Preservice teachers must understand the importance of both factual/procedural fluency and conceptual understanding as critical and complementary components to teaching science and mathematics. This article describes an activity, entitled preservice elementary teachers science and mathematics activity (PETSMA), designed to expose preservice elementary teachers to the multiple domains of teacher knowledge for science and mathematics instruction. In particular, the PETSMA consists of pairs of parallel questions (one factual/procedural and one conceptual) in each subject area for each grade level, K through 6. However, the PETSMA is not intended as a measure of preservice teachers’ content knowledge. Instead, the implementation of the PETSMA in conjunction with a follow-up, whole-class discussion enables instructors to formatively assess the preservice teachers’ perspectives about the knowledge required for teaching science and mathematics and to tailor subsequent instruction accordingly. Summaries of responses and excerpts from the follow-up discussion with a cohort of preservice teachers are shared. In addition, recommendations for use of the PETSMA are made.

Preservice teachers often come to teacher education programs with preconceived notions of what content knowledge they need to develop in order to teach science and mathematics. They believe that the facts, terms, and procedures that they learned in their K–12 schooling will satisfy their content knowledge needs for teaching. An important job of preservice teacher educators is to make these students aware that they must also develop the underlying conceptual understandings in order to effectively teach these subjects (National Research Council, 1996; Shulman, 1986, 1987). The activity described in this article, entitled the preservice elementary teachers science and mathematics activity (PETSMA), is designed to illustrate differences between factual/procedural and conceptual knowledge for a series of K–6 science and mathematics topics. Additionally, implementation of the PETSMA in a preservice methods course enables instructors to formatively assess students’ understandings and beliefs about the knowledge required for teaching science and mathematics.

In what follows, we (a) describe the educational theory that emphasizes the importance of multiple knowledge domains for mathematics and science teaching, (b) provide a description of the PETSMA and its development, (c) make recommendations for the use of the PETSMA by preservice teacher educators, and (d) share sample responses of preservice teachers who participated in the activity.

Teacher knowledge

Although it is not uncommon to find K–12 science and mathematics taught through direct-teach methods, this approach is not aligned with recommendations of current research into best practices for teaching (Adams & Hamm, 1998; National Council of Teachers of Mathematics, 2000; National Research Council, 1996; National Science Teachers Association, 2008). Such direct teaching often results in memorization of facts, terms, and procedures and does not convey the underlying conceptual ideas within the subjects (Ball, 1988; Ball, Thames, & Phelps, 2008; Hill & Ball, 2009; Magnusson, Krajcik, & Borko, 1999; Shulman, 1986, 1987). Furthermore, preservice teachers who learned science and mathematics in direct-teach fashion, without any forms of intervention, will likely teach their future students in the same manner (e.g., Ball, 1988). Teacher knowledge must extend beyond facts, terms, and procedures to include multiple domains including deeper content knowledge, knowledge of students, and knowledge of pedagogy (Ball et al., 2008; Magnusson et al., 1999; Shulman, 1986, 1987). Frameworks have been developed to elaborate on the myriad knowledge domains necessary for mathematics and science teaching.

Mathematical knowledge for teaching (MKT) includes both Shulman’s (1986, 1987) pedagogical content
knowledge (PCK) as well as subject matter knowledge required for mathematics teaching (Ball et al., 2008; Hill & Ball, 2009). The three areas of subject matter knowledge are common content knowledge (CCK), specialized content knowledge (SCK), and horizon content knowledge (HCK). CCK refers to mathematical knowledge that may be held by any individual who is educated in mathematics. SCK is unique to the teaching profession and includes the ability to engage in tasks such as explaining conceptual underpinnings of procedures for solving mathematical problems, recognizing the validity and generalizability of nontraditional procedures, and understanding student misconceptions by their errors. For example, a teacher must not only know the procedure for accurately adding multidigit numbers, but also know the connections between that procedure and the concept of place value. HCK refers to an understanding of the connections between topics across the mathematics curriculum. To effectively teach mathematics, teachers must possess CCK, SCK, and HCK.

Similarly, in science, PCK for science teaching (Magnusson et al., 1999) extends Shulman’s (1986, 1987) PCK to specifically address the knowledge domains required for science teaching. The critical component of PCK for science teaching is orientation toward science teaching, which emphasizes a teacher’s beliefs regarding the goals of science teaching and the instructional strategies that correspond to that particular orientation. For instance, a didactic approach to teaching science often indicates the goal of teaching facts and terminology. However, an inquiry approach to teaching correlates to the goal of fostering the development of process skills and teaching overarching concepts of science. For example, to move beyond didactic teaching, a teacher should not only be able to identify parts of the muscular and skeletal systems, but also know how these two systems interact with each other and other body systems in order to maintain homeostasis in the human body. Thus, teachers’ orientation toward science teaching will dictate the content knowledge that they believe they should possess in order to teach, as well as define the ultimate learning goals they hold for their students. To effectively teach science, a teacher must know scientific facts/terms as well as have the deeper conceptual knowledge that brings meaning to them.

Description of PETSMA

Although the frameworks for MKT and PCK for science teaching are not parallel, they both highlight the distinct nature of knowledge for teaching. In particular, teachers need to know more than facts, terms, and

![Figure 1](image-url)
procedures and understand the conceptual knowledge that supports SCK and a nondidactic orientation to teaching science. Kilpatrick, Swafford, and Findell (2001, p. 5) described conceptual understanding and procedural fluency as two of the core components of mathematical proficiency:

- conceptual understanding—comprehension of mathematical concepts, operations, and relations; and
- procedural fluency—skill in carrying out procedures flexibly, accurately, efficiently, and appropriately.

We applied this construct to science and identified analogous components for science proficiency. In this case, conceptual understanding refers to the comprehension of scientific theories, systems, and relationships between various science disciplines. Factual fluency refers to knowing the language of science (e.g., terms and their functions). The PETSMA was designed to emphasize the distinction between these types of knowledge containing parallel factual/procedural and conceptual questions for an assortment of science and mathematics topics.

In designing the PETSMA, we found one science and one mathematics factual/procedural question for each grade level (K–6) from state-approved textbooks (Baptiste et al., 2000; Biggs, Daniel, Feather, Snyder, & Zike, 2002; Charles et al., 2009; Lappan, Friel, Fey, & Phillips, 2009). For each factual/procedural question, grade-level appropriate conceptual questions of related content were created. (Note: We originally intended to also find the conceptual questions from textbooks. Although we acknowledge that some curricula include conceptually oriented questions, the state-approved texts used to create the PETSMA did not include a sufficient amount of this type of question.)

For example, the second-grade mathematics questions were related to whole-number addition and subtraction, and the second-grade science questions revolved around temperature and heat transfer (Figure 1). As exemplified, all conceptual questions are meant to prompt higher level critical thinking about the task performed in the associated factual/procedural question. The mathematics and science topics, purposefully chosen from a range of content areas, for the remaining K–6 grade levels are outlined in Table 1 with all questions aligning with appropriate grade-level content (Common Core State Standards Initiative, 2011; National Research Council, 1996; Texas Education Agency, 2011). Additionally, each factual/procedural and conceptual question was followed by two Likert-style questions designed to measure confidence in answering the question and teaching the content related to the question.

**Recommendations for using the PETSMA**

The PETSMA may be used with in-service and preservice teachers. Although the PETSMA may be used at any point during a teacher preparation program, we believe that its use is particularly valuable at the beginning of a mathematics or science methods course. Prior to the preservice teachers completing the PETSMA, inform them that the PETSMA is not intended to be an evaluation of their content knowledge and that it is expected that they might not be able to answer some of the questions. Rather, completion of the PETSMA is intended to be a basis for a follow-up discussion. Additionally, remind the preservice teachers to answer the two Likert-style questions for each question. Allocate approximately 30 minutes for completion of the PETSMA.

After the preservice teachers complete the PETSMA, conduct a whole-class discussion about their reactions to and perceptions of the questions and their abilities to answer them. Here are some guiding questions for the discussion:

- What are your general reactions?
- Which questions were easier for you to answer? Which questions were more difficult for you to answer? Why?
- How did the first question for each grade level/subject differ from the second?
- How did your confidence in your ability to answer the first question for each grade level/subject compare to the second?
- How did your perceptions of the first and second questions influence your confidence in your

<table>
<thead>
<tr>
<th>Grade</th>
<th>Mathematics</th>
<th>Science</th>
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<tbody>
<tr>
<td>K</td>
<td>Counting</td>
<td>Animals</td>
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<tr>
<td>1</td>
<td>Measurement</td>
<td>Plant anatomy</td>
</tr>
<tr>
<td>2</td>
<td>Whole-number operations</td>
<td>Temperature</td>
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<tr>
<td>3</td>
<td>Properties of shapes</td>
<td>Astronomy</td>
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<tr>
<td>4</td>
<td>Reading/understanding graphs</td>
<td>Human physiology</td>
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<tr>
<td>5</td>
<td>Probability</td>
<td>Plant physiology</td>
</tr>
<tr>
<td>6</td>
<td>Addition of fractions</td>
<td>Physics of moving objects</td>
</tr>
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TABLE 1

Mathematics and science content by grade level for the PETSMA.
Preservice Teachers’ Perceptions of Knowledge Needs

ability to teach those content areas?
• Which questions were more difficult for you—mathematics or science? Why?

By having this discussion, instructors gain access to preservice teachers’ views of the knowledge required for teaching.

Preservice teachers’ perceptions

We used the PETMSA with 50 preservice teachers concurrently enrolled in their science and mathematics methods courses during their first semester of their teacher preparation program. Initial analysis of the preservice teachers’ responses to the Likert-style questions (Figure 1) regarding their confidence in answering the questions (Figure 2) and teaching the content related to the questions (Figure 3) revealed interesting and distinct results. Figures 2 and 3 show that the preservice teachers’ confidence decreased as the grade level increased with the exception of the sixth-grade science fact-based question about gravity. In addition, both figures convey a higher confidence level for factual/procedural knowledge (labeled as Fact in graphs) over conceptual knowledge. Overall, the preservice teachers were more confident in mathematics (both factual/procedural and conceptual) than in science. Science fact confidence deviated somewhat from these trends. The discussion with the preservice teachers following the completion of the PETMSA explores these trends as well as deviations from them.

Through the discussion, we learned about their perceptions of the natures of science and mathematics, their prior learning experiences that influenced those perceptions, and their views about preparing to teach science and mathematics content. Based on the preservice teachers’ responses to the PETMSA, we found that they had differing views of the roles of factual/procedural and conceptual knowledge between mathematics and science. The preservice teachers found the factual/procedural questions easier in mathematics than in science. Their perception of doing mathematics was using procedures to arrive at answers.

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

In contrast, the preservice teachers viewed the conceptual questions easier than the factual questions in science, which is evident in Figure 2 for Grades 4 and 5.

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.

FIGURE 2
Preservice teachers’ confidence level by grade in answering PETMSA questions.

FIGURE 3
Preservice teachers’ confidence level by grade for teaching the content of PETMSA questions.
Another perceived distinction between mathematics and science that the students discussed was the connectedness of the content across grade levels. They viewed mathematics knowledge as building on itself.

*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, it's more information, I guess.*

Conversely, they felt that science consisted of disconnected disciplines.

*With science, there's so many different [subjects] you're not consistently reminded. I do subtraction every day, but science... you don't name muscles every day, because you don't build off those concepts.*

Some comments indicated that their perceptions stemmed from their learning experiences in science and mathematics.

*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.*

Because the preservice teachers were in the beginning stages of their teacher education program, many of their comments focused on their experiences as learners and the influence of those experiences on their views of science and mathematics. When asked about how they would prepare to teach content in the different subject areas, their comments indicated different needs for mathematics and science. For instance, in regard to mathematics, one student commented on the requisite knowledge of the learner:

*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 [prerequisite knowledge].*

This aligns with their view of the connectedness of mathematics content and indicates a beginning understanding of horizon content knowledge. With respect to science, several made reference to their own requisite knowledge as teachers.

*Well, read their [the students'] 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.*

This recognizes that while gaps in content knowledge may exist, teachers must also possess the ability to research topics sufficient to guide student learning. This idea is evident in the responses to the Likert-style questions, which show that the preservice teachers have higher confidence in teaching both factual and conceptual knowledge in science than in answering the questions (Figure 4). Interestingly, this trend was reversed in mathematics, with the preservice teachers having higher confidence in answering the questions than in teaching the related content.

In summary, with respect to mathematics, the preservice teachers expressed surprise in needing to know the conceptual underpinnings of mathematics procedures, realizing that their knowledge base was incomplete. This set the stage for implementing classroom activities connecting procedural knowledge to larger conceptual ideas. Although the preservice teachers saw the connec-
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Preservice teachers must understand the importance of both factual/procedural fluency and conceptual understanding as critical and complementary components to teaching science and mathematics. To help them move toward this goal, preservice teacher educators must first identify what knowledge their students believe is important for teaching. Likewise, the future teachers must recognize that these distinct types of knowledge exist. The PETSMA helps accomplish these goals.

References

Sarah Quebec Fuentes is an assistant professor in the College of Education at Texas Christian University in Fort Worth, Texas. Mark Andrew Bloom (MarkB@DBU.edu) is an associate professor in the Department of Biology at Dallas Baptist University in Dallas, Texas. Heather Peace is an instructor in the Department of Mathematics at Weatherford College in Weatherford, Texas.