

SPRING/SUMMER 2014 | VOLUME 5, ISSUE 1

JOURNAL OF  
**MATHEMATICS  
EDUCATION**  
AT TEACHERS COLLEGE

*A Century of Leadership in Mathematics and Its Teaching*

**Mathematics Pre-K through 8**

*Published Semiannually by the Program in Mathematics and Education*

**TEACHERS COLLEGE** | COLUMBIA UNIVERSITY

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## Preservice Elementary Teachers' Perspectives about the Roles of Conceptual Understanding and Factual/Procedural Knowledge in Learning and Teaching Mathematics and Science

Sarah Quebec Fuentes  
*Texas Christian University*

Mark Bloom  
*Dallas Baptist University*

Heather Peace  
*Weatherford College*

**ABSTRACT** Preservice teachers often enter teacher education programs with naïve views about mathematics and science as well as the various domains of knowledge needed for effective teaching. A significant body of research has demonstrated that teacher knowledge is multifaceted and consists of both subject matter knowledge and pedagogical content knowledge. In this study, a cohort of preservice elementary teachers participated in an activity involving two components of subject matter knowledge (factual/procedural and conceptual). Analysis compares the preservice elementary teachers' confidence in their understanding of and ability to teach factual/procedural and conceptual knowledge in mathematics and science. Qualitative analysis of a discussion following the activity provides insights into the quantitative findings.

**KEYWORDS** *teacher knowledge, teacher confidence, preservice teacher education, elementary mathematics, elementary science*

Teachers' knowledge and beliefs serve as filters through which they come to understand the components of pedagogical content knowledge. These understandings, in turn, determine how specific components of pedagogical content knowledge are utilized in classroom teaching. (Magnusson, Krajcik, & Borko, 1999, p. 122)

Two of the overarching components of the knowledge needed for teaching—subject matter knowledge and pedagogical content knowledge—are intimately linked. Teachers' content knowledge and beliefs about that knowledge strongly influence their instruction (Guillaume & Kirtman, 2010). Preservice teachers come to teacher education programs with preconceived ideas about the knowledge needs for effective mathematics and science teaching, often based upon their experiences learning the subjects themselves (Ball, 1988; Lortie, 1975). Many times, they possess the faulty ideas that mathematics is a collection of facts and procedures,

science is composed of facts and corresponding terms, and these should be transmitted to students (Borko et al., 1992; Kilpatrick, Swafford, & Findell, 2001; National Research Council [NRC], 2000). However, teachers need knowledge in various domains, unique to the teaching profession and extending far beyond knowledge of facts and procedures, in order to effectively teach mathematics and science in ways that foster students' conceptual understanding.

This paper reports on the use of an activity with preservice elementary teachers which highlights two subdomains of subject matter knowledge: factual/procedural and conceptual knowledge. The activity allows preservice teachers to reflect on their notions of the knowledge needed for mathematics and science teaching as suggested by Magnusson et al. (1999) and underscores the importance of conceptual understanding for mathematics and science proficiency.

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## Literature Review

In order to effectively teach in ways that support the development of students' conceptual understanding of mathematics and science, teachers need *strong, deep, and robust* knowledge of both content and pedagogy (Abd-El-Khalick, 2012; Anderson & Kim, 2003). A significant body of research strives to clearly define distinct components of teacher knowledge (e.g., Ball, Thames, & Phelps, 2008; Hill & Ball, 2009; Magnusson et al., 1999). In addition to general teacher knowledge such as knowledge of learners and their characteristics, Shulman (1986, 1987) identified three distinct subject-specific teacher knowledge categories: content knowledge, curricular knowledge, and pedagogical content knowledge (PCK). The construct of PCK, the "special amalgam of content and pedagogy that is uniquely the province of teachers" (Shulman, 1987, p. 8), has been of particular interest to the educational research community and is the focus of many studies in various subject areas including mathematics and science (Ball et al., 2008). For example, building on Shulman's framework, two discipline specific constructs were developed: Mathematical Knowledge for Teaching (MKT) and PCK for Science Teaching (Ball et al., 2008; Hill & Ball, 2009; Magnusson et al., 1999).

Ball and colleagues (Ball et al., 2008; Hill & Ball, 2009) developed the practice-based theory of Mathematical Knowledge for Teaching (MKT). The two major components of MKT are Pedagogical Content Knowledge and Subject Matter Knowledge. A critical contribution of MKT to the field of teacher knowledge is the identification of distinct subsets of Subject Matter Knowledge. One of these subsets is Specialized Content Knowledge (SCK), which is mathematics content knowledge specific to teaching. With SCK, teachers are able to perform the daily tasks of teaching mathematics such as identifying student errors, listening to and interpreting explanations, and choosing appropriate examples. Research surrounding MKT has shown that there is a significant relationship between the MKT of teachers and the mathematical quality of their instruction (Hill et al., 2008) as well as student achievement (Hill, Rowan, & Ball, 2005; Rockoff, Jacob, Kane, & Staiger, 2008).

Similarly, Magnusson et al. (1999) extended the work of Shulman in the area of science by developing PCK for Science Teaching. The emphasis of PCK for Science Teaching is the teachers' Orientation to Teaching Science; that is, how teachers believe science should be taught and what they perceive are the goals of a science

curriculum. For example, teachers with didactic orientations to science believe the goal of science teaching is to convey facts and terms to their students. By contrast, teachers with inquiry orientations allow their students to engage in investigations with the goal of discovering the underlying scientific concepts. Each distinct orientation to science influences the four subcomponents of PCK for Science Teaching: Knowledge of Science Curricula, Knowledge of Assessment and Scientific Literacy, Knowledge of Instructional Strategies, and Knowledge of Students' Understanding of Science. Zembal-Saul, Starr, and Krajcik (1999) summarized several studies of an elementary science teacher preparation program steered by the aforementioned components of PCK for Science Teaching. Based on the findings, the authors asserted that such a program can help preservice teachers "in developing a conceptual approach to teaching science" (p. 252) rather than a didactic approach.

Although MKT and PCK for Science Teaching both build upon Shulman's (1986, 1987) classification of teacher knowledge, MKT has a greater focus on content knowledge than PCK for Science Teaching. However, Magnusson et al. (1999) emphasize the importance and influence of subject matter knowledge on the various components of PCK for Science Teaching. For example, teachers with strong subject matter knowledge are able to create or modify activities to accommodate diverse settings and/or students. The present study focuses on a subset of subject matter knowledge, namely conceptual understanding, which is defined as the "comprehension of mathematical concepts, operations, and relations" (Kilpatrick et al., 2001, p. 116). Mathematics teachers must possess conceptual understanding in order to develop SCK. Likewise, science teachers must possess a conceptual understanding of content in order to successfully teach with a non-didactic orientation (NRC, 2000).

The National Research Council has issued reports, in both subject areas, that support the need for teachers to have a strong conceptual understanding of the content they teach. *In Adding It Up: Helping Children Learn Mathematics*, Kilpatrick et al. (2001) describe the mathematical knowledge necessary for teaching.

Knowing mathematics for teaching also entails more than knowing mathematics for oneself. Teachers certainly need to be able to understand concepts correctly and perform procedures accurately, but they also must be able to understand the conceptual foundations of that knowledge. In the course of their work as teachers, they must



understand mathematics in ways that allow them to explain and unpack ideas in ways not needed in ordinary adult life. (p. 371)

The report, *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning*, has a similar statement about the knowledge necessary for teaching science.

Teachers need to understand the important content ideas in science... They need to know how the facts, principles, laws, and formulas ... are subsumed by and linked to those important ideas. They also need to know the evidence for the content they teach... In addition, they need to learn the “process” of science. (p. 92)

Both statements clearly indicate that teachers need to know more than facts and procedures and have conceptual knowledge of the content. This conceptual knowledge base supports an understanding of the connections between the various components of subject matter knowledge and of the ways in which knowledge is generated in each field.

Despite the importance of conceptual knowledge for teaching both mathematics and science, many teachers have only a factual or procedural knowledge base and, therefore, view the subjects as sets of facts and/or procedures (Borko et al., 1992; Kilpatrick et al., 2001; NRC, 2000; Wilkins, 2000). This knowledge base and perspective often stem from prior schooling experiences (Wilkins, 2000). For instance, Guillaume and Kirtman (2010) found that a cohort of elementary preservice teachers reported procedural recall as the primary focus of their elementary school experience. This perspective influences instruction and subsequent student learning (Kilpatrick et al., 2001; Magnusson et al., 1999). To break this cycle, preservice teachers must have opportunities to understand the various domains of knowledge necessary for teaching mathematics and science and to develop their knowledge in these domains. The purpose of the present study is to compare preservice elementary teachers’ confidence in their understanding of and ability to teach factual/procedural and conceptual knowledge in mathematics and science.

## Methods

### Preservice Elementary Teachers’ Science and Mathematics Activity (PETSMA)

The PETSMA contains a series of K – 6 science and mathematics questions (Quebec Fuentes, Bloom, & Peace, in press). The mathematics and science content

Table 1

*Mathematics and Science Content Areas by Grade Level for the PETSMA*

Grade	Science	Mathematics
K	Animals	Counting
1	Plant Anatomy	Measurement
2	Temperature	Whole-Number Operations
3	Astronomy	Properties of Shapes
4	Human Physiology	Reading/Understanding Graphs
5	Plant Physiology	Probability
6	Physics of Objects in Motion	Addition of Fractions

for each grade level was purposefully selected in order to represent a distinct content for each grade (Table 1). A core concept for each content area was identified at each grade level (National Council of Teachers of Mathematics, 2000, 2006; NRC, 1996). For example, understanding place-value concepts (a component of the content area of whole number operations) was used to represent second grade mathematics content. There are two mathematics questions and two science questions aligning with the respective core idea at each grade level. The first question is factual/procedural, and the second question addresses the conceptual underpinnings of the content in the first. All factual/procedural questions were taken from state-approved textbooks (Baptiste et al., 2000; Biggs, Daniel, Feather, Snyder, & Zike, 2002; Charles et al., 2009; Lappan, Friel, Fey, & Phillips, 2009). The conceptual questions were created by the authors to correspond to the content of the factual/procedural questions. The level of difficulty of the questions was assessed using the revised Bloom’s Taxonomy (Krathwohl, 2002). All factual/procedural questions were categorized as “remembering” (i.e., recalling information, naming, using a procedure), and all conceptual questions were categorized as “understanding” (i.e., explaining ideas or concepts). Every question was accompanied by two Likert-scale questions to allow the preservice teachers to report their confidence in answering the question and their confidence in teaching the content related to the question. As an example, the third grade mathematics and science questions are shown in Figure 1.

### Participants

This paper describes the use of the PETSMA and the subsequent findings with preservice elementary teachers concurrently enrolled in their mathematics and science methods courses. The preservice teachers take these

courses during their first year in their teacher education program (typically beginning in their junior year) in a college of education at a university in the southwest United States. The preservice teachers completed the PETSMA during one of their mathematics methods classes at the end of their junior year. Thirty-five preservice teachers, from two different sections of the course, were present on the day of the activity and their data is included in the reported findings. All participants were female and, with the exception of three students, between the ages of 20 and 22.

### Procedure


At the beginning of the academic year, the preservice teachers consented to have all classroom activities and related artifacts be used for research purposes. Before completing the PETSMA, the preservice teachers were informed that their experience in completing the activity was going to serve as a basis for a subsequent class discussion, and the purpose was not to evaluate their content knowledge. The students answered all of the questions in approximately 30 minutes. Immediately following the activity, the preservice teachers and the instructor (second author) engaged in a whole-class discussion driven by the preservice teachers' reflections on the activity. The discussions from the two sections, which lasted approximately one hour, were video recorded and transcribed.

### Data Analysis

Descriptive statistics were used to depict preservice teachers' confidence scores in answering factual/procedural and conceptual questions in both mathematics and science. Eight mean confidence scores were calculated for each preservice teacher. Four scores represented the participants' confidence in *answering* the four distinct

**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

Figure 1. The third grade mathematics and science questions from the PETSMA.



question types across the seven grade levels (factual/procedural mathematics, conceptual mathematics, factual/procedural science, and conceptual science). The other four scores represented participants' confidence in *teaching the content* associated with the same four questions types across the seven grade levels. Next, eight mean scores were calculated for the entire group of pre-service teachers, and these overall mean scores are displayed in Tables 2, 3, and 4.

The mean confidence scores were compared with respect to answering and teaching the content related to the factual/procedural and conceptual questions within and across mathematics and science. The Wilcoxon signed rank test was used for each comparison, the

results of which are reported in the following section. The transcribed discussions were analyzed using the constant comparative method (Glaser & Strauss, 1967). Four themes emerged from this analysis: desire to learn more, understanding concepts, becoming a teacher, and content knowledge. The findings from the qualitative analysis added depth to the quantitative findings.

## Results

### Comparison of Confidence Between Subjects

Mean confidence scores for answering factual/procedural and conceptual questions were compared between mathematics and science. Table 2 shows that the preservice teachers were more confident in answering mathematics questions than science questions. Preservice teachers' confidence ratings in answering factual/procedural questions were significantly higher in mathematics than science ( $z = -5.10, p < 0.001$ ). Likewise, in regard to answering conceptual questions, the preservice teachers' confidence levels were significantly higher in mathematics as compared to science ( $z = -4.83, p < 0.001$ ).

Teaching confidence was also compared between mathematics and science for both types of questions. The preservice teachers expressed higher confidence in teaching mathematics than in teaching science for both factual/procedural and conceptual knowledge (Table 2). Confidence in teaching factual/procedural content was significantly higher in mathematics compared to science ( $z = -4.04, p < 0.001$ ). Similarly, confidence in teaching conceptual content was significantly higher in mathematics than in science ( $z = -3.76, p < 0.001$ ).

### Comparison of Confidence Within Subjects

The participants reported different confidence ratings with respect to knowing versus teaching mathematics and science facts/procedures and concepts. Table 3 displays the results of comparing the preservice teachers' confidence in answering questions

Table 2

*Wilcoxon signed rank tests for confidence in answering and teaching mathematics versus science*

	Mathematics		Science		z
	Mean	SD	Mean	SD	
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*
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*

\*  $p < 0.001$

Table 3

*Wilcoxon signed rank tests comparing answering questions and teaching the related content*

	Answering Questions		Teaching		z
	Mean	SD	Mean	SD	
Mean Confidence Ratings for Factual/Procedural Mathematics Questions	2.80	0.26	2.67	0.38	-3.07*
Mean Confidence Ratings for Conceptual Mathematics Questions	2.45	0.34	2.35	0.45	-1.40
Mean Confidence Ratings for Factual/Procedural Science Questions	1.95	0.28	2.27	0.47	-3.63**
Mean Confidence Ratings for Conceptual Science Questions	1.80	0.33	1.94	0.53	-1.84

\*  $p < 0.01$

\*\*  $p < 0.001$

with their confidence in teaching the related content. The preservice teachers' mean confidence levels were significantly higher for answering factual/procedural mathematics questions than teaching the content related to those questions ( $z = -3.07, p < 0.01$ ). However, no statistically significant difference was determined with respect to conceptual mathematics questions.

The teaching confidence ratings for science displayed a curious pattern when compared to confidence in answering the related questions. The preservice teachers' confidence for teaching factual/procedural science content was significantly higher than their confidence in answering the related questions ( $z = -3.63, p < 0.001$ ). The mean value for teaching conceptual science content was greater than that for answering conceptual questions; however, the difference was not statistically significant.

Table 4 shows the results of comparing the preservice teachers' confidence in answering and teaching the related content for factual/procedural questions with their confidence in the corresponding conceptual questions. In mathematics, confidence levels associated with factual/procedural questions were significantly higher than confidence levels associated with conceptual questions for both answering questions ( $z = -4.32, p < 0.001$ ) and teaching the content ( $z = -4.24, p \leq 0.001$ ). For science, the results followed a similar pattern to mathematics. Namely, the preservice teachers were significantly more confident with respect to factual/procedural content than with conceptual content for both answering questions ( $z = -2.82, p < 0.01$ ) and teaching the related content ( $z = -4.41, p < 0.001$ ).

## Discussion

The aim of this study was to compare preservice teachers' confidence regarding factual/procedural and conceptual knowledge in mathematics and science using the PETSMA. Specifically, it examines their confidence in answering questions related to these two distinct types of knowledge and their confidence in teaching the content related to those questions. The analysis of the PETSMA data produced some interesting results.

First, for both questions types (factual/procedural and conceptual), the preservice teachers were more confident

Table 4

*Wilcoxon signed rank test comparing factual/procedural and conceptual confidence*

	Factual/ Procedural		Conceptual		z
	Mean	SD	Mean	SD	
Mean Confidence Ratings for Answering Elementary Mathematics Questions	2.80	0.26	2.45	0.34	-4.32*
Mean Confidence Ratings for Teaching Elementary Mathematics Content	2.67	0.38	2.35	0.45	-4.24*
Mean Confidence Ratings for Answering Elementary Science Questions	1.95	0.28	1.80	0.33	-2.82**
Mean Confidence Ratings for Teaching Elementary Science Content	2.27	0.47	1.94	0.53	-4.41*

\* $p < 0.01$

\*\* $p < 0.001$

in *answering* the mathematics questions than the science questions. During the discussion, the preservice teachers expressed uncertainty regarding their science content knowledge. For example, preservice teacher (PST) 1 stated:

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.

PST 2 offered an explanation for the higher confidence in mathematics.

Math is just easier because you have a lot of formulas... in science it's like I learned this ten years ago and I don't remember any of it.

This comment reflects the preservice teachers' ability to use familiar procedures to answer the mathematics questions. In science, on the other hand, fact-based questions required the preservice teachers to recall highly specific terms and definitions. The mathematical procedures to which the preservice teachers alluded, such as adding whole numbers, are often used regularly both in and out of the classroom setting. Conversely, many science terms and definitions, such as plant anatomy, are used infrequently and may be encountered strictly in a classroom setting.

Similarly, the preservice teachers had higher confidence in *teaching* mathematics than science for both types of knowledge. PST 2 provided a potential explanation:

Before you teach the method [in mathematics], 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.

The presence of a familiar method for determining solutions gave the preservice teachers more confidence in teaching mathematics because they could be confident in evaluating the accuracy of their students' answers. However, this confidence is based upon procedural fluency, which is not sufficient to support the development of specialized content knowledge.

In mathematics, a teacher can resort to teaching a familiar algorithm when challenges arise while attempting to teach the content from a conceptual perspective (e.g., Borko et al., 1992; Hill & Ball, 2009). The preservice teachers expressed alternative views with respect to teaching science.

We know some stuff, but I feel like I really don't know enough content to teach it effectively. If my students were to ask me a certain question, I would feel like 'Well, I learned it when I was in school, but I don't know it now.' So, I guess as teachers it's our job to make sure we're up on that information and research it. (PST 3)

In science, familiarity with the content knowledge is often lacking without reviewing it prior to teaching. However, in both subject areas, the preservice teachers acknowledged the importance of conceptual knowledge for teaching. "I feel like it's good to know the concepts all of the time ... it's good to have a solid grasp on [the concepts] so you can explain" (PST 4). The preservice teachers were differentiating between the two types of knowledge emphasized by the PETSMA. While not discounting the utility of factual/procedural knowledge, the preservice teachers recognized the importance of conceptual knowledge for teaching.

Most strikingly, when comparing confidence in answering with confidence in teaching, the trend in mathematics was different than that seen in science (Figure 2). In mathematics, with both factual/procedural and conceptual questions, the preservice teachers had higher confidence in answering the questions than in teaching the associated content. In referencing the mathematics questions from the PETSMA, PST 5 stated: "The math ones, we can do it, but we have a harder time teaching it." Several of the preservice teachers attributed this difficulty to their earlier learning experiences in mathematics. For example, PST 6 described her frustration in not using the term *borrow* when teaching the subtraction algorithm: "That just makes me angry. Because that's what I learned and that's what I want to teach." While the preservice teachers were familiar with mathematical procedures, they expressed concern about teaching the algorithms and the concepts underlying them.

In science, this relationship was reversed; the preservice teachers had higher confidence in teaching both factual/procedural and conceptual content than in answering the related questions. At first glance, the confidence ratings with respect to science seem counter-intuitive. These results could be disconcerting because teachers should be familiar with the content they teach. However, when paired with the responses from the classroom discussions, the preservice teachers provided insight for this anomaly:

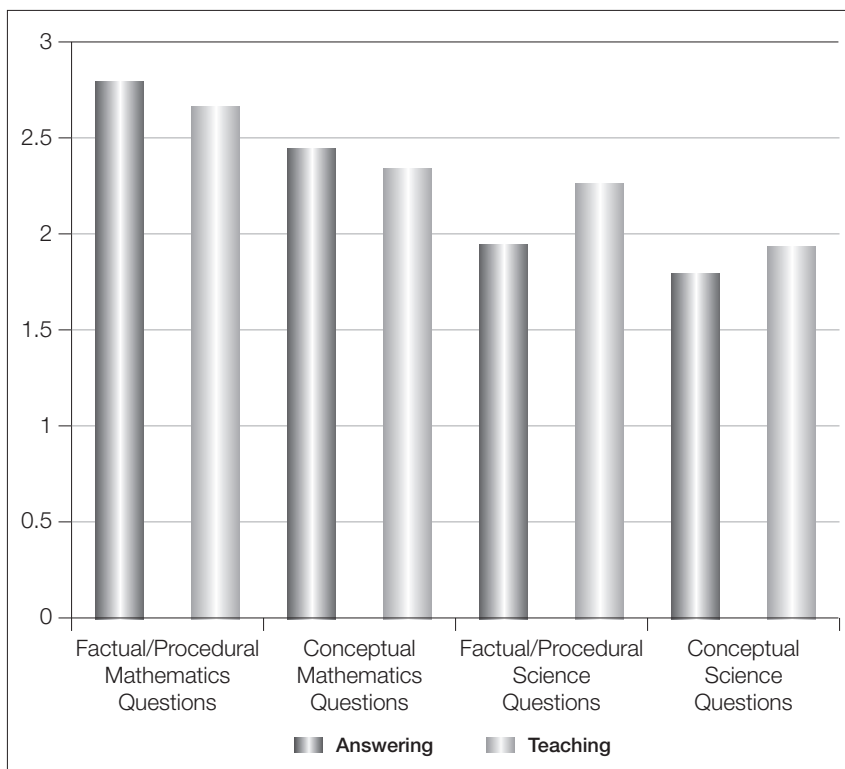


Figure 2. Mean confidence ratings on a scale from 0 to 3 for mathematics and science.

“Because you can look up the vocabulary and the details and things like that right before you teach it” (PST 4). PST 7 believed that knowing how to teach science was more important than being familiar with all science content.

I would rather walk away knowing how to research and how to teach [science], than to know the content and to not know how to teach it. Because now I know, just like for...[the science content] class, 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...[the science content] class how to teach it and how to prepare for it. So, when we go to that point in time [to teach a science lesson], we have the tools to be ready.

The preservice teachers attributed their higher confidence in teaching science over answering the questions to their ability to research and gain content knowledge in preparation for teaching science lessons. This allowed them to be comfortable knowing that they did not need to remember all science content at all times.

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## Conclusion

Preservice elementary teachers begin teacher education programs with varied, and sometimes simplistic, perspectives of the knowledge needed for teaching mathematics and science. The PETSMA was developed to assess preservice teachers' confidence in answering questions and teaching the related content, both factual/procedural and conceptual, in mathematics and science. The completion of the PETSMA in conjunction with a subsequent class discussion provided insight into the preservice teachers' perspectives of these two types of knowledge and their role in teaching. In the present study, the PETSMA and corresponding discussion were conducted at the end of the mathematics and science methods courses. Based on the findings of this study, the authors recommend that the PETSMA be used at the beginning of teacher education programs. Using the PETSMA at the beginning of methods courses allows teacher educators to understand the preservice teachers' perspectives about factual/procedural and conceptual content knowledge, both critical components of teacher knowledge, and tailor instruction accordingly.

Preservice teachers enter teacher education programs with naïve views about mathematics and science as well as the various domains of knowledge needed for effective teaching. They often view mathematics and science as a collection of procedures, facts, and terms,

and their perspectives on teaching these subjects mirror their K – 12 learning experiences. To break this cycle, instruction in mathematics and science methods courses should (1) emphasize the importance of both types of knowledge, (2) help preservice teachers develop the skills to acquire both types of knowledge, and (3) demonstrate how both types of knowledge manifest themselves in effective mathematics and science instruction. The PETSMA achieved the first of these three goals by challenging the preservice teachers' perceptions of mathematics and science subject matter knowledge.

The sample size for the present study was small, but the findings demonstrated the value and potential of the PETSMA. Future research with the PETSMA can use larger sample sizes to examine possible interactions between the factors in addition to the main effects reported herein. Longitudinal studies can examine whether preservice teachers, who develop a sophisticated understanding of the knowledge needs for mathematics and science instruction, acquire factual/procedural and conceptual knowledge and incorporate both in their instruction.

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