 correct OR 2 correct and diamond

Question 2	
0	No response or Just "No"
1	No with an explanation OR Yes with no explanation OR Yes with incorrect or inadequate explanation
2	No but accurately describes a rectangle OR Yes with incomplete explanation
3	Correct Explanation (e.g., Yes, a square is a parallelogram with right angles.)

Third Grade Science

Question 1	
0	0 correct
1	1 or 2 correct
2	3 or 4 correct
3	5 correct

Question 2	
0	No response
1	Incorrect explanation
2	Explanation not fully articulated
3	Correct explanation (e.g., The seasons would not change; No seasons; Describes seasons by location with a qualifies indicating that the will be fixed)

Fourth Grade Mathematics

Question 1	
0	0 correct
1	1 or 2 correct
2	3 correct
3	4 correct

Question 2	
0	No response
1	Identifies aspect that is not misleading
2	Explains why an aspect is misleading OR identifies change
3	Explains why an aspect is misleading AND identifies change

Fourth Grade Science

Question 1	Note: Do not grade the second fill-in.
0	No response OR 0 correct
1	1or 2 correct
2	3 correct
3	4 correct

Question 2	
0	No response
1	Incorrect explanation
2	Identifies roles of muscles and bones independently but does not address how they interact
3	Explains how muscles and bones interact (e.g., muscles pull on bones)

Fifth Grade Mathematics

Question 1	
0	No response
1	Understands that the total number of marbles is the denominator
2	Understands how to express probability but makes mathematical error
3	Correct (does not have to simplify) OR Correct but simplifies incorrectly

Question 2	
0	No response OR incorrect probability with no explanation
1	0.5 with no explanation OR incorrect with explanation
2	0.5 with incorrect explanation
3	0.5 with correct explanation

Fifth Grade Science

Question 1	
0	No response OR 0 correct
1	1 or 2 correct
2	3 or 4 correct
3	5 correct

Question 2	
0	No response
1	Both explanations incorrect
2	One correct explanation and one incorrect explanation
3	Correct explanation addressing both making and using food (e.g., Makes food via photosynthesis and uses food to grow)

Sixth Grade Mathematics

Question 1	
0	No response
1	Understands that a common denominator is needed
2	Minor mathematics error
3	Correct (expressed as either an improper fraction or a mixed number)

Question 2	
0	No response
1	Restates question
2	Indicates developing understanding but cannot articulate well
3	Indicates understanding (e.g., the two addends need to be the same units)

Sixth Grade Science

Question 1	
0	No response OR incorrect
1	NA
2	NA
3	Correct

Question 2	
0	Answers C
1	Answers B
2	NA
3	Answers A

Appendix C – Classroom Discussions Protocol

1) How has the methods courses influenced your scientific and mathematical understandings?
2) How do you feel about the instrument you completed today compared to how you did at the beginning of the methods courses?
3) What do you think about the two types of questions? How are they different?
4) Which was easier 1 (content question) or 2 (big idea) for math, and 1 or 2 for science? Why?
5) What types of knowledge are necessary to teaching mathematics? Science?
6) What are the differences between science and mathematics?
7) Are you more confident in teaching science or mathematics? Why?
8) How has the methods courses influenced your confidence in doing science and mathematics?
9) How has the methods courses influenced your confidence in teaching mathematics and science?
10) In your opinion, what is teaching efficacy? (may need to define for them – teacher efficacy is a construct designed to describe the extent of a teacher's beliefs that student motivation and learning are controlled by the teacher (Tschannen-Moran, Woolfolk-Hoy, & Hoy, 1998))
11) Are teaching efficacy and teaching confidence related? How, in your opinions?

VITA

Personal Background	Heather Marie Bjorum Peace
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	Daughter of James and Jackie Bjorum
	Married to Erik Matthew Keola Peace, August 4, 2007
	Two children
Education	Diploma, Mary Carroll High School, Corpus Christi, Texas, 2000
	Bachelor of Science, Mathematics, Baylor University, Waco, Texas, 2004
	Master of Science, Mathematics, Western Kentucky University, Bowling Green, Kentucky, 2005
	Doctor of Philosophy, Education in Science, Texas Christian University, Fort Worth, Texas, 2012
Experience	Instructor of Mathematics, Weatherford College, Weatherford, Texas, January 2007 – present
Professional Memberships	National Council for Teachers of Mathematics (NCTM)
	School Science and Mathematics Association (SSMA)

ABSTRACT

PRE-SERVICE ELEMENTARY TEACHERS' UNDERSTANDINGS OF KNOWLEDGE DOMAINS AND EFFICACY BELIEFS IN MATHEMATICS AND SCIENCE TEACHING

by Heather Marie Bjorum Peace, Ph.D., 2012
College of Education
Texas Christian University

Dissertation: Judith Groulx, Associate Professor of Experimental Psychology

Sarah Quebec-Fuentes, Assistant Professor of Mathematics Education

Mark Bloom, Assistant Professor of Science Education

This research focuses on a cohort of pre-service elementary teachers and their perspectives with respect to the knowledge required for teaching science and mathematics at the beginning and end of their first academic year in a teacher preparation program. An activity, designed to emphasize the differences between factual/procedural knowledge and conceptual knowledge in elementary mathematics and science, was analyzed along with classroom discussions in order to gain deeper understandings of the perspectives of knowledge for teaching for the given cohort. Additionally, subject specific efficacy beliefs were compared to teaching confidence ratings related to specific science and mathematics topics. The pre-service teachers' expressed a variety of ideas regarding the role of content knowledge, and the different types of content knowledge (i.e., factual/procedural and conceptual), in teaching mathematics and science. Furthermore, their perceptions of the nature of mathematics and the nature of science were discussed. By utilizing both quantitative and qualitative methods, this project was able to not only note data trends, but also obtain depth and richness regarding conceptions of the

knowledge required for teaching mathematics and science provided by the voices of the pre-service teachers.