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Preservice Teachers' Transforming Perceptions of Science and Mathematics Teacher Knowledge *

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Abstract: Teacher Education Programs (TEPs) are intended to prepare students to become qualified professionals in the field of education. Yet, many preservice teachers (PSTs) have difficulty recognizing their new roles, not simply as students in the TEP, but as future educators. As PSTs progress through their coursework, field experiences, and student teaching, their perceptions of teacher knowledge evolves. Teacher educators may assist in positively influencing such transformation through reflective exercises, learning activities, and thoughtful discourse. The present research examines four classroom discussions centered on a mathematics and science activity. These discussions illustrate the changes in perspective with respect to mathematics and science teacher knowledge, among a cohort of elementary PSTs between the beginning and end of their first year in a TEP.

Keywords: *Science/Science Education, Mathematics/Mathematics Education, Teacher Education, Teacher Knowledge, PETSMA*

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Introduction

Teacher knowledge is complex. As Shulman (1986) described, knowledge for teaching extends beyond isolated subject matter knowledge or pedagogy: "Mere content knowledge is likely to be as useless pedagogically as content-free skill" (p. 8). In response to this complexity, researchers (e.g., Ball, Thames, & Phelps, 2008; Magnuson, Kracik, & Borko, 1999) have developed frameworks to elaborate on the various components of teacher knowledge in mathematics and science. The frameworks expose the distinct natures of the subjects as well as the multifaceted interaction between content and pedagogical knowledge necessary for effective instruction. The complexity of mathematics and science teacher knowledge is also represented in the current standards for both fields (National Council of Teachers of Mathematics [NCTM], 2014; National Governors Association Center for Best Practices & Council of Chief State School Officers 2010; Next Generation Science Standards [NGSS] Lead States, 2013).

An important early goal of teacher education programs (TEPs) is to expose preservice teachers (PSTs) to the intricacies of teacher knowledge so that they may begin the transition from being a student to being a teacher (Ball & Forzani, 2009). The present paper is grounded in the theoretical frameworks for teacher knowledge in mathematics and science (Ball et al., 2008; Magnuson et al., 1999). Shulman (1987) described the distinction between the knowledge needs of learners (i.e., ability to understand content knowledge for themselves) and that of teachers; teachers must be able "to elucidate subject matter in new ways, reorganize and partition it, clothe it in activities and emotions, in metaphors and exercises, and in examples and demonstrations, so that it can be grasped by students" (pp. 12-13). The research described herein reports on changes in PSTs' perceptions of teacher knowledge between the beginning and end of their first year in a TEP. Discussions centered on a classroom mathematics and science activity were examined to provide insight into the nature of these changes. Although the methods utilized were not designed to speculate as to the factors bringing about such changes, the inquiry serves to provide a rich analysis of the transformation in perspectives over time. The contrast between the initial and final discussions displays a remarkable evolution that occurred during the formative stages of teacher knowledge development.

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Teacher Knowledge

Pedagogical Content Knowledge

Shulman (1986, 1987) categorized teacher knowledge. He believed that teaching required a unique professional knowledge, which extended beyond general pedagogical knowledge to include content-specific knowledge. By considering content, Shulman (1986) was addressing what he termed the *missing paradigm* in the conversations about teacher knowledge at that time (p. 7). Therefore, in addition to general pedagogical knowledge, Shulman identified three areas of teacher knowledge, which contextualizes teaching within a content area: content knowledge, curricular knowledge, and pedagogical content knowledge (PCK). Content knowledge includes an understanding of the facts and/or concepts of the discipline, comprehension of why an idea or process is valid (syntactic structure), and structural organization of a content area (substantive structure) (Schwab, 1964). Curricular knowledge is comprised of three components: (1) knowledge of the curricular programs and instructional materials for teaching particular topics, (2) the relationship between course content and the content being taught in other subject areas at the same time (lateral curriculum knowledge), and (3) the connections between course content and the content that was previously taught or will be taught in the same subject area (vertical curriculum knowledge). PCK, as described by Shulman, includes an understanding of effective means of representing content to support student learning and student conceptions and misconceptions of various content areas. Since its introduction, PCK has been the focus of many studies in a range of subject areas including mathematics and science (Abell, 2007; Ball et al., 2008).

Mathematical Knowledge for Teaching

Shulman (1986, 1987) acknowledged that his conception of teacher knowledge was incomplete and called for the further development of a theoretical framework for content knowledge for teaching. Ball and colleagues (Ball et al., 2008) pursued this charge in the field of mathematics by developing a framework, which aligns with and elaborates upon Shulman's (1986) components of teacher knowledge, called Mathematical Knowledge for Teaching (MKT). MKT consists of two major domains: Subject Matter Knowledge and Pedagogical Content Knowledge (Table 1). PCK is further divided into *knowledge of content and students* and *knowledge of content and teaching*, which relate to the two main aspects of PCK as described by Shulman (student conceptions/misconceptions and representations). The third piece incorporated into PCK, *knowledge of content and curriculum*, corresponds to one aspect of Shulman's curricular knowledge, namely knowledge of curricular programs and instructional materials for teaching particular topics.

Subject Matter Knowledge is subdivided into three different components. Two components of Subject Matter Knowledge, *common content knowledge* and *specialized content knowledge*, differentiate between content knowledge not exclusive and exclusive to the profession of teaching mathematics, respectively. *Horizon content knowledge* parallels Shulman's (1986) vertical curriculum knowledge. Teachers' knowledge of the content being taught to students is necessary but not sufficient (Hill & Ball, 2009; Hill, Schilling, & Ball, 2004). Teachers also must be able to "unpack" or "decompress" (Ball et al., 2008, p. 400) mathematics content to perform the tasks of teaching. This more detailed breakdown of subject matter knowledge is a noteworthy contribution to the field of teacher knowledge in mathematics (Ball et al., 2008). 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).

Table 1. MKT Components of Subject Matter Pedagogical Content Knowledge (Ball et al., 2008)

Type of Knowledge	Definition	Example
Subject Matter Knowledge		
Common Content Knowledge	Mathematical knowledge that is not unique to the teaching discipline	Carry out the procedure for $23 \times 4 = 92$
Specialized Content Knowledge	Mathematical knowledge that is unique to the teaching discipline	Assess if a student's strategy of changing 23×4 to 46×2 to 92×1 is legitimate (and, if so, why), generalizable, and easier for a particular set of problems
Horizon Content Knowledge	Mathematical knowledge of the connections between topics at a particular grade level and the preceding and subsequent grade levels	Understand the connection between 23×4 and the distributive property (i.e., $23 \times 4 = (20 + 3) \times 4$) which also emerges later in the study of algebra (e.g., $(2x + 3)4$)

Table 1. Continued

Type of Knowledge	Definition	Example
Pedagogical Content Knowledge		
Knowledge of Content and Students	Mathematical knowledge of how students think about different content	Be familiar with common errors and when they will likely occur (e.g., 23 × 14 = 32 demonstrates a misconception that will not be apparent in the problem 23 × 4 = 92)
Knowledge of Content and Teaching	Mathematical knowledge of the pedagogical decisions that influence student learning	Determine the affordances and drawbacks of sequence of examples to build an understanding of the content (e.g., 21 × 3, 23 × 4, and then 23 × 14)
Knowledge of Content and Curriculum	Mathematical knowledge of the variety of curricular programs and instructional materials for teaching particular topics	Choose an appropriate representation and curricular resource (e.g., the area model for multiplication via nlvm.usu.edu)

Pedagogical Content Knowledge for Science Teaching

A corresponding framework was developed for the field of science. Advancing the work of Grossman (1990) and Tamir (1988), Magnusson, Krajcik, and Borko (1999) developed a framework to depict the components of Pedagogical Content Knowledge for Science Teaching (PCK for ST). Their framework consists of four primary components regarding teacher knowledge and beliefs about: (a) science curriculum, (b) student understanding of specific science topics, (c) assessment in science, and (d) instructional strategies for teaching science (Table 2).

The *science curriculum* component corresponds to Shulman's (1986) *curricular knowledge*. Magnusson et al. (1999) specifically identify all three components described by Schulman (curricular programs, vertical knowledge, and lateral knowledge), but embed them within PCK for ST. *Students' understanding of specific science topics* and *instructional strategies for teaching science* align with Shulman's *PCK* as it emphasizes the teacher's need to understand the requirements for students to be able to learn specific science content as well as the science content that students typically find difficult to learn. *Assessment in science* integrates Shulman's *content knowledge* with *PCK*; teachers must know the critical goals for student learning as well as how best to assess them.

The framework also includes a fifth overarching component regarding teacher orientations to teaching science, which shapes and is shaped by the aforementioned knowledge and beliefs components. Magnusson et al. (1999) present multiple orientations for teaching science that teachers could possess and describe the associated goals of each orientation along with the typical type of instruction that would be employed if a teacher held these orientations. Several examples are presented in Table 3.

Table 2. Components of Pedagogical Content Knowledge for Science Teaching (Magnusson et al., 1999)

Component	Definition	Example
Knowledge and Beliefs about Science Curriculum	Refers to teacher understanding of goals and objectives of the science curriculum (vertical and lateral alignment) as well as their knowledge of specific curricular programs and materials with which to teach to achieve those goals	Goals and objectives as described in national guidelines such as A Framework for K-12 Science Education (NRC, 2012), Benchmarks for Science Literacy (AAAS, 1993) FOSS Kits, BSCS, Project Wild, Project Learning Tree
Knowledge and Beliefs about Assessment in Science	Refers to teacher ability to identify the content that should be assessed and choose appropriate forms of assessment to measure student learning	A written test might be appropriate for measuring student ability to interpret graphs, but observational skills might be better measured with an assessment of lab journals or field notebooks
Knowledge and Beliefs about Instructional Strategies for Teaching Science	Refers to teacher ability to choose appropriate general teaching strategies within the domain of science (subject-specific) as well as specific topics within science (topic-specific)	Subject specific teaching strategies such as discovery learning or conceptual change-oriented instruction Topic specific teaching strategies such as representations (e.g., analogies) and/or activities (e.g., field work)

Although PCK for ST does not have a separate category for subject matter knowledge, Magnusson et al. emphasized that their components of PCK for ST are dependent on *strong* subject matter knowledge. The literature on teacher knowledge in science education (e.g., Abell, 2007; Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008) further supports this assertion about the relationship between PCK and subject matter knowledge. For instance, in her extensive literature review, Abell noted how teachers, who did not possess *strong* subject matter knowledge in science, were not successful in some of the tasks of teaching such as building upon student ideas, asking high-level questions, and identifying student misunderstandings. Unquestionably, teachers must have *strong*, *deep*, and *robust* subject matter knowledge to effectively teach so that students develop a conceptual understanding of the content (Abd-El-Khalick, 2013; Anderson & Kim, 2003; Loughran, Mulhall, & Berry, 2004).

Table 3. Possible Orientations to Science Teaching (Magnusson et al., 1999)

Orientation	Goals	Typical Instruction
Didactic	To transmit the facts of science to the learners	Teacher presents information to the students via lectures and/or discussion and questions students to determine if students know the facts
Discovery	Students will discover scientific concepts through exploration of the natural world	Students discover patterns in nature through self-guided exploration and the teacher ensures students come to accurate conclusions *(student-centered instruction)*
Inquiry	To present science as the process of inquiry as opposed to the knowledge generated by the process	Teacher provides materials and opportunity for students to explore phenomena; teacher guides the development of the question and the method of exploration *(investigation-centered instruction)*
Conceptual Change	To expose learners to contexts that challenge their misconceptions or expose their knowledge gaps	Students present their views/understandings of science concepts and then are challenged to support their views over alternative explanations; teacher facilitates the discussion to ensure students arrive at accurate explanations

Current Standards Documents in Mathematics and Science

Current guiding documents in the fields of mathematics and science education reflect the complexity of teacher knowledge (NCTM, 2014; NGA & CCSSO, 2010; NGSS Lead States, 2013). For example, the *Common Core State Standards in Mathematics* (*CCSSM*) (NGA & CCSSO, 2010) and NCTM's (2014) *Principles to Actions: Ensuring Mathematical Success for All* describe the depth of knowledge required for the effective teaching of mathematics. The *CCSSM* reflect three major shifts in mathematics (focus, coherence, and rigor) all of which require various aspects of MKT especially specialized content knowledge. The mathematics curriculum should *focus* on fewer topics with more depth. Further, *coherence* is established by making connections between various mathematical ideas within and across grades. Similarly, NCTM (2014) describes an excellent mathematics program as one that "includes a curriculum that develops important mathematics along coherent learning progressions and develops connections among areas of mathematical study and between mathematics and the real world" (p. 70). In order to implement such a curriculum, teachers need both lateral (or horizontal) and vertical curriculum knowledge (NCTM, 2014; Shulman, 1986). Lastly, *rigor* is achieved through the balanced treatment of conceptual understanding, procedural fluency, and the application of such knowledge. NCTM (2014) argues that too much time is currently spent on teaching procedures at the expense of conceptual understanding and application. In response to this unproductive practice, one of the eight Mathematics Teaching Practices, *Build procedural fluency from conceptual understanding*, states: "Effective teaching of mathematics builds fluency with procedures on a foundation of conceptual understanding so that students, over time, become skillful in using procedures flexibly as they solve contextual and mathematical problems" (NCTM, 2014, p. 10). Therefore, teachers need to have a conceptual understanding of the mathematics themselves so that they can provide learning opportunities for their students to develop this understanding and make connections between procedures, the concepts underlying them, and their application.

A similar shift in science teaching is revealed in the *Next Generation Science Standards* (NGSS Lead States, 2013). Teaching and learning science in the 21st century must reflect a move from the traditional form of teachers delivering disjointed and apparently unrelated factual content to their students who, in turn, commit to memory such facts via rote memorization. *NGSS* further recommends that science teachers guide students' use of science and engineering practices to explore core ideas of the science discipline and discover crosscutting concepts that connect science to other disciplines (Authors, 2015). This requires a much more sophisticated level of teacher knowledge. Rather than disseminating facts and terms, science instruction should focus on overarching core ideas rather than the facts used to exemplify them (Authors, 2014; NGSS Lead States, 2013). The complexity of teacher knowledge needed to effectively teach science is summed up in the National Research Council's *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning* (NRC, 2000):

> 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)

Along with these many elements of teacher content knowledge, the teacher should have knowledge of the science curriculum and students understanding of specific science topics. That is, the teacher should be aware of how the content (core ideas and facts) connects to what students have already learned and what they will learn at the next grade band in order to ensure coherence throughout the K-12 progression (NGSS Lead States, 2013).

Purpose

The purpose of the present study is to examine a cohort of PSTs' perspectives about the complex nature of teacher knowledge at the beginning and end of their first year in a TEP. The current standards documents emphasize the importance of conceptual understanding; linking mathematical procedures with the underlying concepts; and, in science, linking factual content to the crosscutting concepts that explain them (NCTM, 2014; NGSS Lead States, 2013). For the present study, procedural knowledge in mathematics and factual knowledge in science is referred to as recall knowledge, representative of the lowest level (remember) of the revised Bloom's taxonomy (Krathwohl, 2002). Recall knowledge is contrasted with the next level (understand) of the revised Bloom's taxonomy, denoted as conceptual knowledge. As such, this study addressed the question: How do PSTs' perspectives of recall knowledge and conceptual knowledge, two aspects of teacher content knowledge, differ at the beginning and end of their first year in a TEP?

Method†

Participants

The participants for this study consisted of 50 female PSTs concurrently enrolled in their mathematics and science methods courses at a private university in the southwest United States. These courses are required during the first year of the TEP, which typically occurs during the PSTs' junior year at the university. During this year, the PSTs took other content area methods courses as well as educational psychology and participated in field placements involving observation and teaching. The participants were equally divided into two separate class sections. With the exception of three students, all were between ages 20 and 22.

Preservice Elementary Teachers' Science and Mathematics Activity (PETSMA)

To elicit the PSTs' perspectives about recall and conceptual knowledge in mathematics and science, the researchers designed an activity, the PETSMA (Authors, 2014). The PETSMA consists of two mathematics and two science content questions per grade-level (K–6) representing a variety of content areas within each discipline (Table 4). The two questions for each subject are based on the same content area with the first question representing recall knowledge and the second question representing conceptual knowledge.

Table 4. PETSMA Mathematics and Science Content by Grade Level

Grade	Mathematics Content	Science Content
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

The researchers selected the recall questions from state-approved textbooks (Baptiste et al., 2000; Biggs, Daniel, Feather, Snyder, & Zike, 2002; Charles et al., 2009; Lappan, Friel, Fey, & Phillips, 2009) and created the corresponding

† We certify that we have complied with APA ethical principles regarding research with human participants in the conduct of the research presented in this manuscript.

conceptual questions. The researchers used the revised Bloom's taxonomy (Krathwohl, 2002) to assess the type of knowledge targeted by the questions; each of the recall questions was categorized as *remembering* and each conceptual question as *understanding*. For each question, the PSTs indicated, via a Likert scale, their level of confidence in (a) answering the question and (b) their ability to teach the content associated with the question. An example of mathematics and science questions (for fifth grade) is provided in Figure 1.

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

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?

____

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 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.

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. PETSMA Fifth grade mathematics and science questions.

Procedure

At the beginning of the fall semester, all PSTs individually completed the PETSMA. The researchers informed the PSTs that the purpose of the PETSMA was not to evaluate their content knowledge. Instead, the PETMSA was designed to elicit critical thinking regarding knowledge for teaching and the differences between recall and conceptual knowledge. Additionally, the activity was intended to serve as a basis for subsequent focus group discussion. The PSTs completed the PETSMA in approximately 30 minutes. Immediately following, the PSTs discussed the activity for 15 minutes in small groups. The PSTs were arranged at six tables in groups of four to five students. The instructor of the science methods course, one of the researchers, then used a topic guide to facilitate an hour-long focus group discussion with all of the students in each of the class sections (McMillan, 2012). The instructor used the same procedure (activity completion, small-group discussions, and focus group discussions) at the end of the spring semester with each class section. The resulting four focus group discussions (two pre and two post for each section of the course) provide the data that inform the present paper.

Data Analysis

The pre- and post-focus group discussions for both sections of the course were video recorded and transcribed, and pseudonyms were assigned to all participants. One researcher, the first author, coded the transcriptions using the constant comparative method (Glaser & Strauss, 1967). First, the transcriptions were read while watching the video recordings to isolate data units. All data units were coded, reshuffled, and re-coded to insure consistency in interpretation. The finalized codes were then organized into overarching themes. This process was completed separately for the pre- and post-focus group discussions. The coding of the aggregated data from the two initial focus group discussions resulted in174 data units, 20 distinct codes, and four themes. For the aggregated data from the two final focus group discussions, there were 266 data units, 26 codes, and four themes (Appendix). After coding both pre- and post-focus group discussions, the researcher identified a noteworthy distinction in the comments of the PSTs regarding their perspectives of content knowledge - that of a student and that of a teacher. To establish credibility, the researcher met with a critical friend, the second author, to engage in peer debriefing (Creswell, 2009). After confirming the aforementioned distinction, a second layer of analysis was conducted. Each data unit was classified as student perspective, teacher perspective, or neither. This distinction in perspectives is used to frame the organization of the findings.

Findings

Initial Discussions

The initial discussions consisted of 20 distinct codes organized into four themes: *recalling their education*, *importance of understanding why*, *knowledge building*, and *preparation and study*. Additionally, within each theme, all data units were classified as *student perspective* about content knowledge, *teacher perspective* about content knowledge, or neither (Table A1). Data units that were classified as neither tended to be specific to the PETSMA: "For the fourth grade math questions, the second question, it's almost like… you're looking for what's wrong with the graph. It's a different style of question. Instead of trying to figure something out, you're looking to see what's wrong" (Beth). For the 174 data units from the initial discussions, 107 data units (61.5%) were classified as being from a student perspective, 22 (12.6%) were from a teacher perspective, and 45 (25.9%) were neither. When considering the codes, 12 codes aligned with student perspective, 8 codes aligned with teacher perspective and 2 codes were neither. (The data units within two of the codes were divided between student perspective and teacher perspective.) Refer to Table A2for a detailed alignment of themes and codes with respect to the student/teacher perspective classification. The following two sections elaborate on the views of the PSTs with respect to the student perspective and teacher perspective at the time of the initial focus group discussions.

Student perspective. When asked to share their thoughts regarding the PETSMA, many of the PSTs recalled previous learning experience. However, these previous learning experiences were largely limited to situations in which the PSTs were in the student role.

> 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 the names. In math, it was just like, we're not going to explain it to you because this is the way you do it and that's it. There's no other way, so do it this way and follow this formula and you'll be fine. (Rose)

While Rose's comment draws attention to the different teaching approaches she observed for the two subjects, she did not mention how she would approach teaching mathematics and science once she became a classroom teacher. This trend was common amongst the PSTs. They were eager to recall and share the teaching techniques they observed over the years; however, very few openly considered how they would approach teaching the content.

In discussing the difference between recall knowledge and conceptual knowledge, many of the PSTs held the misconception that mathematics was strictly recall, while science tended to be more conceptual. The PETSMA required students to explain the logic underlying certain mathematical procedures (e.g., determining a common denominator before adding fractions). As such, many of the PSTs expressed frustration with respect to their lack of conceptual mathematics content knowledge.

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

While Paige's comment describes the perceived simplicity in performing mathematical procedures, it also exemplifies the difficulty in understanding content conceptually.

While the PSTs had difficulty articulating mathematics procedures conceptually they noted the manner in which mathematics content builds upon previous topics. However, the PSTs failed to recognize such connections between concepts in science: "Yes, it's all of related [mathematics content], whereas science is different topics under one subject." (Vera). Gwen elaborated on Vera's comment by discussing the nature of mathematics content compared to the nature of science content.

> We talked about, for math, you build off of simple concepts and you just keep building, so you always remember how to do it. Everything builds on adding, so you just remember. With science, there are so many different topics, you are not consistently reminded. I do subtraction every day, but science. You do not name muscles every day, because you do not build off those concepts. (Gwen)

Based on this, and other similar comments, the PSTs appeared to view the nature of mathematics content to be very different from the nature of science content. Mathematics was described as requiring constant reinforcement of earlier content. Conversely, science was described as being very discrete, with a plethora of isolated disciplines all classified as science. As students, the PSTs had developed a limited understanding of both science and mathematics.

In addition to having an incomplete perspective with regard to the nature of mathematics and science content, the PSTs also had misconceptions about the purpose of the PETSMA. Prior to beginning the activity, the facilitator explained that the PETSMA was not a graded assignment. Yet, many PSTs still expressed concern over how their performance on the activity would be judged: "If I had the material for an hour, I would have known all of it." (Violet). Violet expressed both a desire to achieve the correct answers, and a notion regarding the importance of preparation and study as it relates to student performance. As students, the PSTs frequently used independent preparation and study skills to develop understanding of content in order to answer questions: "If I had been able to review it before, I could come up with a logical reason why that works." (Zoe). However, few PSTs elaborated on the difference between recall and conceptual mathematics/science content knowledge.

Teacher perspective. After some discussion regarding the differences between recall and conceptual knowledge, the instructor inquired how the PSTs would explain the reasoning behind certain scientific phenomena (e.g., the relationship between the Earth's tilt and seasons). The PSTs grew quiet, until one PST reluctantly spoke: "Reasons behind why we do certain things…if I was having to teach a child, I don't have the vocabulary to…you just take that for granted…it's kind of like going back to the basics" (Mia). Mia expressed concern over an inability to teach topics she learned long ago. Mia's comment reflected her thoughts about her future practice, but she made no reference to actual teaching experiences. In fact, only one PST commented about a teaching experience.

> I tutored for ninth grade [State standardized exam] and… some of those kids that come in from the previous grades haven't mastered [previous content objectives], so you have to be able to teach them…some kids that I was tutoring in ninth grade didn't know how to multiply. (Mandy)

Mandy's reflection on her tutoring experience allowed her to note the importance of *horizon content knowledge* for mathematics teachers (Ball et al., 2008). In other words, Mandy noted that mathematics teachers must not only know the content they are expected to teach; they also need a strong understanding of content in the prior and subsequent grade levels.

The initial focus group data units primarily revealed student perspectives. Two themes, the *importance of understanding why* and *knowledge building*, crossed both student and teacher perspectives. However, the other two themes, *recalling their education* and *preparation and study* were comprised almost entirely of data units from the student perspective (Table A2). This trend changed in the final focus group discussions.

Final Focus Group Discussions

The final focus group discussions consisted of 266 data units. The data units separated into 26 distinct codes, which were organized into four themes: *desire to learn more*, *understanding concepts*, *becoming a teacher*, and *content knowledge*. Of the 266 data units, 103 (38.7%) were classified as being from the student perspective, 115 (43.2%) were from the teacher perspective, and 48 (18.1%) were neither (Table A1). With respect to the codes, 10 were associated with a student perspective, 14were associated with a teacher perspective, and three were neither. One code, understanding concepts, included data units representing both the student and teacher perspective. Table A3 details how the themes and codes related to the student/teacher perspective classification. The following two sections elaborate on the views of the PSTs with respect to the student perspective and teacher perspective at the time of the final focus group discussions.

Student perspective. During the final focus group discussions, the PSTs still made comments demonstrating their student perspectives about content knowledge. They were quick to recollect previous educational experiences and conveyed apprehensions about their educational backgrounds. "And that is 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" (Shanna). Shanna expressed concern that, while she could recall many scientific facts, she did not believe she had a thorough conceptual understanding. Other PSTs had similar trepidations over their lack of content knowledge. For example, one PST described her apprehension regarding an upcoming exam: "I just wish we had another science class before we had to take the test on science stuff" (Rita). Rita's and Shanna's comments reveal their developing understanding that knowledge for teaching extends beyond recall and includes a conceptual understanding which they felt they lacked.

In addition to discussing a desire to learn more, the PSTs considered how frequently they used content knowledge in their daily lives. In particular, the PSTs noted that science recall knowledge (e.g., vocabulary) was seldom utilized, but underlying concepts were ever present in their environment.

> It's easier to know the concept in science than to know the specific information [vocabulary]. At least for me, because I don't know a lot about science and knowing about the plants and how they make food, yeah I get that, but if I haven't looked at the words in the past year, I'm not going to know it. (Mandy)

Mandy recognizes the importance of understanding photosynthesis at a conceptual level, but admits that she would need to review the related recall knowledge. Later in the conversation, Mandy reiterates this idea with respect to both mathematics and science: "[mathematics and science] have a lot of big broad concepts that have vocabulary underneath them you can learn, but you need to understand the broad ideas" (Mandy). Her comment demonstrates a clear shift from the perspective expressed during the initial focus group discussions that mathematics content knowledge is recall in nature and science is conceptual. During the final focus group discussions, the PSTs demonstrated a more nuanced understanding of mathematics and science content knowledge.

Teacher perspective. Just as concerns about content knowledge were expressed from a student perspective, the PSTs also made comments about content knowledge from a teacher perspective. Such comments generally involved taking the onus upon themselves to develop teacher knowledge.

> We know some of the 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. (Barbara)

The PSTs recognized the importance of content knowledge in teaching. When expressing insecurities with respect to their teacher knowledge, they openly discussed the role of research and preparation for instruction. Moreover, they communicated a commitment to take responsibility for learning all aspects of teacher knowledge, recall and conceptual, prior to teaching a lesson.

A critical need for teaching mathematics and science is the ability to differentiate between the various subdomains of content knowledge. In the present study, the PSTs were able to distinguish between two of the subdomains highlighted by the PETSMA: recall and conceptual understanding. In the final focus group discussions, the PSTs articulated the differences in their perspectives about learning within each of these two subdomains.

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

Vera acknowledged the importance of having a strong conceptual understanding of content. Reviewing recall content knowledge prior to teaching a lesson is more feasible than needing to review or learn the concepts. The PSTs also acknowledged the importance that teachers understand how students learn. While discussing science content, Shanna commented: "You have to be equipped to know how students think about big ideas in science and how students are going to learn them." The PSTs recognized that knowledge for teaching included recall and conceptual understanding, as well as knowledge of how students think about various content areas.

Furthermore, Vera's quote about science content demonstrates an awareness of the distinction between recall and conceptual understanding. The PSTs similarly showed evidence of recognizing this distinction with regard to mathematics content. "I think understanding the why [conceptual understanding] makes it easier to teach, but even if we do not understand the why as well, we can do it [recall understanding] but it's a lot harder to teach" (Paige). While the PSTs recognized that teacher knowledge requires both recall and conceptual understanding, they also realized the importance of teaching their future students from a conceptual standpoint. "It just seems like [our professors] have so much time to ask those deep questions and really get kids thinking, but I feel like when you are an actual teacher, you have to be conscious with your time management" (Helen). Helen expressed a desire to support students in developing a conceptual understanding of content, but acknowledged the conflicts between personal teaching goals and curricular expectations.

Discussions of the types of knowledge necessary for teaching gradually became discussions of the types of lessons and activities the PSTs hoped to implement in their future classrooms. While the PSTs still focused on citing observed examples of other teachers, the context of the comments had changed. The PSTs no longer described themselves as students in a classroom; they discussed how their observations informed their future practice. Carol contrasted between two different observations of the same content material; one in which the teacher utilized a didactic approach, and the other in which the teacher used an inquiry approach.

> [The students] were still learning a lot, they were just talking to each other and doing a lot of hands-on [activities], and the other classroom … all [the teacher] had was worksheets, so I think you can take the curriculum for math, science, or anything and use [pedagogical approaches] we are learning here. (Carol)

Carol, as well as other PSTs, expressed a desire to utilize pedagogical approaches designed to engage students. "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). Observing the techniques discussed in the TEP encouraged Vera to use hands-on activities. In addition to considering the types of teachers they hoped to become, the PSTs noted challenges facing many inservice teachers. "I would like to [use inquiry and problem-based learning] in certain situations, but it depends on the school, and the principal, and what we are asked to do" (Colleen).The final focus group discussions regarding the PETSMA documented a transition toward understanding the complexity of science and mathematics content knowledge for teaching and the means for conveying such knowledge.

Discussion

The analysis of the initial and final focus group discussions demonstrates the profound changes that occurred after one academic year in a TEP. The study was not designed to speculate about the factors affecting such changes; however, the PSTs demonstrated a shift in their understanding of science and mathematics content knowledge by integrating the perspective of a future teacher into their prior schema that had been dominated by a student perspective.

Specifically, Figure 2 depicts this transition. For the initial focus group discussions, 61.5% of data units represented student perspectives; and 12.6% of data units represented teacher perspectives. In contrast, during the final focus groups, the perspectives had shifted with 38.7% of data units representing student perspectives and 43.2%

representing teacher perspectives. Thus, from the beginning to the end of the academic year, the percentage of student perspective data units dropped 22.8%, and the percentage of teacher perspective data units more than tripled

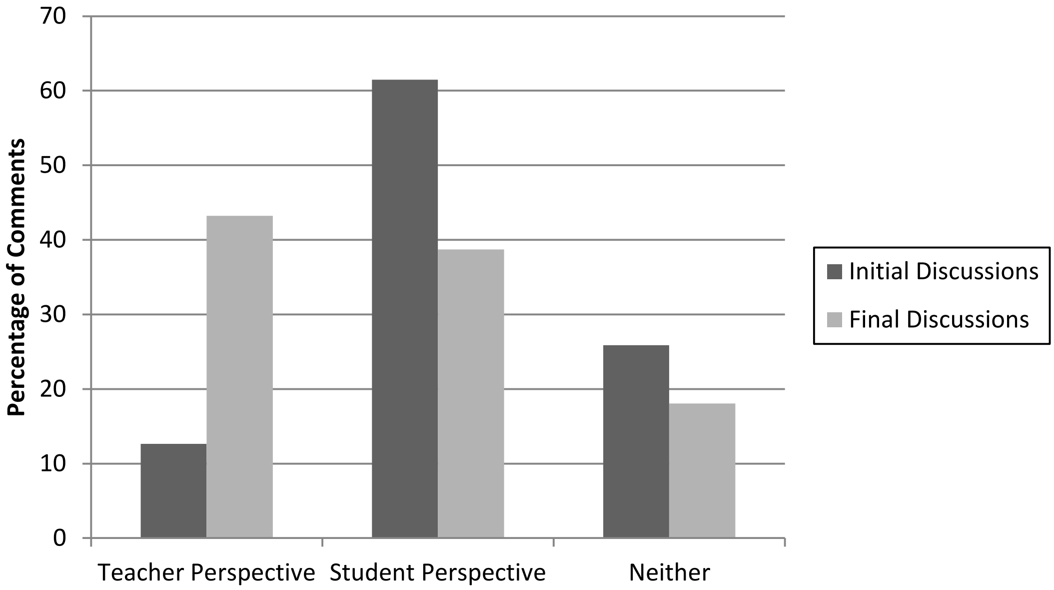

Figure 2. Bar graph representing the percentage of comments from the initial and final focus group discussions classified as teacher perspective, student perspective, or neither.

In addition to the quantitative change, the qualitative analysis displayed noteworthy transitions in four distinct areas: 1) content knowledge, 2) learning experiences, 3) the nature of mathematics and science, and 4) preparation and study. In the context of the present study, *content knowledge* refers to the PSTs' understanding of two subdomains of mathematics and science content knowledge (i.e., recall and conceptual) and the role of these subdomains in teaching mathematics and science. The area of *learning experiences* corresponds to how the PSTs' classroom experiences and observations lead them to perceive mathematics and science content, both as students and as future teachers. Making such connections enabled PSTs to reflect upon *the nature of mathematics and science* in order to cultivate better learning experiences. Lastly, *preparation and study* references the PSTs' expressed desire to learn more mathematics/science content (both recall and conceptual) and the function of preparation and study in the teaching profession.

Students are often required to demonstrate an understanding of mathematics and science content. However, for PSTs, the nature of content knowledge expands to include multiple domains of knowledge (Ball, 1988; Ball et al., 2008; Feiman-Nemer & Buchman, 1985; Hill & Ball, 2009; Magnusson et al., 1999; Shulman, 1986, 1987). During the initial focus group discussions, many of the PSTs were not aware of the importance of conceptual mathematics knowledge, claiming that mathematics is recall in nature and placing importance on solely attaining the answer to a question. In science, the PSTs expressed tension because they were unaware of many science vocabulary terms (e.g., recall knowledge). In contrast, during the final focus group discussions, many of the PSTs described conceptual understanding as more important for teaching than recall knowledge for both mathematics and science, and their orientation for teaching deviated from a didactic approach (Ball, 1988; Ball et al., 2008; Magnusson et al., 1999). Conceptual knowledge is a fundamental component in building specialized content knowledge. The transition that occurred among the PSTs during the academic year included an expansion of their understanding of the types of content knowledge necessary for teaching.

Furthermore, the initial discussions revealed that many of the PSTs had never considered themselves as *a teacher*. At the time of the initial discussions, only one of the PSTs, who was a tutor, had any formal teaching experience. Thus, the majority of the PSTs' comments regarding the nature of learning stemmed from their experiences as students. The PSTs' desire to become teachers and enter a TEP is based on perceptions of teaching from learning experiences as students. Therefore, the PSTs entered the TEP with preconceived notions of the nature of teacher knowledge. The various learning experiences that occurred, between the initial and final discussions, helped to alter the PSTs' conceptions of themselves as teachers and initiated reflection upon the multiple facets of teacher content knowledge. In particular, the teacher observations were cited as being highly influential on their prospective teaching goals. However, the PSTs also noted concerns about balancing personal teaching goals with cultural expectations. During the final discussions, the PSTs made note of their uncertainties regarding the ability to maintain the pedagogical philosophies adopted during their studies in the TEP. The PSTs recognized the importance of guiding students to build procedural fluency from conceptual understanding (NCTM, 2014), however, they noted that this was not they were witnessing in their observations. Over the course of a year in the TEP, the PSTs progressed along the continuum from thinking like a student to thinking like a teacher (Author, 2016; Sutherland, Howard, & Markauskaite, 2010).

In addition to recognizing the expectations and issues facing in-service teachers, the PSTs developed more profound understandings of the nature of mathematics and science learning. During the initial discussions, the PSTs noted that mathematics content regularly builds upon prior knowledge and described science content as being discrete pieces of information pulled from various fields. As students, the PSTs were able to appreciate the importance of understanding one mathematics idea (e.g., finding a common denominator) before learning a new mathematics idea (e.g., adding fractions). However, the PSTs described science as disconnected areas of study in which topics could be viewed distinctly (e.g., learning about photosynthesis did not apply to understanding heat transference). During the final discussions, the PSTs emphasized the importance in understanding the underlying concepts and interrelation of content (e.g., why common denominators are necessary when adding fractions and what role heat transference plays in photosynthesis) (Ma, 1999; NGSS Lead States, 2013). Interestingly, by the end of the academic year, the PSTs noted the importance of conceptually understanding mathematics and science content from both the teacher and student perspectives.

At the time of the initial focus group discussions, the PSTs were comfortable adhering to their traditional role of student. While the themes of the initial discussions centered on knowledge and learning, the comments modeled the thoughts and concerns associated with a student culture. For example, the PSTs were concerned with getting correct answers and whether they would be judged or graded on the results of the activity. Specifically, the PSTs desired time to study the material in order to perform better on the PETSMA. In the final focus group discussions, the prominent themes still addressed content knowledge, but the comments involved knowledge for teaching and professional development. While the PSTs still desired the correct answers, the objectives of such desires were centered on improving knowledge for teaching (Author, 2016).

The balance of *student perspective* and *teacher perspective* data units in the final discussions illustrates the *two-worlds pitfall* in which PSTs are attempting to reconcile differences between the expectations of two distinct cultures (Feiman-Nemser & Buchman, 1985). TEPs serve to aid PSTs in developing content knowledge for teaching. During the final focus group discussions, the PSTs approached the classroom observations as both *students learning content* and *teachers learning pedagogy*. This dichotomy demonstrates that their understanding of the roles and knowledge needs of teachers were still developing. Moreover, the PSTs exhibited a richer student perspective and deeper understandings regarding the nature of mathematics and science learning. Hypothesizing as to why the PSTs underwent such significant changes is not in the scope of this study. However, the examination of the focus group discussions does display a significant transformation in the PSTs understanding of the complex nature of teacher knowledge.

Conclusion

Teacher education is a unique field in that it encompasses both content and pedagogical knowledge. In order to appropriately prepare PSTs for the rigors of their future careers, TEPs must construct environments that expose PSTs to the complexity of teacher content knowledge and provide the support to help PSTs develop the various aspects of such knowledge. The research presented in this study outlines four areas of profound change PSTs' perspectives of teacher knowledge over one academic year (i.e., content knowledge, learning experiences, nature of mathematics and science, and preparation and study). Teacher educators may utilize these four areas to create reflective exercises that encourage the development of mathematics and science content knowledge for teaching. By developing methods course activities that require PSTs to contemplate their new roles as future mathematics/science teachers, teacher educators can draw attention to aspects of teacher knowledge not previously considered by PSTs and openly address such complexities in a safe environment. Furthermore, future research can examine such practices in an effort to determine which factors are most beneficial to PSTs' awareness and development of the multifaceted nature of teacher knowledge.

For students newly entering a TEP, the changes in expectations can be surprising. For the PSTs in the present study, comparison of the initial and final focus group discussions revealed changes in their perceptions of content knowledge for teaching. Teacher educators must be conscious of the nature of such changes in order to better support this transformation.

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Appendix

Data Analysis

Table A1. Number of Data Units by Theme for the Initial and Final Discussions

Initial Discussions' Themes	Teacher Perspective	Student Perspective	Neither
Recalling their education	1	28	
Importance of understanding why	10	28	
Knowledge building	6	29	
Preparation and study	5	22	
Specific questions on the PETSMA			28
Types of questions on the PETSMA			17
Final Discussions' Themes	**Teacher Perspective**	**Student Perspective**	**Neither**
Desire to learn more	23	27	
Understanding concepts	17	53	
Becoming a teacher	56		
Content knowledge	19	23	
Specific questions on the PETSMA			6
Types of questions on the PETSMA			15
Listing big ideas in mathematics and science			27

Table A2. Categorization of Codes within Themes from the Initial Discussions

	Recalling their education	Importance of understanding why	Knowledge Building	Preparation and study
Student Perspective	Recalling education (8 data units) Usefulness of information (6 data units) Definite answer (14 data units)	Understanding why (13 data units) Open-ended questions (15 data units)	Foundational knowledge (12 data units) Systems (8 data units) Big ideas (5 data units) Connections (4 data units)	Preparation and study (9 data units) Difficulty (10 data units) Vocabulary (3 data units)
Teacher Perspective	Teaching approaches (1 data unit)	Understanding logic and reasoning (4 data units) Common knowledge (3 data units) Open-ended questions (3 data units)	Students' prior knowledge (1 data unit) Connecting content (1 data unit) Knowledge building (4 data units)	Preparation and study (5 data units)

Table A3. Categorization of Codes within Themes from the Final Discussions

	Desire to learn more	Understanding concepts	Becoming a teacher	Content knowledge
Student Perspective	Desire to learn more (11 data units) Misconceptions (10 data units) Complexity of problems (6 data units)	Experiences that helped them learn (7 data units) Understanding concepts (27 data units) Overlap of math and science (14 data units) Critical thinking (5 data units)		Desire to know the correct answer (9 data units) Usefulness of information (7 data units) Memorization (7 data units)
Teacher Perspective	Uncertainty of accuracy to teach (6 data units) Preparation and study (11 data units) Learning to teach through experience (6 data units)	Inquiry teaching (4 data units) Understanding concepts (13 data units)	Observations (16 data units) Confidence in becoming a teacher (10 data units) Teaching theory versus practices (4 data units) Pedagogical approaches (11 data units) Classroom goals (3 data units) Concerns about teaching practices (9 data units) Teaching experiences (3 data units)	Knowledge for teaching (6 data units) Role of content knowledge in teaching (13 data units)