A Structural Model of Elementary Teachers' Knowledge, Beliefs, and Practices for Next Generation Science Teaching

Katahdin Abigail Cook Whitt

Wright State University

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A STRUCTURAL MODEL OF ELEMENTARY TEACHERS’ KNOWLEDGE, BELIEFS, AND PRACTICES FOR NEXT GENERATION SCIENCE TEACHING

A dissertation to be submitted in partial fulfillment of the requirements for the degree of Doctor of Education

By

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ABSTRACT


The publication of the National Research Council’s *Framework for K-12 Science Education* (2012) and the *Next Generation Science Standards* (NGSS Lead States, 2013) marked a turning point in science education characterized by a shift away from the idea that students should *learn about* a set of science facts and toward the idea that students should *figure out* core science ideas by solving problems and making sense of phenomena. To successfully realize the vision for science education that was articulated in the reform documents, teachers’ science classroom practices will need to change, particularly at the elementary level. Science education research has suggested that teachers’ science subject matter knowledge, topic specific professional knowledge, and beliefs about effective science instruction may impact teachers’ implementation of classroom practices consistent with the reforms.

The goal of this causal structural analysis using an ex post facto research design was to empirically test a proposed conceptual model for teachers’ knowledge, beliefs, and practices and to examine the direct and indirect effects of science subject matter knowledge, topic specific professional knowledge, and beliefs about effective science instruction on teachers’ implementation of science classroom practices consistent with the reforms. The sample for this study consisted of 731 elementary teachers who were surveyed as part of the 2012 National Survey of Science and Mathematics Education.
Structural equation modeling was used to test the overall model structure, the amount of variance in science classroom practices that could be explained by the model, and the direct and indirect effects of science subject matter knowledge, topic specific professional knowledge, and beliefs about effective science instruction on science classroom practices. Results from analyses supported the conclusion that science subject matter knowledge, topic specific professional knowledge, and beliefs about effective science instruction work together to impact science classroom practices. Furthermore, science subject matter knowledge and topic specific professional knowledge emerged as particularly important variables in the model.

To support elementary teachers in implementing classroom practices consistent with the reforms, pre-service and in-service professional learning experiences need to focus attention on developing elementary teachers’ science subject matter knowledge in combination with topic specific professional knowledge. Recommendations for future research include creating and utilizing instruments to measure teachers’ three dimensional beliefs about effective science instruction, further testing and revising the conceptual model for teachers’ knowledge, beliefs, and practices, and investigating strategies to improve elementary teachers’ science subject matter knowledge and topic specific professional knowledge.
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DEDICATION

Dedicated to my students—

past, present, and future.

You are my inspiration and my motivation.
CHAPTER 1: INTRODUCTION

In July 2011, the National Research Council issued a report entitled *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, which will herein be referred to as the Framework (National Research Council, 2012). The authors of the Framework (National Research Council, 2012) articulated a new vision for K-12 science education and advocated for a departure from traditional approaches to science teaching and learning. Central to the new vision was the recommendation that science education should be built around three major dimensions: (a) science and engineering practices, (b) disciplinary core ideas, and (c) crosscutting concepts. The key components of each dimension are listed in Table 1.

The Framework (National Research Council, 2012) included a broad set of expectations that were intended to guide the development of next generation standards for K-12 science education. Based on the guidance from the Framework (National Research Council, 2012), the *Next Generation Science Standards: For States, By States* (NGSS Lead States, 2013), which will herein be referred to as the NGSS, were drafted and released. The standards in the NGSS were written as performance expectations for students in kindergarten through twelfth grade. Each performance expectation combined a science and engineering practice with a disciplinary core idea and a crosscutting concept. The performance expectations were grouped into four core science disciplines: (a) physical science, (b) life science, (c) Earth and space science, and (d) engineering. Together, the performance expectations were designed to help students coherently build scientific understanding across disciplines and grade levels (NGSS Lead States, 2013).
Table 1

*Components of the Three Dimensions of the NGSS*

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<th>Dimension</th>
<th>Overview</th>
<th>Components</th>
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| Science and Engineering    | The practices in which scientists and engineers regularly engage as they  | Asking questions and defining problems  
| Practices                   | investigate and build models and theories                                | Developing and using models  
|                            |                                                                          | Planning and carrying out investigations  
|                            |                                                                          | Analyzing and interpreting data  
|                            |                                                                          | Using mathematics and computational thinking  
|                            |                                                                          | Constructing explanations and designing solutions  
|                            |                                                                          | Engaging in argument from evidence  
| Disciplinary Core Ideas    | The core ideas in four disciplinary areas of science                     | Physical Sciences  
|                            |                                                                          | Life Sciences  
|                            |                                                                          | Earth and Space Sciences  
|                            |                                                                          | Engineering, Technology, and Applications of Science  
| Crosscutting Concepts      | The concepts that unify the study of science and engineering across      | Patterns  
|                            | disciplinary areas                                                       | Cause and effect  
|                            |                                                                          | Scale, proportion, and quantity  
|                            |                                                                          | Systems and system models  
|                            |                                                                          | Energy and matter  
|                            |                                                                          | Structure and function  
|                            |                                                                          | Stability and change  

Taken together, the release of the Framework (National Research Council, 2012) and the NGSS marked an important paradigm shift in the field of science education.

Kuhn (1996) characterized a paradigm as a way of thinking about and explaining phenomena. Educational paradigms drive what is studied, the interpretation of data, and educational practice. The shift in science education was from a paradigm characterized by the view that science is a set of facts that students should *learn about* to a paradigm characterized by the view that science is comprised of core ideas and concepts that students should *figure out*. 

2
The paradigm in which students *learn about* a set of science facts will be referred to herein as the *traditional paradigm*. Teaching and learning within the traditional paradigm is generally teacher-centered. Typical learning experiences include teacher presentation of material, student memorization of facts, and lab activities designed to reinforce concepts that students have previously learned. Key science and engineering practices and core disciplinary ideas are often considered to be separate entities and are thus taught and assessed separately. For instance, designing and conducting an investigation would be taught as a stand-alone unit rather than being integrated into units that also address core disciplinary ideas. Science standards published prior to the NGSS often reinforced teaching and learning consistent with the traditional paradigm by presenting science and engineering practices and core disciplinary ideas separately (National Research Council, 1996, 2008).

The paradigm in which students *figure out* core science ideas by engaging in science learning at the nexus of the three major dimensions of science will be referred to herein as the *three dimensional* paradigm. In three dimensional teaching and learning, students engage in science and engineering practices to explore the disciplinary core ideas of each scientific discipline and make sense of the ways by which ideas connect across disciplinary areas. Teaching and learning within the three dimensional paradigm is generally student-centered. Typical learning experiences involve students actively building and revising their scientific understanding through reasoning and sense-making about phenomena. The key characteristics of the three dimensional paradigm were outlined in the Framework (National Research Council, 2012) and the NGSS.
The traditional and three dimensional paradigms are fundamentally different in that the traditional paradigm separates science practices from core science ideas whereas the three dimensional paradigm is situated at the nexus of the three dimensions of science education (National Research Council, 1996, 2008; NGSS Lead States, 2013). Furthermore, in the three dimensional paradigm an emphasis is placed on the importance of sense-making and reasoning about phenomena. By situating science learning at the nexus of the three dimensions and by emphasizing the importance of sense-making and reasoning about phenomena, the authors of the Framework (National Research Council, 2012) and the NGSS promoted a constructivist approach to science teaching and learning. The shift to constructivist pedagogy was a departure from previous approaches to science teaching and learning, which were generally teacher-centered.

In order to realize the vision for science teaching and learning that was articulated by the authors of the Framework (National Research Council, 2012) and the NGSS, K-12 science teachers in states that have adopted the NGSS must transition to three dimensional classroom practices. The transition to three dimensional classroom practices is particularly important at the elementary level because the performance expectations in the NGSS were designed to build progressively and coherently across grade levels. Building a strong foundation at the elementary level is essential for students’ continued success in middle school and high school. Because the pedagogical shifts called for by the Framework (National Research Council, 2012) and the NGSS are so significant, teachers must be supported through the process of developing the knowledge and skills necessary to change their classroom practices.
Identifying variables related to elementary teachers’ implementation of three-dimensional classroom practices can help focus and guide professional learning experiences for both pre-service and in-service teachers. Several variables have already been identified as important predictors of teachers’ implementation of three-dimensional classroom practices (Banilower, Heck, & Weiss, 2007; Jetty, 2015; A. A. Smith, Banilower, Nelson, & Smith, 2013; Weiss, Pasley, Smith, Banilower, & Heck, 2003). Most of the variables, however, are very difficult or impossible to change through pre-service teacher education or in-service professional development. Such variables include: the size of the school, the location of the school, the quality of resources available for science instruction, per-pupil expenditures, principal support, professional autonomy of teachers, the percent of students classified as limited English proficient, and prior student achievement (Banilower et al., 2007; Jetty, 2015; A. A. Smith et al., 2013; Weiss et al., 2003). The remaining variables could change as a result of professional learning opportunities. These variables include teachers’ science subject matter knowledge (SMK), pedagogical content knowledge (PCK), and beliefs about effective science instruction (Banilower et al., 2007; A. A. Smith et al., 2013; Weiss et al., 2003). Science SMK is the knowledge of the subject or topic in science whereas PCK is the knowledge needed to teach a particular subject or topic in science. The beliefs about effective science instruction construct refers to teachers’ opinions regarding three-dimensional teaching and learning and the importance of developing students’ conceptual understanding of science.

Relationships among teachers’ SMK, PCK, beliefs about effective science instruction, and classroom practices have been frequently explored in the literature base,
but not in the context of three dimensional reforms (Abell, 2007; Jones & Carter, 2007; Jones & Leagon, 2014; van Driel, Berry, & Meirink, 2014). Given the likely relationships among teachers’ SMK, PCK, beliefs about effective science instruction, and classroom practices, in combination with the potential to impact change in these components of teachers’ knowledge through professional learning experiences, it becomes clear that changing elementary teachers’ SMK, PCK, and beliefs about effective science instruction could be instrumental in promoting shifts in teachers’ implementation of three dimensional classroom practices. The purpose of the present investigation was to examine the relationships among elementary teachers’ SMK, PCK, beliefs about effective science instruction, and classroom practices in the context of the three dimensional paradigm for science teaching and learning.

**Conceptual Framework**

Teachers’ science subject matter knowledge (SMK), pedagogical content knowledge (PCK), beliefs about effective science instruction, and classroom practices have been an area of interest since Shulman (1986, 1987) proposed the idea of PCK. Shulman (1986, 1987) suggested that PCK was a specialized form of content knowledge specific to teaching that included knowledge of how students learn science ideas and instructional strategies that can support student learning. Since the initial proposal of PCK, researchers have revised, modified, and built upon the ideas presented by Shulman (1986, 1987). Although multiple variations on PCK models have been proposed (Abell, 2007; Grossman, 1990; Magnusson, Krajcik, & Borko, 1999; Park & Oliver, 2008; Shulman, 1986, 1987), researchers have not agreed on a common conceptual model to guide PCK research in science education (Gess-Newsome, 2015; Kind, 2015). In 2012, a
group of researchers interested in science teacher knowledge gathered for a PCK research summit (Carlson, Stokes, Helms, Gess-Newsome, & Gardner, 2015). One of the major outcomes was the development of a consensus model for science teacher knowledge, classroom practice, and student outcomes. The model, which will herein be referred to as the consensus model, can be found in Figure 1. Although the consensus model has yet to be empirically verified, it represents the thinking of the time about the knowledge bases for science teachers and the ways in which the knowledge bases interact to impact classroom practices and student outcomes (Gess-Newsome, 2015; Kind, 2015).

Figure 1. Consensus model for teacher knowledge, classroom practice, and student outcomes. Reproduced from “On the beauty of knowing then not knowing: Pinning down the elusive qualities of PCK,” by V. Kind, 2015, in A. Berry, P. Friedrichsen, & J. Loughran (Eds.), Re-examining pedagogical content knowledge in science education, p. 192. Copyright 2015 by Routledge. Reproduced with permission.
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The consensus model was used as the conceptual framework for the present investigation. The consensus model includes a variety of knowledge bases for teaching and illustrates the ways in which the knowledge bases interact to impact classroom practices and student outcomes. The model begins in teacher professional knowledge bases. Teacher professional knowledge bases, such as SMK and pedagogical knowledge, interact with and influence topic specific professional knowledge (TSPK). The TSPK construct includes many types of teacher knowledge that have previously been conceptualized as components of PCK. Next, TSPK, such as knowledge of instructional strategies or student understanding, is either amplified or filtered by teachers’ beliefs about science instruction, teachers’ orientations toward science teaching, prior knowledge held by teachers, and the teaching context to contribute to determining teachers’ classroom practices. Classroom practices are then either amplified or filtered by students’ beliefs, prior knowledge held by students, and students’ behaviors to contribute to student outcomes. The model is recursive and dynamic in that multiple feedback loops underscore the complexities of teaching (Kind, 2015).

Statement of the Problem

In previous investigations, researchers exploring the relationships among teachers’ science subject matter knowledge (SMK), pedagogical content knowledge (PCK), beliefs about effective science instruction, and classroom practices documented partial conclusions with respect to the impact teachers’ knowledge and beliefs have on predicting classroom practices (Lederman & Gess-Newsome, 1992; Park & Chen, 2012; Roehrig & Luft, 2004a, 2004b; Saad & BouJaoude, 2012). Most of the researchers have concluded that relationships among teachers’ knowledge, beliefs, and practices exist, yet
the exact nature of the relationships among the constructs and the degree to which each construct contributes to predicting three dimensional classroom practices is still unclear. Prior research examining the relationships among the constructs has been limited in that most of the studies were qualitative and used small sample sizes. Furthermore, previous studies examining the relationships among teachers’ knowledge, beliefs, and practices used conceptual models that pack too many ideas into one construct for PCK (Gess-Newsome, 2015).

The authors of the consensus model unpacked the ideas previously included as part of PCK into separate constructs by introducing topic specific professional knowledge (TSPK). Studies investigating the relationships among teachers’ knowledge, beliefs, and practices have yet to apply the newly unpacked consensus model. Using the consensus model as a conceptual framework guiding a large, quantitative investigation of the structure of teachers’ knowledge, beliefs, and practices can offer new insights into the nature of the relationships among the constructs. Understanding the relationships among teachers’ knowledge, beliefs, and practices could provide a powerful framework to guide the transition in science teaching and learning called for by the authors of the Framework (National Research Council, 2012) and the NGSS. Supporting teachers through the transition to three dimensional teaching and learning is particularly important at the elementary level because students develop foundational ideas and practices in the K-6 grade bands.

The primary purpose of the present investigation was to determine whether the consensus model held true when tested empirically using data that were collected from elementary science teachers. To do so, one path within the consensus model was tested.
Specifically, the path from SMK, to TSPK, to teachers’ beliefs about effective science instruction, and finally to classroom practices was examined. The four constructs used in the structural model were selected as representative constructs within the larger categories of the consensus model because of their relevance to three dimensional teaching and learning. In addition to determining whether the consensus model held true when tested empirically, the amount of variance in elementary teachers’ science classroom practices explained by the combined effect of SMK, TSPK, and beliefs about effective science instruction was determined. Finally, the nature of the relationships among elementary teachers’ science SMK, TSPK, beliefs about effective science instruction, and science classroom practices was examined.

**Research Questions**

The consensus model for teacher knowledge, classroom practice, and student outcomes (see Figure 2) has yet to be empirically tested. The purpose of the present study was to empirically test one path within the consensus model. The path that was tested was the path from teachers’ science subject matter knowledge (SMK), to topic specific professional knowledge (TSPK), to beliefs about effective science instruction, and finally to classroom practices. As shown in Figure 3, a hypothesized structural model was constructed using the aforementioned path in combination with previous findings regarding the relationships among science SMK, TSPK, beliefs about effective science instruction, and science classroom practices. The three research questions and sub-questions that guided the investigation are listed in this section.

Research Question 1. Does the hypothesized model produce an estimated population covariance matrix consistent with the sample covariance matrix?
Figure 2. Consensus model for teacher knowledge, classroom practice, and student outcomes. Reproduced from “On the beauty of knowing then not knowing: Pinning down the elusive qualities of PCK,” by V. Kind, 2015, in A. Berry, P. Friedrichsen, & J. Loughran (Eds.), Re-examining pedagogical content knowledge in science education, p. 192. Copyright 2015 by Routledge. Reproduced with permission.

Figure 3. Hypothesized model for the relationships among science subject matter knowledge (SMK), topic specific professional knowledge (TSPK), three dimensional beliefs about effective science instruction, and three dimensional classroom practices.
Research Question 2. How much of the variance in three dimensional classroom
practices is accounted for by the combined effect of SMK, TSPK, and three
dimensional beliefs about effective science instruction?

Research Question 3. What is the nature of the relationships among SMK, TSPK,
three dimensional beliefs about effective science instruction, and three
dimensional classroom practices?

Sub-Question A. What effect does SMK have on TSPK?

Sub-Question B. What effect does SMK have on three dimensional beliefs
about effective science instruction?

Sub-Question C. What effect does SMK have on three dimensional classroom
practices?

Sub-Question D. What effect does TSPK have on three dimensional beliefs
about effective science instruction?

Sub-Question E. What effect does TSPK have on three dimensional classroom
practices?

Sub-Question F. What effect does three dimensional beliefs about effective
science instruction have on three dimensional classroom practices?

Sub-Question G. Does TSPK mediate the effect of SMK on three dimensional
classroom practices?

Sub-Question H. Does three dimensional beliefs about effective science
instruction mediate the relationship between TSPK and three dimensional
classroom practices?
Sub-Question I. Does three dimensional beliefs about effective science instruction mediate the relationship between SMK and three dimensional classroom practices?

Sub-Question J. Do TSPK and three dimensional beliefs about effective science instruction mediate the relationship between SMK and three dimensional classroom practices?

**Definitions of Relevant Terms**

*Elementary Teachers:* Using the definition for elementary teachers that was developed by the authors of the 2012 National Survey of Science and Mathematics Education (NSSME), elementary teachers were defined as kindergarten through fifth grade teachers and sixth grade teachers with self-contained classrooms. Self-contained classrooms are classrooms in which one teacher teaches the majority of the subject areas to one group of students.

*Subject Matter Knowledge:* Science subject matter knowledge (SMK) is knowledge of the science subject or topic being taught.

*Pedagogical Content Knowledge:* Pedagogical content knowledge (PCK) is personal knowledge that is held by an individual teacher and developed through the actual practice of teaching. It is the knowledge of, the reasoning behind, the planning for, and the practice of teaching a particular topic in a particular way for a particular purpose to particular students (Gess-Newsome, 2015).

*Topic Specific Professional Knowledge:* Topic specific professional knowledge (TSPK) is canonical knowledge held by the science education community and is generated through research. It is available for all teachers to learn and to use and is not
specific to an individual teacher or a particular context. The TSPK construct is specific to a topic and includes the knowledge necessary to determine instructional strategies or content representations, to understand students’ developing conceptions, and to integrate the science and engineering practices, crosscutting concepts, and disciplinary core ideas (Gess-Newsome, 2015).

**Three Dimensional Beliefs About Effective Science Instruction:** Three dimensional beliefs about effective science instruction are teachers’ opinions about three dimensional pedagogy. Specifically, three dimensional beliefs are opinions regarding the centrality of phenomena, the use of evidence, and the importance of sense-making in science teaching and learning. Teachers that hold three dimensional beliefs about effective science instruction value the centrality of phenomena, the use of evidence, and the importance of sense-making.

**Three Dimensional Classroom Practices:** Classroom practices are the approaches to teaching and learning used by teachers in the classroom. Three dimensional classroom practices are specific practices used in science teaching and learning that are consistent with the three dimensional paradigm for science education. The authors of the consensus model used the term classroom practice to describe the sum of teachers’ actions in the classroom. In the present student, the term three dimensional classroom practices is used to describe the instructional strategies that a teacher may choose to employ that align with three dimensional reforms. The plural version of the term practice is used when referring to three dimensional classroom practices because there are many different three dimensional classroom practices that a teacher could employ and because teachers may employ one or many three dimensional classroom practices.
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Scope

The scope was limited to elementary science teachers who teach kindergarten through fifth grade and sixth grade teachers in self-contained classrooms and who participated in the 2012 National Survey of Science and Mathematics Education (NSSME). The 2012 NSSME was based on a national probability sample of teachers in the 50 United States and the District of Columbia (Weis & Banilower, 2013). The sample for this study consisted predominately of White female teachers.

Assumptions

It was assumed that each teacher reflected his or her own thinking in responding to items on the 2012 National Survey of Science and Mathematics Education (NSSME) and that the survey management program accurately recorded all responses. In addition, because all survey responses were self-reported, it was assumed that all self-reports were reflective of teachers’ actual knowledge, beliefs, and practices. In comparing survey data to actual practice, Mayer (1999) determined that generally, teachers reported accurate estimates of implementation of classroom practices, though they did not necessarily accurately report the quality of implementation of classroom practices. Because the purpose of this study was to examine only the implementation, and not the quality of implementation, survey data were considered to be an appropriate measure.

Significance

The purpose of this quantitative study was to test the consensus model for teacher knowledge and skill and to determine the relationships among elementary teachers’ science subject matter knowledge (SMK), topic specific professional knowledge (TSPK), beliefs about effective science instruction, and science classroom practices in the context
of three dimensional reforms for science teaching and learning. Findings from this study could contribute to the field in two ways. First, the findings may provide additional information regarding the relationships among the constructs included in the consensus model. In doing so, the findings may yield important implications for professional learning. For example, the structure may suggest that in order to change teachers’ classroom practices, the teacher must have high levels of both SMK and TSPK. If this is the case, professional learning experiences should be designed to focus specifically on increasing teachers’ SMK and TSPK.

Second, this study may provide a deeper understanding of the ways by which teachers’ knowledge and beliefs interact to predict classroom practices in the context of the three dimensional paradigm for science education. For instance, this study may provide support for using the TSPK construct to more clearly delineate among the various types of teacher knowledge that were previously included within the pedagogical content knowledge (PCK) construct. This study may also provide evidence that supports the argument that SMK, TSPK, and three dimensional beliefs about effective science instruction interact to predict three dimensional classroom practices. Understanding the ways by which teachers’ knowledge and beliefs interact to predict three dimensional classroom practices can facilitate the transition in science teaching and learning called for by the Framework (National Research Council, 2012) and the NGSS.

**Organization**

This dissertation consists of five chapters organized to offer a comprehensive examination of the topic. In Chapter 1, the background, conceptual framework, problem statement, relevant terms, research questions, assumptions, scope, and significance of the
study are presented. In Chapter 2, a comprehensive review of literature including all relevant topics and constructs is provided. In Chapter 3, the research questions, research design, data set and sample, instrumentation, and analysis are reviewed. In Chapter 4, the findings are presented. Finally, in Chapter 5 an interpretation of the findings is offered, limitations to the study are discussed, and a summary of the implications and conclusions is presented.
CHAPTER 2: LITERATURE REVIEW

The authors of the Framework (National Research Council, 2012) and the Next Generation Science Standards (NGSS) articulated a vision for K-12 science education centered on supporting students as they actively construct scientific understanding through engagement with three major dimensions of science education: (a) science and engineering practices, (b) disciplinary core ideas, and (c) crosscutting concepts. Science and engineering practices are the key practices used by scientists as they investigate and explain scientific phenomena, disciplinary core ideas are the main ideas in each science discipline, and crosscutting concepts are ideas that unify science and engineering across disciplinary areas.

The vision for next generation science teaching and learning that was articulated in the Framework (National Research Council, 2012) and the NGSS is often referred to as three dimensional teaching and learning. The three dimensional paradigm diverges from previous approaches to science education, which generally fit within the traditional paradigm. Approaches to teaching and learning in the traditional paradigm are teacher focused, emphasize learning discrete facts, and use lab activities to reinforce concepts. Approaches to teaching and learning in the three dimensional paradigm are student focused, emphasize sense-making, and place scientific phenomena at the center of science learning. When students engage in three dimensional learning, they work to make sense of scientific phenomena at the intersection of the three dimensions.

Given the differences in pedagogy between the traditional paradigm and the three dimensional paradigm, many K-12 teachers of science will need to make significant
changes to their classroom practices as states adopt the NGSS (Banilower et al., 2013). A call to change classroom practices simultaneously generates a call to transition teachers’ knowledge and beliefs because of the interconnected nature of teachers’ subject matter knowledge (SMK), pedagogical content knowledge (PCK), beliefs about effective science instruction, and science classroom practices (Abell, 2007; Gess-Newsome, 2015).

From the time Shulman (1986, 1987) first proposed the idea of PCK, a range of conceptual models for teacher knowledge and PCK have emerged (Gess-Newsome, 2015; Grossman, 1990; Kind, 2015; Magnusson et al., 1999; Park & Oliver, 2008). A consensus model for teacher knowledge was proposed as a result of a 2012 research summit (Gess-Newsome, 2015; Kind, 2015). The consensus model included a variety of teacher knowledge bases that were amplified or filtered by teachers’ beliefs, orientations, prior knowledge, and context. In the model, teachers’ knowledge and beliefs ultimately influenced teachers’ classroom practices. The consensus model was distinct from previous conceptual models for teacher knowledge in that it separated PCK into two constructs: PCK and a new construct called topic specific professional knowledge (TSPK). The TSPK construct untangled many of the ideas previously packed into the idea of PCK by separating knowledge that is held by the professional community from knowledge that is specific to an individual teacher in a particular context.

Supporting teachers through the transition to three dimensional classroom practices will likely require changing teachers’ science SMK, TSPK, and beliefs about effective science instruction. Understanding the ways by which teachers’ knowledge and beliefs impact three dimensional classroom practices could provide important insights into the ways by which educators may begin to transition to the model of teaching and
learning called for by the Framework (National Research Council, 2012) and the NGSS. The purpose of the present study was to empirically test the recently developed consensus model by examining the relationships among science SMK, TSPK, beliefs about effective science instruction, and classroom practices in the context of the three dimensional reforms. Additionally, the nature of the relationships among science SMK, TSPK, beliefs about effective science instruction, and classroom practices was explored.

In the following Literature Review, the conceptual framework is presented. Particular attention is paid to elementary teachers in the context of the three dimensional reforms. Prior research related to science SMK, TSPK, three dimensional beliefs about effective science instruction, and three dimensional classroom practices is included. The review of literature will demonstrate that a clear understanding of the relationships among elementary teachers’ science SMK, TSPK, beliefs about effective science instruction, and classroom practices is needed to better support teachers through the transition in classroom practices called for by the authors of the Framework (National Research Council, 2012) and the NGSS.

**Conceptual Framework**

Teachers’ knowledge, beliefs, and practices have been of particular interest to researchers over the years. The theoretical foundations for understanding and researching teachers’ knowledge, beliefs, and practices in science education, however, have undergone significant changes. The guiding conceptual framework for this study was the consensus model that was developed as a result of a 2012 research summit (see Figure 4). The hypothesized model for this study (see Figure 5) was developed to test one of the paths included in the consensus model.
Figure 4. Consensus model for teacher knowledge, classroom practice, and student outcomes. Reproduced from “On the beauty of knowing then not knowing: Pinning down the elusive qualities of PCK,” by V. Kind, 2015, in A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining pedagogical content knowledge in science education*, p. 192. Copyright 2015 by Routledge. Reproduced with permission.

Figure 5. Hypothesized model for the relationships among science subject matter knowledge (SMK), topic specific professional knowledge (TSPK), three dimensional beliefs about effective science instruction, and three dimensional classroom practices.
In order to demonstrate how the consensus model was developed, a historical review of preceding conceptual models is presented. Examining the models preceding the development of the consensus model provides insight into the constructs included in both the consensus and the hypothesized models. The four constructs included in the hypothesized model – science subject matter knowledge (SMK), topic specific pedagogical knowledge (TSPK), three dimensional beliefs about effective science instruction, and three dimensional classroom practices – were interwoven throughout previous conceptual models. Tracing the development of these four constructs can provide context for the inclusion of the constructs in both the consensus model and the hypothesized model. In the figures included in this section, different colors were used to highlight SMK (red), TSPK (yellow), beliefs about effective science instruction (green), and classroom practices (blue) so that the constructs can be traced through previous conceptual models to the development of the consensus and the hypothesized models. Often, the models included additional constructs beyond SMK, TSPK, beliefs about effective science instruction, and classroom practices. Such constructs are not highlighted with color, because they were not a primary focus for the present study.

**Early Conceptions of Teacher Knowledge**

Early researchers studying effective teaching investigated a variety of variables related to teacher characteristics and student outcomes but did not explicitly mention teacher knowledge (Fenstermacher, 1994). Researchers generally worked from a behaviorist perspective and explored only the inputs and outputs of teaching in a manner referred to as process-product research (Gage, 1978). For instance, Northfield and Fraser (1977) compared teacher characteristics to student outcomes using teacher characteristic
variables such as sex, teaching experience, attitude toward pupil-centeredness, and attitude toward structure. Teachers’ knowledge of the subject and knowledge of teaching practice were not included as potential variables because they were viewed as static teacher characteristics. In this respect, early attention was clearly paid to the input variables believed to be related to teacher effectiveness and there was a notable absence of investigations that examined teacher knowledge.

In the 1980s, a series of research programs emerged that began to conceptualize teachers as “knowers” (Abell, 2007; Clandinin & Connelly, 1996; Cochran-Smith & Lytle, 1999; Fenstermacher, 1994; Shulman, 1986, 1987). Research shifted from generating a knowledge base for teaching to investigating and appreciating the ways through which teacher knowledge developed (van Driel et al., 2014). Foundational to the study of teacher knowledge was Shulman’s (1986, 1987) work with pedagogical content knowledge (PCK). In two influential publications, Shulman (1986, 1987) argued that the knowledge held by experts in a particular subject was different from the knowledge needed to teach that same subject. Shulman (1986, 1987) proposed that PCK was an additional type of knowledge of subject matter as it relates to teaching and described PCK as the knowledge needed to represent topics so that they are accessible and comprehensible to the learner.

**Preliminary Models for Teacher Knowledge and Skill**

Since it was proposed, the pedagogical content knowledge (PCK) construct has resonated with both researchers and practitioners for its ability to describe the complex nature of the knowledge needed for teaching (Abell, 2007; Fernandez, 2014; Kind, 2009, 2015; van Driel et al., 2014). Many researchers have continued to build upon and revise
initial ideas about PCK (Gess-Newsome, 2015; Grossman, 1990; Kind, 2015; Magnusson et al., 1999; Park & Oliver, 2008). For instance, Grossman (1990) integrated PCK into a larger model for teacher knowledge (see Figure 6) that included four interacting components that form the knowledge base for teaching: (a) subject matter knowledge (SMK), (b) general pedagogical knowledge, (c) PCK, and (d) knowledge of context.


Building on Grossman’s (1990) model, Magnusson et al. (1999) suggested that PCK was composed of five sub-components (see Figure 7): (a) orientations toward science teaching, (b) knowledge of the curriculum, (c) knowledge of science assessment, (d) knowledge of science learners, and (e) knowledge of instructional strategies. Most significantly, Magnusson et al. (1999) added orientations toward teaching science to the model as an important subcomponent through which all other subcomponents were filtered. Examples of orientations toward teaching science included didactic approaches,
project-based science, and inquiry (Fernandez, 2014). In a subsequent analysis of the model proposed by Magnusson et al. (1999), Park and Oliver (2008) suggested that orientations toward teaching science included three components: (a) beliefs about purposes of learning science, (b) decision making in teaching, and (c) beliefs about the nature of science. As such, orientations toward teaching science can be considered to be closely related to or the same as beliefs about effective science instruction.

Park and Oliver (2008) subsequently added a sixth component to the Magnusson et al. (1999) model. The sixth component, efficacy of the teacher, captured what the teacher considers to be the most effective pedagogies in promoting student learning. In addition, the authors introduced the idea of integrating the components of PCK such that each component influences all other components. This model (see Figure 8), often referred to as the hexagonal model for PCK, also placed an emphasis on the importance of teacher reflection.

Figure 8. Park and Oliver’s (2008) hexagonal model for pedagogical content knowledge (PCK). Adapted from “Revisiting the conceptualization of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals,” by S. Park and J. S. Oliver, 2008, Research in Science Education, 38, p. 279. Copyright 2008 by Springer. Reproduced with permission.

To frame a review of the literature on science teacher knowledge, Abell (2007) created yet another model for teacher knowledge that combined the components of
several of the previously proposed models. At its core, Abell’s model (see Figure 9), included Grossman’s (1990) assertion that pedagogical knowledge, SMK, and knowledge of context influenced PCK. In the model, PCK was subdivided into components as suggested by Magnusson et al. (1999). Although Abell’s model successfully combined many of the previously proposed conceptions of PCK, it did not represent a conceptual model for teacher knowledge that was widely agreed upon by the science education research community, likely due to its complexity.


Consensus Model for Teacher Knowledge and Skill

Although multiple models for teacher knowledge have been used since Shulman’s (1986, 1987) initial proposal for pedagogical content knowledge (PCK), the science
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education research community has yet to agree upon a consensus model for PCK. Van Driel et al. (2014) provided an example of the clear disagreement over conceptual models for teacher knowledge in the most recent review of literature for science teacher knowledge. In this review, van Driel et al. (2014) used the original Grossman (1990) model despite all the work that had been done to develop a more comprehensive model (Abell, 2007; Magnusson et al., 1999; Park & Oliver, 2008). The authors referenced the complications in identifying a conceptual model for teacher knowledge as the reason for returning to the Grossman (1990) model and suggested that the Grossman (1990) model may be the most parsimonious.

Although the Grossman (1990) model may be the most simple model to use, it does not necessarily capture many of the complexities of PCK. In an effort to develop a consensus model of teacher knowledge that reflected current thinking about the topic, many of the top PCK researchers met for a research summit in 2012 (Carlson et al., 2015). During the summit, 22 science education researchers reconsidered their models for teacher knowledge and drafted a consensus model of teacher knowledge and skill (Gess-Newsome, 2015; Kind, 2015). Although it has yet to be empirically tested, the consensus model (see Figure 10) represented an integrated version of all of the previously proposed models (Kind, 2015).

In the consensus model, several of the constructs that continue to be problematic have been unpacked. The model originates in generic teacher professional knowledge bases which include knowledge of assessment, pedagogy, content, students, and curriculum. Some of the generic teacher professional knowledge bases such as knowledge of pedagogy, knowledge of content, and some aspects of knowledge of
students are reflective of the Grossman (1990) model in that pedagogy, content, and context all contribute to PCK. Other knowledge bases such as knowledge of assessment and knowledge of curriculum had been previously packed into PCK. Such knowledge bases, however, are generic and shared across the education community. In the consensus model, PCK was defined as being specific to a particular teacher and a particular context. Given the shared nature of knowledge of assessment and knowledge of curriculum, these knowledge bases were separated from PCK (Gess-Newsome, 2015).

Figure 10. Consensus model for teacher knowledge, classroom practice, and student outcomes. Adapted from “On the beauty of knowing then not knowing: Pinning down the elusive qualities of PCK,” by V. Kind, 2015, in A. Berry, P. Friedrichsen, & J. Loughran (Eds.), Re-examining pedagogical content knowledge in science education, p. 192. Copyright 2015 by Routledge. Reproduced with permission.
Generic teacher professional knowledge bases then inform and interact with topic specific professional knowledge (TSPK), a new category of knowledge included in the consensus model (Gess-Newsome, 2015; Kind, 2015). TSPK consists of knowledge held by the profession, yet is distinct from generic teacher professional knowledge bases in that TSPK is topic specific (Gess-Newsome, 2015). The TSPK construct blends subject matter and pedagogy that are specific to the topic, but not specific to the teacher. The blend of subject matter and pedagogy was previously included as a significant component of PCK in all of the previous models. In the consensus model, however, TSPK was distinguished from PCK in that TSPK is professional knowledge held by the community and PCK is knowledge held by an individual teacher for an individual context. Specifically, TSPK includes knowledge of instructional strategies, content representations, student understandings, science practices, and habits of mind (Gess-Newsome, 2015).

In the consensus model, TSPK is subsequently filtered through teacher level amplifiers and filters such as teachers’ beliefs, orientations, prior knowledge, and context. At this point, the model begins to include teacher-specific constructs rather than knowledge held publically by those in the profession. Teachers’ beliefs and orientations have been included in previous models in a variety of ways. For example, Grossman (1990) included a variation on teachers’ beliefs, conceptions of purposes for teaching the subject matter, as a subcomponent of PCK. Magnusson et al. (1999) transformed this idea to include orientations toward science teaching as a filter for the other subcomponents of PCK. Park and Oliver (2008) revised the inclusion of orientations toward science teaching to focus more specifically on teachers’ beliefs about effective
science instruction. In the consensus model, teachers’ beliefs have been separated from PCK and are treated as an amplifier or filter between TSPK and classroom practices. In doing so, the amplifiers and filters represent the ways by which a teacher may personalize professional knowledge. Although a teacher may have strong knowledge about content, pedagogy, and science practices, he or she may not necessarily enact them if his or her beliefs act as a filter.

The consensus model situates PCK within classroom practices. Two separate yet related constructs were defined relating to PCK. The first construct, *personal PCK*, is the knowledge of, reasoning behind, and planning for a particular topic with a particular group of students in a particular context. Personal PCK can be thought of as an antecedent to the actual practice of teaching. The second construct, *personal PCK and skill (PCK&S)* is the actual act of teaching a particular topic with a particular group of students in a particular context. Personal PCK&S can be thought of as the actual practice of teaching (Gess-Newsome, 2015).

It is important to note that the authors of the consensus model used the term *classroom practice* to refer to the sum of teachers’ actions in the classroom. This may include teachers’ instructional approaches, classroom management techniques, and resources used. In the consensus model, a teacher’s classroom practice was the sum of all of the teachers’ behaviors within the classroom setting. In the present study, the term *classroom practices* is used when referring to three dimensional classroom practices. This is because three dimensional classroom practices are instructional strategies that a teacher may choose to employ that align with three dimensional reforms. Such practices include but are not limited to: having students engage in laboratory activities or
investigations; having students represent and/or analyze data using tables, charts, or graphs; and requiring students to supply evidence in support of their claims. Because three dimensional classroom practices are instructional strategies that can be employed by teachers, they are referred to in the plural, whereas the sum of a teacher’s behaviors in the classroom is referred to as a singular activity.

Classroom practices are then filtered or amplified by students’ beliefs, prior knowledge, and behaviors. For instance, external influences such as socio-economic status, parental involvement, and community expectations influence the learning process (Hattie, 2003). Student amplifiers and filters subsequently impact student outcomes. Though it is tempting to link classroom practices directly to student outcomes, the relationship between classroom practices and student outcomes is often not direct. Student amplifiers and filters act as important intervening variables and varying measures of student outcomes impact the validity of the relationship between classroom practices and student outcomes.

In summary, the authors of the consensus model attempted to unpack some of the complicated constructs previously embedded into PCK. In particular, the formal aspects of PCK have been moved into TSPK. Although the consensus model may be a strong theoretical model for teacher knowledge, it has yet to be empirically tested. As Kind (2015) indicated, the mechanisms connecting the model’s components remain undescribed, vague, and open to debate. In the present study, the consensus model was used as the conceptual framework guiding the investigation into the relationships among teachers’ knowledge, beliefs, and practices in kindergarten through sixth grade science settings in the context of the three dimensional paradigm for science education.
Three Dimensional Paradigm for Science Education

The release of the Framework (National Research Council, 2012) and the NGSS marked an important turning point in science education. The Framework (National Research Council, 2012) outlined a new vision for K-12 science education that emphasized coherence across grades and disciplines, breadth over depth, and science teaching and learning situated at the nexus of three major dimensions of science education: (a) science and engineering practices, (b) disciplinary core ideas, and (c) crosscutting concepts. The suggestions made in the Framework (National Research Council, 2012) were subsequently woven into performance expectations that were articulated in the NGSS. Since the release of the two documents, the Framework (National Research Council, 2012) and the NGSS, have driven the three dimensional era of science reform.

Both documents outlined the fundamental aspects of the three dimensional paradigm for science teaching and learning. Beyond situating science teaching and learning at the nexus of three major dimensions of science education, the authors of the Framework (National Research Council, 2012) and the NGSS advocated for three additional changes to science teaching and learning. First, the authors of the Framework (National Research Council, 2012) articulated a need to organize science content around learning progressions centered on core disciplinary ideas. As progress is made through the grade bands, core disciplinary ideas become increasingly more sophisticated. Second, the authors of the Framework (National Research Council, 2012) included a smaller number of core disciplinary ideas to be mastered at a greater depth. Third, the authors of the Framework (National Research Council, 2012) called for science teaching and
learning that engages students in constructing their own understanding of science ideas by engaging in investigations, modeling, arguing from evidence, and developing explanations. An emphasis was placed on centering instruction around phenomena and working in groups to make sense of the phenomena (National Research Council, 2012). A summary of the educational shifts from the traditional paradigm to the three dimensional paradigm as articulated in the Framework (National Research Council, 2012) and the NGSS can be found in Table 2.

Table 2

*Educational Shifts from the Traditional to the Three Dimensional Paradigm*

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<th>Three Dimensional</th>
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<tbody>
<tr>
<td>Students learn facts (e.g. parts of the cell)</td>
<td>Students explain natural phenomena (e.g. how cell structures relate to cell functions)</td>
</tr>
<tr>
<td>Teaching and learning is focused on single dimensions of science (e.g. disciplinary core ideas for physical science)</td>
<td>Teaching and learning is focused on interconnections of three dimensions of science (e.g. science and engineering practices, crosscutting concepts, disciplinary core ideas)</td>
</tr>
<tr>
<td>Content focus occurs at the grade level content (e.g. middle school life science)</td>
<td>Content focus is on the progression of core ideas and practices across K-12 (e.g. coherent horizontal and vertical development of concepts and practices)</td>
</tr>
<tr>
<td>Science is taught as a single discipline (e.g. biology)</td>
<td>Science and engineering are integrated (e.g. practices of engineering design incorporated with science)</td>
</tr>
<tr>
<td>Science is considered a body of knowledge (e.g. conceptual structure of a discipline)</td>
<td>Science is considered a way of knowing (e.g. nature of science as an extension of practices and crosscutting concepts)</td>
</tr>
<tr>
<td>Science is presented as a stand-alone discipline (e.g. separate time or course in curriculum)</td>
<td>Science is connected with common core (e.g. English language arts and mathematics incorporated with science)</td>
</tr>
</tbody>
</table>

Although the major contributions of the Framework (National Research Council, 2012) and the NGSS are related to the integration of the science and engineering practices with core science content, the idea of engaging students in the science and engineering practices is not new. Historically, engagement with the science and engineering practices in classroom settings has been referred to as inquiry or inquiry-based learning. Dewey (1916, 1938) and Bruner (1960, 1966) emphasized the importance of engaging students in science investigations so that they may construct their own understanding of scientific phenomena. All of the science education reform documents since the 1980s mentioned the importance of engaging students in inquiry (American Association for the Advancement of Science, 1990, 1993; National Research Council, 1996, 2008, 2012; NGSS Lead States, 2013).

Even though an emphasis on inquiry in science has been apparent since the 1960s, the implementation of inquiry in science classrooms has been largely unsuccessful (National Research Council, 2007). In fact, Linn and Eylon (2006) characterized the typical activity structure of most science classrooms in the United States as “motivate, inform, assess,” in which teachers motivate interest in a science idea, present the current understanding of the idea, and assess student understanding. As a result, students begin to view science as having a right answer or final form (National Research Council, 2007). The authors of empirical investigations on inquiry in science classrooms have suggested that even the most highly qualified teachers struggle to enact inquiry (Banilower et al., 2013; Capps & Crawford, 2013; Trygstad, Smith, Banilower, & Nelson, 2013).

One of the reasons that the call for integrating inquiry and science practices into science classrooms has been largely unsuccessful is because of a lack of common
understanding of inquiry in both the researcher and practitioner communities (Crawford, 2014). Differing presentations of inquiry have contributed to confusion among teachers regarding the multiple meanings of inquiry and has led to a wide variety of interpretations of inquiry (Barrow, 2006). Some of the variations of inquiry have included project-based science, problem-based science, authentic science, citizen science, and model-based inquiry (Crawford, 2014).

The authors of the Framework (National Research Council, 2012) addressed the inconsistencies surrounding inquiry by transitioning the idea of inquiry to the science and engineering practices. Using the term practices, rather than inquiry, implies an interconnected set of performances that are dependent on the content and rely heavily on evaluation and critique (Ford, 2015). Furthermore, the term practices places an emphasis on the importance of engaging students in science investigations so that they may make sense of scientific phenomena and learn the epistemology of science (Berland et al., 2015; Crawford, 2014). The practices carry over many of the ideas embedded in inquiry, but add an additional emphasis on modeling and argumentation rather than simply forming and testing hypotheses (Crawford, 2014). Some of the differences and similarities between essential features of inquiry and the science and engineering practices can be found in Table 3.

As students engage in the science and engineering practices, they work to make sense of a phenomenon through science investigations, modeling, argumentation, and explanation. By engaging in the practices, students learn core disciplinary ideas and essential scientific skills. More importantly, though, students develop procedural knowledge for engaging in science in addition to epistemological knowledge about
science (Berland et al., 2015; Osborne, 2014). Procedural and epistemic knowledge contribute to a student’s sense of knowing why certain strategies are important in addition to his or her sense of the ways by which scientific knowledge is developed, critiqued, and revised. In sum, students’ learning extends beyond knowing the what of science to knowing the how and why.

Table 3

Comparing Inquiry to the Science and Engineering Practices

<table>
<thead>
<tr>
<th>Inquiry</th>
<th>Science and Engineering Practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learners are engaged by scientifically oriented questions</td>
<td>→ Asking questions (for science) and defining problems (for engineering)</td>
</tr>
<tr>
<td></td>
<td>Developing and using models</td>
</tr>
<tr>
<td></td>
<td>Planning and carrying out investigations</td>
</tr>
<tr>
<td>Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions</td>
<td>→ Analyzing and interpreting data</td>
</tr>
<tr>
<td></td>
<td>Using mathematics and computational thinking</td>
</tr>
<tr>
<td></td>
<td>Constructing explanations (for science) and designing solutions (for engineering)</td>
</tr>
<tr>
<td>Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding</td>
<td>→ Engaging in argument from evidence</td>
</tr>
<tr>
<td>Learners communicate and justify their proposed explanations</td>
<td>→ Obtaining, evaluating, and communicating information</td>
</tr>
</tbody>
</table>

Transitioning from inquiry to the science and engineering practices represents an attempt to implement many of the constructivist ideas previously presented as part of inquiry. The goals of the Framework (National Research Council, 2012) and the NGSS were to establish an agreed upon perspective of science education. The authors took the first steps necessary to connect the three dimensional paradigm with practice. The success of this paradigm is now dependent upon the successful translation of research to practice. In other words, success will be evident once teachers utilize the recommendations in the Framework (National Research Council, 2012) and the NGSS to adjust and modify classroom practices.

**Teachers’ Knowledge, Beliefs, and Classroom Practices**

Teachers will need support from the science education community to make the pedagogical changes called for by the authors of the Framework (National Research Council, 2012) and the NGSS. Supporting elementary teachers through the transition is particularly important. One of the educational transitions that is integral to the Framework (National Research Council, 2012) is the emphasis on learning progressions and the gradual building of understanding of core disciplinary ideas throughout the elementary, middle, and high school levels. As students engage with the core disciplinary ideas at each grade band, the ideas become progressively more complex and sophisticated. Strong three dimensional classroom practices in the K-6 grade bands are required in order to establish foundational understanding of core disciplinary ideas, science and engineering practices, and crosscutting concepts. In later grade bands, students will be more successful if they are able to build upon strong foundational
understandings of the three dimensions of the Framework (National Research Council, 2012) and the NGSS.

To support teachers in making the necessary changes to classroom practices, teacher educators must carefully design professional learning experiences so that they have the greatest impact on changing classroom practices. According to the consensus model for teacher knowledge and skill (see Figure 11), changes in classroom practices must be preceded by changes in teachers’ science subject matter knowledge (SMK), topic specific professional knowledge (TSPK), and beliefs about effective science instruction. This means that teacher educators and professional development providers will likely need to focus on changing teachers’ science SMK, TSPK, and beliefs about effective science instruction in order to impact classroom practices. The exact nature of the relationships among SMK, TSPK, beliefs about effective science instruction, and classroom practices, and the effect that each construct has on three dimensional classroom practices, however, has yet to be determined.

In the present study, the nature of the relationships among science SMK, TSPK, beliefs about effective science instruction, and classroom practices was considered. This section of the Literature Review includes a discussion of each of the four constructs included in the hypothesized model (see Figure 12): science SMK, TSPK, three dimensional beliefs about effective science instruction, and three dimensional classroom practices. Three dimensional classroom practices is discussed first because it is the endogenous variable in the hypothesized model and because the other three constructs (SMK, TSPK, and beliefs about effective science instruction) relate to three dimensional classroom practices either directly or indirectly. Next, SMK and three dimensional
beliefs about effective science instruction will be discussed with respect to the impact each construct has on classroom practices. Finally, TSPK will be discussed. Because TSPK is a new construct, it is not frequently found in the literature base; the discussion of TSPK will be limited to research that has been conducted using TSPK-like constructs.

At the beginning of each section, a figure illustrating the position of the construct of interest in the consensus model and the hypothesized model is presented. This section of the Literature Review will demonstrate that science SMK, TSPK, and three dimensional beliefs about effective science instruction all impact three dimensional classroom practices but that the nature of the relationships among the constructs has yet to be determined.

**Figure 11.** Consensus model for teacher knowledge, classroom practice, and student outcomes. Reproduced from “On the beauty of knowing then not knowing: Pinning down the elusive qualities of PCK,” by V. Kind, 2015, in A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining pedagogical content knowledge in science education*, p. 192. Copyright 2015 by Routledge. Reproduced with permission.
Figure 12. Hypothesized model for the relationships among science subject matter knowledge (SMK), topic specific professional knowledge (TSPK), three dimensional beliefs about effective science instruction, and three dimensional classroom practices.

Classroom Practices

In order to achieve the vision for next generation science teaching that was articulated in the Framework (National Research Council, 2012) and the NGSS, elementary teachers will need to adjust their practices in order to align with the reforms. The purpose of the present study was to determine the ways by which teachers’ knowledge and beliefs interact to impact teachers’ classroom practices. This section of the Literature Review includes a discussion of elementary teachers’ classroom practices in science and the relationships among classroom practices and the other constructs in the consensus and the hypothesized models.

In the consensus model (see Figure 13), teachers’ classroom practices are indirectly influenced by topic specific professional knowledge (TSPK) and teacher professional knowledge bases, such as subject matter knowledge (SMK), and directly influenced by TSPK and teachers’ beliefs about effective science instruction. Furthermore, classroom practices can impact TSPK through a recursive path. In the
hypothesized model, the indirect relationships from SMK and TSPK to classroom practices and the direct relationships from TSPK and beliefs to classroom practices were maintained. Three dimensional classroom practices was considered the endogenous variable in the hypothesized model, however, so the recursive aspect of the path was not included. In addition, much of the research included in this section of the Literature Review suggested the existence of a direct relationship between science SMK and three dimensional classroom practices, so an additional path from science SMK to three dimensional classroom practices was added to the hypothesized model.

Figure 13. Three dimensional classroom practices in the consensus model and the hypothesized model. Consensus model reproduced from “On the beauty of knowing then not knowing: Pinning down the elusive qualities of PCK,” by V. Kind, 2015, in A. Berry, P. Friedrichsen, & J. Loughran (Eds.), Re-examining pedagogical content knowledge in science education, p. 192. Copyright 2015 by Routledge. Reproduced with permission.

**Elementary science classroom practices.** To make the changes in elementary science classroom practices called for by the Framework (National Research Council, 2012) and the NGSS, it is first necessary to understand the current state of classroom practices in kindergarten through sixth grade science. Analyses of current classroom
practices suggested that students do not have sufficient exposure to science ideas in elementary school. In fact, elementary teachers tend to spend relatively little time on science. Results from the 2012 National Survey of Science and Mathematics Education (NSSME) revealed that very few of 200 kindergarten through sixth grade science teachers reported that they delivered science instruction every day of the week. Less than 35% of kindergarten through sixth grade classrooms received science instruction all or most days every week. Additionally, 41% of kindergarten through third grade classes and 32% of fourth through sixth grade classes only received science instruction some weeks, but not other weeks. Rather, most of the classroom time was devoted to math or language arts (Banilower et al., 2013; Trygstad et al., 2013). In a mixed-methods study of approximately 150 kindergarten through sixth grade teachers from three districts in different states, survey results indicated that most respondents spent at least an hour every week on science, but only 36% taught science for more than two hours every week (Aschbacher & Roth, 2002). High stakes testing in language arts and mathematics likely contributed to the reduced time spent on science (Banilower et al., 2007; Weiss et al., 2003). In order for students to progressively build core disciplinary ideas over time, as recommended by the Framework (National Research Council, 2012) and the NGSS, more time will need to be devoted to science instruction at the elementary level.

In addition to authors that indicated that elementary school teachers did not spend a great deal of time on science, several researchers have indicated that the overall quality of science instruction, particularly at the elementary level, is low. In an observational study of a national sample of kindergarten through fifth grade classrooms, science lessons were given an overall quality rating between 1 and 5. Ratings were determined by
independent observers using an observation protocol that addressed lesson design, lesson implementation, science content addressed, and classroom culture. Of the 55 classrooms participating in the study, 58% of classrooms received a low quality observational rating while only 18% received a high quality rating (Weiss et al., 2003). Moreover, only 13% of the classrooms received high ratings in providing opportunities for students to engage in science practices (Weiss et al., 2003), a finding which is particularly alarming for the proponents of the three dimensional paradigm for science education.

**Three dimensional classroom practices.** In addition to studying elementary science classroom practices in general, a variety of researchers have investigated the extent to which elementary science teachers engage in three dimensional or inquiry-based science teaching. Prior to the release of the Framework (National Research Council, 2012) and the NGSS, the terms *inquiry-based* or *reform-oriented* classroom practices were often used to describe constructivist approaches to science education. As such, three dimensional, inquiry-based, and reform-oriented classroom practices are considered synonymous for the purposes of this Literature Review even though subtle yet important differences exist.

An initial investigation that established a preliminary definition for inquiry was conducted by Aschbacher and Roth (2002). In an effort to determine the quality of science teaching at the primary level, the researchers observed 40 primary teachers engaged in science teaching. Through the observations, the researchers identified three general patterns for practice. The first pattern was termed *recipe science*, which consisted of teaching and learning that focused on the steps of an activity or investigation and a superficial discussion of what students observed after the activity. In recipe
science, students completed hands-on activities, but attention was not drawn to the inquiry process (Aschbacher & Roth, 2002). The second pattern was termed *principled science*, which consisted of student engagement in activities and investigations in a similar way to recipe science, but more emphasis was placed on developing understanding and linking data to claims. This pattern most closely relates to inquiry-based science, though the relationship is loose. The third pattern was *minimal science*. In minimal science classrooms, lessons were often confusing, poorly controlled, or had an unclear focus. Of the 40 lessons observed, 62% were categorized as recipe science, 18% as principled science, and 20% as minimal science (Aschbacher & Roth, 2002). The findings were cause for concern because over 80% of the observed teachers failed to engage students in meaningful science learning related to three-dimensional classroom practices. Even the lessons that were categorized as principled science often demonstrated only slight improvements over recipe science and did not necessarily incorporate all aspects of inquiry-based science (Aschbacher & Roth, 2002). Based on a loose definition of inquiry-based science, the authors demonstrated that elementary teachers generally did not engage students in three-dimensional classroom practices as called for by the Framework (National Research Council, 2012) and the NGSS.

Subsequent studies using large-scale data sets yielded similar findings. As previously mentioned, elementary teachers from the 2012 National Survey of Science and Mathematics Education (NSSME) generally did not engage students in reform-oriented teaching practices (Banilower et al., 2013; Trygstad et al., 2013). In the 2012 NSSME, reform-oriented teaching practices were measured using a self-reported survey of practices that generally aligned with the vision of the Framework (National Research Council, 2012).
Council, 2012) and the NGSS. Survey items were designed to collect the frequency of teachers’ use of science investigations, the teachers’ emphasis on the use of evidence in supporting claims, and the students’ use of data. Using the same data set, Trygstad et al. (2013) asserted that elementary and middle school students likely had limited opportunities to engage in the science practices because teachers reported a high prevalence of teacher explanation and relatively infrequent use of lab activities. Banilower et al. (2013) and Trygstad et al. (2013) suggested that despite calls for the use of inquiry in science classrooms, teachers were largely teaching in accordance with the traditional paradigm for science teaching and learning. Moreover, findings from the Trends in International Mathematics and Science Study (TIMSS) 1999 Video Study suggested that teachers in the United States generally failed to focus on meaningful science content, rarely used phenomena to situate learning, and did not emphasize conceptual understanding in science lessons (Roth et al., 2006). An additional analysis of the transcripts from the TIMSS 1999 Video Study revealed that teachers focused more on canonical, procedural, and experimental knowledge rather than real-world connections and the nature of science (Furtak & Alonzo, 2010).

**Variables associated with three dimensional classroom practices.** Beyond simply investigating the quality of instruction and the ways in which classroom practices align or fail to align with the vision of the Framework (National Research Council, 2012) and the NGSS, some researchers have identified variables involved in predicting implementation of three dimensional classroom practices. A summary of the findings is presented in Table 4. In the literature, most of the researchers used the term reform-oriented classroom practices to describe three dimensional classroom practices, though
the operational definition for reform-oriented classroom practices matched the definition for three dimensional classroom practices that is used in the present study.

Table 4

Variables that Predict Three Dimensional Classroom Practices

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Teacher Knowledge and Beliefs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMK</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>PCK</td>
<td>✓</td>
<td>-</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>Three dimensional beliefs</td>
<td>✓</td>
<td>NS</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Extent of Professional Learning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-service teacher training</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>In-service teacher training</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Teaching experience</td>
<td>✓</td>
<td>NS</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>School Demographics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of students enrolled</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Student Characteristics</td>
<td>✓</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Community type</td>
<td>✓</td>
<td>-</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>Resources available for</td>
<td>-</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>science instruction</td>
<td></td>
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<tr>
<td>Professional Culture and</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Context</td>
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<tr>
<td>Principal support</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>✓</td>
</tr>
<tr>
<td>Professional autonomy</td>
<td>-</td>
<td>✓</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Professional culture of</td>
<td>-</td>
<td>✓</td>
<td>-</td>
<td>✓</td>
</tr>
<tr>
<td>school context</td>
<td></td>
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</table>

Note: SMK = subject matter knowledge; TSPK = topic specific professional knowledge; ✓ = significant predictor of three dimensional classroom practices; - = variable not investigated; NS = not significant.

In an investigation of the variables involved in predicting three dimensional classroom practices, A. A. Smith et al. (2013) examined a broad range of variables that could predict the use of reform-oriented classroom practices. After surveying a national
sample of 465 middle school teachers, a multiple regression analysis was completed. Factors that were significant predictors of reform-oriented objectives and classroom practices included teachers’ years of experience, teachers’ perceptions of content preparedness, teachers perceptions’ of preparedness to implement instruction in a particular unit, teachers’ participation in professional development opportunities, whether or not the teacher held a degree in the natural sciences or engineering, the prior achievement level of students in the class, money spent per pupil on science instruction, and school community type (A. A. Smith et al., 2013). Perceptions of content preparedness was used as a proxy for SMK and perceptions of preparedness to implement instruction in a particular unit was used as a proxy for PCK. Whether or not a teacher held a degree in the natural sciences or engineering was interpreted as a measure for SMK. The authors posited that the most influential and adaptable teacher level variables impacting classroom practices aligned with the Framework (National Research Council, 2012) and the NGSS, included SMK and PCK.

A study conducted by Weiss et al. (2003) yielded similar findings. After observing and interviewing a national sample of 31 primary teachers, the researchers concluded that the most important factors to influence instructional strategies were teachers’ knowledge, beliefs, and experiences. Similarly, Banilower et al. (2007) concluded that SMK, PCK, beliefs and attitudes toward teaching science, participation in professional development, teachers’ years of experience, student characteristics, the number of students enrolled, and principal support were significant predictors of reform-oriented instructional practices. Although Banilower et al. (2007), A. A. Smith et al. (2013), and Weiss et al. (2003) concluded that SMK, PCK, and beliefs about effective
science instruction impact three dimensional classroom practices, Jetty (2015) concluded that the direct effects of SMK and beliefs about effective science instruction on three dimensional classroom practices were not significant. Rather, the significant predictors of three dimensional classroom practices were pre-service and in-service teacher training, professional culture, and professional autonomy. In the analysis, however, the indirect effects of SMK and beliefs about effective science instruction on three dimensional classroom practices were not examined.

Results from studies that were designed to identify the variables involved in predicting implementation of three dimensional classroom practices indicated that SMK, PCK, and beliefs about effective science instruction were likely significant predictors of three dimensional classroom practices, though the relationships among the variables may be indirect. Furthermore, student-level and school-level predictors such as student characteristics, school context, and professional context were also important predictors of three dimensional classroom practices.

In summary, current elementary science classroom practices tend not to meet the pedagogical and content requirements called for by the Framework (National Research Council, 2012) or the NGSS. Although some exemplary classrooms exist, research with science teachers documents a lack of knowledge and preparation necessary to implement the classroom practices called for by the current reform documents. As the cases reviewed in this section of the Literature Review have demonstrated, teachers’ knowledge and beliefs played an important role in promoting three dimensional classroom practices. Improving knowledge bases and beliefs for elementary science teachers are in order to positively impact classroom practices.
Subject Matter Knowledge

Teachers’ science subject matter knowledge (SMK) plays an important role in promoting three dimensional classroom practices. Often referred to as content knowledge, SMK has been well researched across grade levels and disciplines. In fact, considering all of the constructs that may impact classroom practices, SMK is, perhaps, the most well-defined (Abell, 2007). To date, studies about teachers’ science SMK employed fairly consistent research methods and the resultant findings generally confirmed theory that SMK is one of numerous constructs contributing to classroom practices (Abell, 2007; van Driel et al., 2014).

Figure 14. Science subject matter knowledge (SMK) in the consensus model and the hypothesized model. Consensus model reproduced from “On the beauty of knowing then not knowing: Pinning down the elusive qualities of PCK,” by V. Kind, 2015, in A. Berry, P. Friedrichsen, & J. Loughran (Eds.), Re-examining pedagogical content knowledge in science education, p. 192. Copyright 2015 by Routledge. Reproduced with permission.

In the consensus model (see Figure 14), science SMK is considered to be one of the teacher professional knowledge bases. It has a direct effect on topic specific professional knowledge (TSPK) and an indirect effect on beliefs about effective science
TEACHERS’ KNOWLEDGE, BELIEFS, AND PRACTICES IN SCIENCE

instruction and classroom practices. In the hypothesized model (see Figure 14), all direct and indirect effects were maintained. An additional direct effect from SMK to three dimensional classroom practices was added to reflect the relationship between SMK and three dimensional classroom practices that was documented in the literature that is reviewed in this section. Furthermore, an additional direct effect from SMK to three dimensional beliefs about effective science instruction was added because it was hypothesized that three dimensional beliefs about effective science instruction could mediate the relationship between SMK and three dimensional classroom practices.

**Types of subject matter knowledge.** In initial studies about SMK, an indicator for SMK was the number of college-level science courses a teacher had taken. For instance, in a meta-analysis of 65 studies conducted between 1966 and 1975, Druva and Anderson (1983) documented a positive relationship between science training and teacher effectiveness. For the meta-analysis, SMK was measured by the number of science courses taken and teacher effectiveness was measured by an effectiveness scale developed by the authors. The effectiveness scale included multiple components of effective teaching such as method of teaching, content development, and questioning.

In the 1980s, when the conception of the science teacher as the “knower” emerged, researchers began examining teachers’ conceptions of science rather than focusing simply on science coursework. At this time, measures of SMK became more varied in nature, and ultimately assessed a range of components related to SMK. For instance, some studies examined understanding of selected science topics or conceptual knowledge, others examined understanding of the nature of the discipline or nature of science, and still others examined subject matter knowledge structures or how teachers
formed networks of related science content (Gess-Newsome, 1999; Lederman & Gess-Newsome, 1992). The trend of assessing various components of SMK such as conceptual knowledge of a topic, knowledge of the nature of science, and knowledge structures, has continued in current work (van Driel et al., 2014). As a result, literature connecting SMK to classroom practices is often varied depending upon the conceptualization of SMK. The present study examined SMK as it relates to conceptual knowledge of particular topics in science. Gess-Newsome (1999) defined conceptual knowledge of topics as the facts, concepts, principles, and procedures that are typically taught in a science classroom.

TEACHERS’ KNOWLEDGE, BELIEFS, AND PRACTICES IN SCIENCE

practices was conducted through classroom observations and indirect assessment of classroom practices was measured by asking teachers to describe how they would plan or prepare for instruction or react to simulated teaching situations (Lederman & Gess-Newsome, 1992). SMK was measured in a variety of ways that extended beyond the number of science courses taken. Techniques for assessing SMK included card sorting tasks and interviews (Brickhouse, 1989, as cited in Lederman & Gess-Newsome, 1992; Roth et al., 1987; D. C. Smith & Neale, 1989) in addition to more traditional paper and pencil assessments of content knowledge (Dobey & Schafer, 1984; Duschl & Wright, 1989; Lederman & Zeidler, 1987; Zeidler & Lederman, 1989). In the review, Lederman and Gess-Newsome (1992) documented whether or not relationships between SMK and classroom practices were detected, but did not comment on the types of relationships. Analysis revealed that out of the seven studies utilizing direct observations of teachers, four detected a positive relationship between SMK and classroom practices (Brickhouse, 1989, as cited in Lederman & Gess-Newsome, 1992; Dobey & Schafer, 1984; Roth et al., 1987; D. C. Smith & Neale, 1989) and three failed to uncover a relationship between SMK and classroom practices (Duschl & Wright, 1989; Lederman & Zeidler, 1987; Zeidler & Lederman, 1989). Moreover, in all of the studies that utilized indirect measures of classroom practice, positive relationships between SMK and classroom practices were detected (Baxter et al., 1985, as cited in Lederman & Gess-Newsome, 1992; Carlsen, 1989, as cited in Lederman & Gess-Newsome, 1992; Clermont & Krajcik, 1989, as cited in Lederman & Gess-Newsome, 1992; Hashweh, 1986, as cited in Lederman & Gess-Newsome, 1992; Krajcik & Layman, 1989, as cited in Lederman & Gess-Newsome, 1992).
The presence and absence of relationships can be interpreted in two ways. First, an indirect relationship between SMK and classroom practices, as mediated by pedagogical content knowledge (PCK) or beliefs about effective science instruction, could contribute to the tenuous relationship between SMK and classroom practices. Intervening variables such as PCK and teachers’ beliefs could potentially mediate the relationship between SMK and classroom practices. Second, the differences in findings depending on the method of measuring classroom practices may indicate that the investigations were, in fact, measuring two different constructs. When SMK was measured by direct observation of classroom practice, the authors may have actually measured personal pedagogical content knowledge and skill (PCK&S), or the actual practice of teaching. On the other hand, when SMK was measured using indirect measures of classroom practice, the authors may have actually measured personal PCK, or the planning and preparing for teaching. Regardless, the results from these studies suggested that SMK is related to classroom practices, although the nature of the relationship between SMK and classroom practices is still unclear.

**Subject matter knowledge and three dimensional classroom practices.** More recent research has explored the relationship between SMK and inquiry-based, reform-oriented, and three dimensional classroom practices. In general, these studies have been qualitative in nature with small sample sizes (Carlsen, 1993; Gess-Newsome & Lederman, 1995; Hollon, Roth, & Anderson, 1991; Sanders, Borko, & Lockard, 1993). In addition, most of the studies focused on middle school and high school science teachers. The conclusions have demonstrated that SMK matters in a teacher’s selection of classroom practices, though the exact nature how it matters is still unclear.
Several of the studies relating SMK to constructivist classroom practices have demonstrated that when teachers have lower levels of SMK, they tend to rely on algorithms and facts, guidance from textbooks or curricula, and teacher-centered instruction (Gess-Newsome, 1999; Hashweh, 1987; Lee, 1995; Sanders et al., 1993). For instance, the authors of three case studies investigating the relationship between SMK and use of instructional materials provided evidence to suggest that teachers with lower levels of SMK tended to rely more heavily on instructional materials (Hashweh, 1987; Lee, 1995; Sanders et al., 1993). In two of the studies, low and high levels of SMK were artificially produced by asking teachers to plan both within and outside of their science content area of expertise (Hashweh, 1987; Sanders et al., 1993). For instance, biology teachers were asked to plan both biology lessons and physics lessons. When biology teachers planned physics lessons, the teachers were planning outside of their content area of expertise. In the research, SMK was assessed using paper and pencil assessments, concept mapping, card sorting for conceptual knowledge on a particular topic (Hashweh, 1987), and teacher interviews (Lee, 1995; Sanders et al., 1993). Teaching practices were assessed using indirect measures such as planning tests or responding to teaching situations (Hashweh, 1987) and direct measures such as classroom observations (Lee, 1995; Sanders et al., 1993). Results from all three studies indicated that teachers not only depended more heavily on instructional materials in areas in which they had lower SMK, but they were also more likely to emphasize the facts and procedures of an activity (Hashweh, 1987; Lee, 1995; Sanders et al., 1993). When teachers planned in areas in which they had higher levels of SMK, they were better able to modify existing activities or investigations to incorporate additional concepts and science practices, reorganize
instructional materials to improve coherence and flow, and add concepts to existing lessons or unit plans to enhance student learning (Hashweh, 1987).

Teachers with lower levels of SMK not only relied more heavily on instructional materials, but they also tended to have a more limited instructional repertoire. This means that teachers with lower levels of SMK tended to have limited flexibility in instructional approaches and generally depended on classroom practices consistent with the traditional paradigm for science education. Traditional practices included lecture-based approaches, limited hands-on experiences, and limited flexibility with respect to activity structure. Evidence for these claims has been substantiated by three case studies that examined inquiry-based instructional practices as they related to SMK (Canbazoğlu, Demirrelli, & Kavak, 2010; Hollon et al., 1991; Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008). For instance, Rollnick et al. (2008) observed a lack of flexibility with respect to instructional approaches and a reliance on algorithms or facts on the part of the teacher, an observation consistent with the claims made by Gess-Newsome (1999). Hollon et al. (1991) demonstrated that higher levels of SMK helped teachers determine both the main ideas of the content and the ways in which these ideas connected with each other. Teachers with higher levels of SMK tended to engage students in sense-making and knowledge building more than the teachers with lower levels of SMK. Canbazoğlu et al. (2010) concluded that low levels of SMK limited the planning and implementation of instructional activities to more traditional approaches.

Results from the aforementioned case studies indicated that teachers were more constrained with respect to activity structure and instructional approaches when they had lower levels of SMK; they had a limited instructional repertoire and their instructional
approaches typically aligned with the traditional paradigm for science teaching and learning. Findings from these case studies clearly indicated that low levels of SMK can limit instructional repertoire in ways that may prevent the implementation of three-dimensional teaching and learning.

**Variables associated with subject matter knowledge.** Although SMK appears to play a role in successfully implementing constructivist classroom practices or three-dimensional classroom practices, SMK by itself is not sufficient. Shulman (1987) argued that teachers with similar levels of SMK may not be equally effective, implying that there are other mediating factors that impact effective teaching. Constructs such as teachers’ beliefs and PCK play an important role in mediating the relationship between SMK and successfully implementing three-dimensional classroom practices.

In a study demonstrating the mediating role of intervening variables, Gess-Newsome and Lederman (1995) interviewed and observed five male high school teachers. The authors deduced SMK from classroom observations. The resultant analysis of classroom practices suggested varied relationships between SMK and classroom practices. A direct relationship between SMK and classroom practices was detected for one of the teachers. For the other teachers, however, there was a limited translation of SMK to practice. The differences offer support for the hypothesis that intervening variables play an important role in the translation of SMK to practices.

In a similar example involving a professional development opportunity that aimed to improve inquiry-based classroom practices, Alonzo (2002) tracked changes in SMK by exposing primary teachers to more advanced science subject matter and by modeling inquiry-based pedagogy. The author indicated that when teachers achieved high levels of
learning or high SMK, they used their content knowledge more extensively to question and guide students’ learning. At lower levels of SMK, teachers tended to revert to direct instruction to tell students how “it” worked. Although SMK increased over the time of the study, few teachers demonstrated growth in their ability to incorporate content knowledge more effectively into their classroom practices. This suggests that although teachers may grow in content knowledge, SMK may not directly or immediately impact classroom practices, implying that mediating variables may play an important role in the relationship between SMK and classroom practices.

In summary, SMK is necessary but not sufficient for successful implementation of three dimensional classroom practices. There are likely variables mediating the relationship between SMK and three dimensional classroom practices. Some of the intervening constructs include PCK and beliefs about science teaching and learning. These constructs will be explored in the following sections of the Literature Review.

**Beliefs About Effective Science Instruction**

According to the consensus model for teacher knowledge and classroom practices, subject matter knowledge (SMK) impacts topic specific professional knowledge (TSPK), which in turn is filtered or amplified by teachers’ beliefs to influence classroom practices. Examining the impact of teachers’ beliefs on classroom practices is critical to understanding the ways by which teachers’ knowledge, beliefs, and practices interact within the three dimensional paradigm for science teaching and learning.

In the consensus model (see Figure 15), TSPK has a direct effect on beliefs about effective science instruction. In addition, beliefs about effective science instruction has a direct effect on three dimensional classroom practices. In the hypothesized model, a
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direct relationship between SMK and three dimensional beliefs about effective science instruction was added to test the hypothesis that three dimensional beliefs about effective science instruction mediates the relationship between SMK and three dimensional classroom practices.

Figure 15. Three dimensional beliefs about effective science instruction in the consensus model and the hypothesized model. Consensus model reproduced from “On the beauty of knowing then not knowing: Pinning down the elusive qualities of PCK,” by V. Kind, 2015, in A. Berry, P. Friedrichsen, & J. Loughran (Eds.), Re-examining pedagogical content knowledge in science education, p. 192. Copyright 2015 by Routledge. Reproduced with permission.

**Types of beliefs.** Teacher beliefs and knowledge are intertwined constructs that can be difficult to separate. In fact, the two constructs are often viewed as independent yet overlapping (Alexander & Dochy, 1995); defining each construct without the other can be complicated (Jones & Leagon, 2014). Pajares (1992) acknowledged the poor conceptualizations and differing perspectives on teacher beliefs documented in the literature and suggested that beliefs can refer to perceptions, attitudes, values, and implicit or explicit theories about effective science instruction and the ways by which students learn. Building on Pajares’ (1992) work, Jones and Leagon (2014) proposed that

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knowledge is distinct from beliefs in that knowledge is strictly cognitive in nature while
beliefs have both cognitive and affective components.

Multiple types of beliefs are associated with science teaching and learning
including epistemological beliefs, beliefs about the nature of science, beliefs about
learning, self-efficacy beliefs, beliefs about students, and beliefs about inquiry (Jones &
Leagon, 2014). Although all beliefs are involved in science teaching and learning, some
beliefs are more strongly related to classroom practices than others. Jones and Carter
(2007) organized the various types of beliefs into a blended theoretical framework for
teachers’ beliefs. The theoretical framework was developed by reviewing science teacher
attitude and belief literature and by incorporating theoretical models from social
psychology. In the model developed by Jones and Carter (2007), a particular emphasis
was placed on the impact of epistemologies, or beliefs about effective science teaching
and learning, on classroom practices. Similarly, Friedrichsen, van Driel, and Abell
(2011) suggested that beliefs about effective science instruction was one of three core
beliefs impacting classroom practices. The other two core beliefs were beliefs about the
purposes and goals of science teaching and beliefs about the nature of science.
Furthermore, Lotter, Harwood, and Bonner (2007) demonstrated that beliefs about
effective science instruction represented a core belief that guided high school science
teachers’ use of inquiry. The literature base clearly supports the claim that beliefs about
effective science instruction has an important impact on three dimensional classroom
practices.

Three dimensional beliefs and classroom practices. Researchers have
demonstrated a relationship between teachers’ beliefs about effective science instruction
and classroom practices in multiple case studies. Analyses and interviews in a study of four effective primary teachers suggested that teachers’ beliefs about effective science instruction in combination with contextual factors had a significant impact on classroom practices (Fitzgerald, Dawson, & Hackling, 2013). Similarly, in a case study of three high school science teachers, Brickhouse (1990) demonstrated that teachers’ views on how scientists construct knowledge are consistent with the ways in which teachers believe students should learn science. Beliefs about how students should learn science, in turn, impacted how teachers approached classroom practices.

Although studies have demonstrated a positive relationship between teachers’ beliefs about effective science instruction and classroom practices, the findings are not always consistent. For instance, Anderson (2015) examined the espoused beliefs and teaching practices of three primary teachers. The espoused beliefs of two of the three teachers were reflected in their teaching practices, but this relationship did not exist for the third teacher. Rather, the third teacher’s espoused beliefs about effective science instruction related to three dimensional learning despite the fact that the teacher’s classroom practices related more to fact finding than to figuring out. Similarly, Crawford (2007) observed five prospective teachers as they worked to enact inquiry. Although the teachers articulated beliefs about effective science instruction consistent with inquiry-based learning, the classroom practices included a range of practices from traditional or lecture style practices to full and open inquiry. Crawford (2007) suggested that the disagreement between beliefs and practices was likely because teachers hold complex and sometimes conflicting beliefs. For instance, the teachers in the study also held beliefs about the purpose of school and the role of the teacher and students, such as
teacher oriented beliefs, which conflicted with beliefs about inquiry as an effective instructional approach. In a review, Mansour (2009) identified consistencies and inconsistencies between beliefs and practices and argued that teachers’ beliefs, knowledge, and practices are intertwined in a complex network.

The relationship between beliefs about effective science instruction and classroom practices may sometimes be unclear because beliefs act as a filter or amplifier between teacher knowledge and classroom practice, only partially explaining classroom practices. For example, SMK may have a strong impact on classroom practices and this impact may be mediated by beliefs. Both Mansour (2009) and Kagan (1992) regarded beliefs as filters through which information passes to interpret new experiences. In this way, beliefs can act as an information organizer or priority categorizer (Mansour, 2009) and are appropriately included in the consensus model.

**Three dimensional beliefs and three dimensional classroom practices.** If beliefs act as a filter or amplifier between teacher knowledge and classroom practices, it is likely that beliefs about effective science instruction consistent with three dimensional science teaching and learning would amplify the likelihood of teachers implementing classroom practices consistent with the proposed reforms. A variety of studies examining the relationship between beliefs about effective science instruction and instructional practices consistent with the reforms called for by the Framework (National Research Council, 2012) and the NGSS have demonstrated that teachers’ beliefs can amplify the likelihood of classroom practices consistent with the proposed reforms. For instance, Roehrig and Luft (2004b) examined the beliefs and practices of ten beginning chemistry teachers. Through interviews and observations of practice, the authors drew the
conclusion that teachers with didactic or traditional beliefs were more likely to have traditional classroom practices while teachers with constructivist beliefs were more likely to practice inquiry in the classroom. Hashweh (1985, 1996) demonstrated that teachers with constructivist views held larger repertoires of teaching strategies, tended to use strategies that promoted conceptual change, and were more likely to recognize students’ alternative conceptions. In a case study of two middle school teachers, beliefs about science as a body of facts inhibited the implementation of an inquiry-based curriculum (Cronin-Jones, 1991). Although these findings do not necessarily demonstrate that constructivist beliefs immediately lead to implementation of three dimensional classroom practices, they do demonstrate that when beliefs about effective science instruction are at odds with a constructivist curriculum, the conflict may inhibit the implementation of the constructivist curriculum (Benson, 1989).

The findings relating constructivist beliefs to classroom practices consistent with practices called for by the Framework (National Research Council, 2012) and the NGSS are promising in that they suggest that changing teachers’ beliefs about effective science instruction will likely impact classroom practices. Unfortunately, most current teachers were not trained in three dimensional learning and have not yet developed beliefs about effective science instruction that are consistent with the reforms called for by the three dimensional paradigm for science teaching and learning. For instance, 200 primary teachers representing a national sample from the 2012 NSSME completed a survey about their beliefs about science teaching and learning. Forty percent of primary teachers surveyed indicated that teachers should explain ideas to students before having them consider evidence for the idea. More than half of the respondents indicated that lab
activities should be used primarily to reinforce ideas that students have already learned, and 80% agreed that students should be given definitions of new vocabulary at the beginning of instruction on an idea (Trygstad et al., 2013). These opinions are consistent with the traditional paradigm for science teaching and learning and not the three-dimensional paradigm.

Variables associated with three dimensional beliefs. Because beliefs about effective science instruction act as a filter or amplifier in the consensus model, beliefs about effective science instruction play an important role in determining the overall nature of the relationships among variables included in the consensus model. The importance of beliefs about effective science instruction in determining the overall structure of the relationships among the variables in the consensus model was demonstrated in a study using the pentagon model for teacher knowledge (Park & Oliver, 2008). Park and Chen (2012) mapped the relationships among the components of teacher knowledge. Using observations, interviews, lesson plans, instructional materials, and work samples from four high school biology classrooms teaching about heredity and photosynthesis, the authors developed iterative PCK maps over multiple observations to document the interconnectedness among the components of teacher knowledge. Using these maps, Park and Chen (2012) concluded that knowledge of student understanding and knowledge of instructional strategies and representations were very important in influencing PCK and classroom practices. Furthermore, didactic or traditional beliefs about effective science instruction directly shaped teachers’ instructional strategies and thus limited the connections between instruction strategies and other model components.
such as knowledge of the science curriculum. As such, it can be concluded that didactic beliefs had the ability to change the relationships in the model.

Although a path from subject matter knowledge (SMK) to beliefs about effective science instruction does not exist in the consensus model, the path was added in the hypothesized model. Gess-Newsome (2015) asserted that teachers’ beliefs can act as amplifiers or filters between topic specific professional knowledge (TSPK) and classroom practices. If teachers’ beliefs can act as amplifiers or filters between TSPK and classroom practices, it follows that teachers’ beliefs should act as amplifiers or filters between SMK and classroom practices. As Pajares (1992) commented, two teachers may have similar levels of SMK but implement different classroom practices. Differences in teachers’ beliefs may mediate the relationship between SMK and classroom practices. As such, a path from SMK to beliefs about effective science instruction was added to the hypothesized model.

**Topic Specific Professional Knowledge**

Intervening constructs such as pedagogical content knowledge (PCK) and beliefs about effective science instruction likely mediate the relationship between subject matter knowledge (SMK) and three dimensional classroom practices. In the consensus model (see Figure 16), some components of PCK have been unpacked into a new construct called topic specific professional knowledge (TSPK). The new TSPK construct is directly affected by SMK and has direct effects on beliefs about effective science instruction and classroom practices in the consensus model. In the hypothesized model (see Figure 16), all direct and indirect effects were maintained. This section will review literature related to TSPK.
Figure 16. Topic specific professional knowledge (TSPK) in the consensus model and the hypothesized model. Consensus model reproduced from “On the beauty of knowing then not knowing: Pinning down the elusive qualities of PCK,” by V. Kind, 2015, in A. Berry, P. Friedrichsen, & J. Loughran (Eds.), Re-examining pedagogical content knowledge in science education, p. 192. Copyright 2015 by Routledge. Reproduced with permission.

Defining topic specific professional knowledge. Before proceeding, an important distinction must be made between PCK and TSPK. When Shulman (1986, 1987) first introduced the idea of PCK, the intention was to distinguish between the knowledge teachers have for teaching a topic and the knowledge of subject matter experts or general teaching knowledge. As researchers further investigated the construct of PCK, it became clear that PCK was a larger construct than originally conceptualized. In addition, some researchers conceptualized PCK as a knowledge base while others viewed PCK as both a knowledge base and a skill used in the practice of teaching (Gess-Newsome, 2015). The varying perspectives led to questions about whether PCK could be measured separately from the act of teaching (Gess-Newsome, 2015).

Although PCK is a well-researched construct, the operational definitions and subsequent approaches for examining PCK have varied greatly (Abell, 2007; Grossman,
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1990; Magnusson et al., 1999; Park & Oliver, 2008; Shulman, 1986, 1987). The participants in the 2012 research summit aimed to resolve some of the differences by developing the consensus conceptual model for PCK (Gess-Newsome, 2015; Kind, 2015). In an effort to unpack the ideas embedded into the PCK construct, the PCK summit team separated the components of PCK that were specific to the individual teacher (personal knowledge) from knowledge that was shared among members of the community (professional knowledge). The result was the creation of a new construct called TSPK.

As a construct, TSPK includes many of the ideas formerly packed into PCK (Gess-Newsome, 2015). TSPK is general knowledge held by the science education community and generated through research. It is not specific to a particular context or a particular group of students. TSPK is a blend of subject matter and pedagogy that occurs at the topic level. It includes the knowledge necessary to determine instructional strategies, understand students’ developing understanding, and knowledge to integrate the three dimensions of science teaching and learning (Gess-Newsome, 2015).

Because TSPK is a new construct and because the types of TSPK being explored are related to relatively new reforms, the construct has yet to appear as a widely accepted construct in the literature base. Although TSPK has not been extensively addressed in the literature, several studies examining a construct the authors defined as PCK may have actually been measuring components of TSPK. For instance, a research team working in South Africa investigated components of TSPK, but used a different name for the construct (Rollnick & Mavhunga, 2015). Leading up to the identification of the TSPK-like construct, Rollnick and Mavhunga (2015) had been working to develop measurement...
instruments for PCK. Mavhunga (2012) recognized the importance of the interaction between SMK and PCK and proposed that SMK transforms five knowledge components of PCK for effective use in teaching: (a) students’ prior knowledge, (b) curricular saliency, (c) what makes a topic difficult to teach, (d) representations, and (e) conceptual teaching strategies. Mavhunga (2012) further argued that the transformation of the five knowledge components previously mentioned is topic specific. The transformation of knowledge within that topic ultimately impacts teaching practices for that topic. Rather than continuing to refer to the five knowledge components of PCK transformed by SMK as sub-components of PCK, Mavhunga (2012) proposed that a new construct, topic specific PCK (TSPCK), could be used. Rollnick and Mavhunga (2015) suggested that TSPCK is closely aligned to mathematical content knowledge for teaching (Ball, Thames, & Phelps, 2008) and to TSPK in the consensus model.

**Topic specific professional knowledge and three dimensional classroom practices.** Some studies have investigated the relationship between TSPK and three dimensional classroom practices, though the components of TSPK were packed into the complex PCK construct. For instance, Park, Jang, Chen, and Jung (2011) videotaped and scored science lessons using a reform-oriented observation protocol in an effort to determine which aspects of PCK are necessary for reform-oriented science teaching. The researchers measured PCK using a rubric that included the five subcomponents of PCK proposed by Magnusson et al. (1999). The subcomponents were orientations toward science teaching, knowledge of assessment, and knowledge of student understanding, knowledge of instructional strategies, and knowledge of science curricula. Pearson correlations were calculated between the subcomponents of PCK and scores on the
observation protocol. The authors detected a strong correlation between PCK and reform-oriented classroom practices \( (r = .831, p < .01) \), particularly for the knowledge of student understanding \( (r = .819, p < .01) \) and knowledge of instructional strategies \( (r = .795, p < .01) \) subcomponents. These findings are especially relevant to TSPK because two of the measures used for PCK – knowledge of student understanding and knowledge of instructional strategies - were most likely measuring what is now referred to as TSPK. The authors concluded that knowledge of student understanding and knowledge of instructional strategies were necessary for reformed teaching, leading to the conclusion that TSPK is likely necessary for reformed science teaching.

In a larger study, the researchers involved in the 2012 NSSME used what they called a proxy measurement for PCK (A. A. Smith et al., 2013). The proxy measurement asked teachers to report their perceptions of preparedness to teach a particular unit. The items used for this measure addressed perceptions of preparedness to address student prior conceptions and anticipate student difficulties. In the consensus model, this aspect of PCK would be included as a component of TSPK. A. A. Smith et al. (2013) then regressed multiple teacher-level predictors, including the proxy for PCK, on reform oriented instructional practices. Teachers who had higher perceptions of PCK were more likely to emphasize reform oriented instructional objectives \( (\beta = 0.27, p < .05) \). Findings from this multiple regression analysis clearly indicated that TSPK played an important role in predicting three dimensional classroom practices.

In summary, TSPK is a new construct that has yet to appear regularly in the literature base. Several researchers who previously investigated components of PCK may have actually been exploring TSPK. In such studies, the authors have detected a
relationship between TSPK and three dimensional classroom practices. Because TSPK is a new construct, however, more research is needed to determine the ways by which TSPK interacts with science SMK, beliefs about effective science instruction, and three dimensional classroom practices.

**Interactions Among Teachers’ Knowledge, Beliefs, and Classroom Practices**

The teacher knowledge, beliefs, and practices literature reviewed thus far has examined one of the constructs in detail or has examined the relationship between two of the constructs. For instance, the literature base for subject matter knowledge (SMK) examined only SMK or the relationships between SMK and classroom practices. It did not, however, examine the structure of the relationships among SMK, pedagogical content knowledge (PCK), beliefs about effective science instruction, and classroom practices. Although investigating the duality between two constructs may provide important insights, most researchers have concluded that many constructs work in larger combinations to influence classroom practices. Teaching is a complex activity that is influenced in many different ways. Accordingly, many researchers have advocated for the importance of examining the interactions among multiple constructs and the ways by which they influence classroom practice, rather than restricting investigations to the impact of one construct on another (Abell, 2008; Friedrichsen et al., 2011; Keys & Bryan, 2001; Park & Chen, 2012; Park & Oliver, 2008).

Several researchers have started to examine the complex relationships among teachers’ knowledge, beliefs, and practices. For instance, Roehrig and Luft (2004a) qualitatively assessed 14 teachers to determine constraints that teachers face when attempting to implement inquiry-based instructional practices. A variety of constructs
were examined including SMK, views on the nature of science, beliefs, and pedagogical knowledge. Roehrig and Luft (2004a) concluded that none of the aforementioned variables could independently predict implementation of inquiry-based instruction. Rather, all of the factors appeared to work collectively, yet in different degrees, to influence instruction. When reinterpreted in light of these findings, it becomes clear that some previous studies investigating the influence of SMK, PCK, and beliefs on classroom practices may have yielded unclear results because the interaction among the constructs may play an important role in predicting classroom practices.

In addition to qualitative studies, the authors of a quantitative study investigated the interactions among SMK, PCK, beliefs about effective science instruction, and classroom practices. Through questionnaires and observations of 34 teachers, Saad and BouJaoude (2012) related teachers knowledge and beliefs to classroom practices. The authors were not able to detect significant relationships among beliefs, knowledge, and practices. The failure to detect relationships among the constructs may have been because Saad and BouJaoude (2012) tested the relationship using correlations between pairs of constructs rather than examining the interacting structure among all of the constructs. As demonstrated through the studies published by Roehrig and Luft (2004a, 2004b), correlations between two variables may not exist. Rather, the relationships among the variables may become significant when the entire structure is examined such that all variables are included in the model. In sum, the literature that detailed investigations among teacher knowledge, beliefs, and practices suggested that the relationships among the constructs are complex and interdependent.
Summary and Implications of the Literature Review

The paradigm shift in science education to three dimensional teaching and learning will require most teachers of science in states that have adopted the NGSS to transition from traditional to three dimensional classroom practices. Three dimensional classroom practices integrate science and engineering practices, disciplinary core ideas, and crosscutting concepts. Drawing from a constructivist framework, three dimensional classroom practices are characterized by student engagement in *figuring out* rather than *learning about* science phenomena. Changing classroom practices will be particularly important for teachers of science in kindergarten through sixth grade. This is because the three dimensional framework is built upon the idea of the progressive building of understanding. Over time, students build more sophisticated knowledge of science ideas. In order to be successful, students must start to build understanding early in their academic career. As has been demonstrated, however, kindergarten through sixth grade teachers generally struggle to teach science and classroom practices generally align with the traditional paradigm for science education. In order for reforms to succeed, kindergarten through sixth grade teachers will need to change classroom practices in science.

Changing classroom practices will require shifts in teachers’ knowledge and beliefs. The consensus model for teacher knowledge (Gess-Newsome, 2015; Kind, 2015) can provide a useful framework for examining the interconnections among teachers’ knowledge, beliefs, and practices. The consensus model suggests that teachers’ subject matter knowledge (SMK) contributes to the development of topic specific professional knowledge (TSPK), which is filtered or amplified by teachers’ beliefs to impact
classroom practices. Prior research has demonstrated that SMK clearly plays a role in effecting classroom practices, but that SMK on its own is insufficient in explaining all of the variance in classroom practices. Rather, researchers have hypothesized that both pedagogical content knowledge (PCK), which is reinterpreted as TSPK in the consensus model, and teachers’ beliefs may also contribute to classroom practices. As has been demonstrated, multiple lines of evidence have supported the claim that teachers’ beliefs either amplify or filter teacher knowledge bases to impact classroom practices. TSPK, which reinterprets certain aspects of PCK, is a new construct that has yet to be explored. Previous research on PCK, however, suggests that TSPK may play an important role in affecting classroom practices.

Given the complex interrelationships among teachers’ knowledge, beliefs, and practices, several researchers have proposed that it may be more effective to examine the structure of all of the influences on classroom practices together rather than examining the impact of only one influence on classroom practices. Initial studies examining the interrelationships among teachers’ knowledge, beliefs, and practices have supported this hypothesis, though the structure and strengths of the relationships are still unclear. The present study aimed to uncover the underlying structure of the relationships among teachers’ knowledge, beliefs, and practices and determine the relative strengths of the relationships.
CHAPTER 3: RESEARCH METHODS

The release of the Framework (National Research Council, 2012) and the *Next Generation Science Standards* (NGSS) marked an important moment in the paradigm shift from the traditional paradigm for science teaching and learning to the three dimensional paradigm. In the traditional paradigm, students *learn about* science facts. In the three dimensional paradigm, students *figure out* core science ideas. The fundamental components of the three dimensional paradigm align with constructivist philosophies. In three dimensional learning, students work to make sense of and explain scientific phenomena using the key science and engineering practices, core disciplinary ideas, and crosscutting concepts identified in the Framework (National Research Council, 2012) and the NGSS.

For the vision of three dimensional teaching and learning to become a reality, three dimensional classroom practices must replace traditional classroom practices. Given the significant pedagogical shifts required for the replacement, teachers will need support to successfully transition classroom practices. In particular, elementary teachers will need to be supported through the transition because of the added emphasis on building core understanding in early grade levels.

Teachers’ subject matter knowledge (SMK), pedagogical content knowledge (PCK), and three dimensional beliefs about effective science instruction play a role in the successful implementation of three dimensional classroom practices, though the exact structure and nature of the relationships among the constructs has yet to be thoroughly identified and defined (Gess-Newsome, 2015; Kind, 2015). For instance, prior research
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has demonstrated that SMK is necessary but not sufficient in supporting three-dimensional classroom practices (Abell, 2007; Alonzo, 2002; van Driel et al., 2014). Three-dimensional beliefs about effective science instruction appear to be related to the implementation of three-dimensional classroom practices and could strengthen the relationship between three-dimensional classroom practices and other constructs (Anderson, 2015; Crawford, 2007; Fitzgerald et al., 2013; Jones & Carter, 2007; Jones & Leagon, 2014). In addition, PCK impacts classroom practices, though the PCK construct is complex, incorporates many subcomponents, and has been studied using a variety of conceptual frameworks and methods (Gess-Newsome, 2015).

The consensus model for teacher knowledge, classroom practice, and student outcomes that was developed at a 2012 research summit may provide a useful framework for determining the structure and nature of the relationships among teachers’ knowledge, beliefs, and practices in the context of three-dimensional reforms (Gess-Newsome, 2015; Kind, 2015). The contributors to the consensus model unpacked many ideas that were previously part of PCK into a new construct called topic-specific professional knowledge (TSPK). The new construct, TSPK, consists of knowledge of subject matter and pedagogy that is specific to a topic but not to a particular teacher or group of students. It is distinct from PCK in that TSPK is knowledge held by the professional community that is not specific to an individual teacher. On the other hand, PCK is knowledge held by an individual teacher and is specific to teaching a particular topic to a particular group of students in a particular context.

The consensus model (see Figure 17), is a new model for understanding the relationships among teacher knowledge, beliefs, and practices and is the first to
incorporate the TSPK construct. In the consensus model, SMK impacts TSPK, which is amplified or filtered through teachers’ beliefs to influence classroom practices. The relationships among SMK, TSPK, teachers’ beliefs, and classroom practices have yet to be tested using the consensus model as the theoretical framework.

The goals of the present study were to (1) empirically test one path embedded within the consensus model; (2) determine the amount of variance in three dimensional classroom practices that can be explained by the combined effect of science SMK, TSPK, and three dimensional beliefs about effective science instruction; and (3) examine the direct and indirect relationships among science SMK, TSPK, three dimensional beliefs about effective science instruction, and three dimensional classroom practices. In this Chapter, the three research questions and associated sub-questions are listed. Descriptions of the research design and data source are then presented. A review of the instruments used to measure each construct is offered. Particular emphasis is placed on the development of the instrument used to measure three dimensional beliefs about effective science instruction because the beliefs composite was newly constructed for the present study. Finally, a description of the data analysis is detailed.

**Research Questions**

The overall purpose of the present investigation was to (1) empirically test the consensus model; (2) determine the amount of variance in three dimensional classroom practices that can be explained by the combined effect of science subject matter knowledge (SMK), topic specific professional knowledge (TSPK) and three dimensional beliefs about effective science instruction; and (3) examine the direct and indirect relationships among the constructs included in the model. A hypothesized model (see
Figure 18) was developed to represent one path within the consensus model. Additional relationships were included in the hypothesized model to reflect findings from relevant research and to include the hypothesized mediating role of three dimensional beliefs about effective science instruction. Three research questions centered on the hypothesized model guided this study about the structure and nature of the relationships among teachers’ science SMK, TSPK, three dimensional beliefs about effective science instruction, and three dimensional classroom practices.

Figure 17. Consensus model for teacher knowledge, classroom practice, and student outcomes. Reproduced from “On the beauty of knowing then not knowing: Pinning down the elusive qualities of PCK,” by V. Kind, 2015, in A. Berry, P. Friedrichsen, & J. Loughran (Eds.), Re-examining pedagogical content knowledge in science education, p. 192. Copyright 2015 by Routledge. Reproduced with permission.
Figure 18. Hypothesized model for the relationships among science subject matter knowledge (SMK), topic specific professional knowledge (TSPK), three dimensional beliefs about effective science instruction, and three dimensional classroom practices.

Resesarch Question 1. Does the hypothesized model produce an estimated population covariance matrix consistent with the sample covariance matrix?

Resesarch Question 2. How much of the variance in three dimensional classroom practices is accounted for by the combined effect of SMK, TSPK, and three dimensional beliefs about effective science instruction?

Resesarch Question 3. What is the nature of the relationships among SMK, TSPK, three dimensional beliefs about effective science instruction, and three dimensional classroom practices?

Sub-Question A. What effect does SMK have on TSPK?

Sub-Question B. What effect does SMK have on three dimensional beliefs about effective science instruction?

Sub-Question C. What effect does SMK have on three dimensional classroom practices?
Sub-Question D. What effect does TSPK have on three dimensional beliefs about effective science instruction?

Sub-Question E. What effect does TSPK have on three dimensional classroom practices?

Sub-Question F. What effect does three dimensional beliefs about effective science instruction have on three dimensional classroom practices?

Sub-Question G. Does TSPK mediate the effect of SMK on three dimensional classroom practices?

Sub-Question H. Does three dimensional beliefs about effective science instruction mediate the relationship between TSPK and three dimensional classroom practices?

Sub-Question I. Does three dimensional beliefs about effective science instruction mediate the relationship between SMK and three dimensional classroom practices?

Sub-Question J. Do TSPK and three dimensional beliefs about effective science instruction mediate the relationship between SMK and three dimensional classroom practices?

**Research Design**

An ex post facto research design with hypotheses was the framework for a causal structural analysis of the relationships among science subject matter knowledge (SMK), topic specific professional knowledge (TSPK), three dimensional beliefs about effective science instruction, and three dimensional classroom practices (Vogt & Johnson, 2011). Data from a cross sectional survey were analyzed. The relationships among SMK,
TSPK, three dimensional beliefs about effective science instruction, and three
dimensional classroom practices were examined using structural equation modeling
(SEM). The overall model fit, variance in three dimensional classroom practices
explained by the combined effect of SMK, TSPK, and three dimensional beliefs about
effective science instruction, and specific estimates of relationships among SMK, TSPK,
three dimensional beliefs about effective science instruction, and three dimensional
classroom practices were determined.

Using SEM allowed for the examination of the relationships among multiple
independent and dependent variables (Tabachnick & Fidell, 2013). SEM falls within the
general linear model family and is closely related to other linear models such as ANOVA
and multiple regression. Using SEM provided several advantages over other statistical
models (Hoyle, 2012). First, SEM allowed for the examination of multiple variables at
the same time. Furthermore, the variables in SEM could be treated as both exogenous
and endogenous variables (Hoyle, 2012). This feature of SEM was especially important
when examining teachers’ knowledge, beliefs, and practices because of the complex
interactions among the constructs. Examining the interactions among SMK, TSPK, three
dimensional beliefs about effective science instruction, and three dimensional classroom
practices allowed for an examination of the ways by which each construct strengthened
or weakened the relationships among the other constructs. Second, SEM allowed for the
examination of constructs that were measured at different levels (Hoyle, 2012). For
instance, variables measured on different quasi-continuous scales, such as survey
variables, can be used in SEM. A final advantage of SEM is that it allowed the
researcher to test a theoretical model (Kline, 2011). Because the aim of this study was to
provide empirical support for the consensus model, a new theoretical model, by testing a hypothesized model that was constructed using the consensus model as a guide, SEM was an appropriate statistical analysis technique.

Data Source

Data for this study were collected as part of the 2012 National Survey of Science and Mathematics Education (NSSME). The 2012 NSSME was the fifth in a series of national surveys of science and mathematics education used to measure current trends in mathematics and science education. The first NSSME was administered in 1977. Horizon Research, Inc., led by Weis and Banilower (2013) and Banilower et al. (2013) designed and administered the survey through a grant from the National Science Foundation.

There were many advantages for using public-use, extant, secondary data from the 2012 NSSME. The first advantage was sample size. Using the 2012 NSSME data allowed for examination of a sample of 731 kindergarten through sixth grade teachers. The second advantage was that the measurements of two of the composites included within the hypothesized model were previously developed and tested. The measurements for topic specific professional knowledge (TSPK) (α = 0.88), and three dimensional classroom practices (α = 0.72) were carefully developed by the research team and tested for reliability (Weis & Banilower, 2013). The third advantage of secondary data was that probability sampling was conducted prior to collecting the data such that a nationally representative sample was surveyed (Weis & Banilower, 2013).

Despite the many advantages, one disadvantage of using secondary data was that the research was restricted to the pre-existing items and composites included in the
survey; the survey did not include an existing measure for three dimensional beliefs about effective science instruction. As a result, it was necessary for a new composite to be constructed to measure three dimensional beliefs about effective science instruction. The items available for the composite, however, were limited to the items that were already included in the 2012 NSSME, which did not fully address the many facets of three dimensional beliefs about effective science instruction. Furthermore, the survey only included self-reported items for SMK and TSPK. Using self-reported items can be a disadvantage because self-reported items measure teachers’ opinions of their SMK and TSPK and are thus an indirect measure.

Data Collection

Survey data were collected the same year that the Framework (National Research Council, 2012) was published and a year prior to publication of the NGSS. Prior to data collection, Horizon Research, Inc. secured permission to implement the study from appropriate state, district, and school level personnel (Banilower et al., 2013). Letters were mailed to the chief state school officers and superintendents of the districts of sampled schools. Survey instruments were provided upon request. Survey letters were mailed to teachers beginning in February 2012. Sampled teachers were offered a $25 honorarium for completing the teacher survey. Phone calls and e-mails were made to school coordinators to encourage participation. After data were collected, Horizon Research, Inc. made the 2012 National Survey of Science and Mathematics Education (NSSME) data set available for public use.

The Wright State University Institutional Review Board determined that the present study did not meet the Federal definition for human subjects research because the
data used in the study were de-identified. Therefore, the project did not require approval from the Institutional Review Board (see Appendix B). An application to access the 2012 NSSME public use data set was submitted to Horizon Research, Inc. on December 10, 2015. Access to the public use data set was granted to the researcher on December 16, 2015.

**Population and Sampling**

The sample for the 2012 National Survey of Science and Mathematics Education (NSSME) was a national probability sample of kindergarten through twelfth grade science and mathematics teachers in the 50 states of the United States and the District of Columbia (Weis & Banilower, 2013). The target population for the 2012 NSSME included teachers employed by all regular and private schools in the United States, excluding vocational/technical schools, schools offering alternative, special, or adult education only, and preschool/kindergarten-only schools. The present study used a subsample of kindergarten through sixth grade teachers who completed the 2012 NSSME science survey and reported about physical science, life science, or Earth and space science units.

The sample design for the 2012 NSSME involved clustering and stratification. First, schools were selected into the sample. A sampling frame for schools was constructed from the 2008-2009 Common Core of Data and 2007-2008 Private School Survey databases, both of which are programs of the U.S. Department of Education’s National Center for Education Statistics. Schools were stratified according to grade span as the primary strata, followed by Census region, school metro status, and school type. Schools were then randomly selected such that every school had a known, positive
probability of being drawn into the sample. A total of 2,000 public and private schools were solicited to participate and 1,504 schools agreed to participate (Weis & Banilower, 2013).

After schools were selected into the sample, the teacher sample was constructed. The target population for the teacher sample consisted of teachers in eligible schools who taught science and/or math. Of the 10,012 teachers selected into the sample, 77% returned surveys (Weis & Banilower, 2013). The authors of the survey considered the response rate to be excellent.

The sample used in the present study was a subset of the 2012 NSSME sample. The full 2012 NSSME sample included kindergarten through twelfth grade teachers who responded to the math or science surveys. The subsample used in the present study consisted of elementary teachers who responded to the science survey and who reported about teaching units in physical science, life science, or Earth and space science. As defined in the 2012 NSSME, elementary was defined as kindergarten through fifth grade plus sixth grade self-contained classrooms. Self-contained classrooms are classes in which one teacher teaches all of the core subject areas. In some cases, sixth grade students traveled to different teachers for different subject areas. Such classrooms were not included in the present study. Sampled teachers were randomly assigned either the science or the mathematics teacher survey. Only teachers who completed the science teacher survey were used in the sample for the present study.

As part of the survey, teachers were asked to reflect on teaching a particular unit in science. Teachers were asked to indicate whether their unit was a physics, chemistry, life science, Earth and space science, environmental science, or engineering unit.
Teachers who reported about a physical science, life science, or Earth and space science unit were included in the sample. Chemistry and physics units were both considered physical science units. Teachers who did not report about teaching a particular unit were excluded from the sample. Because the subset of teachers reporting about an engineering unit was so small (< 2% of the entire sample), teachers reporting about an engineering unit were also excluded from the sample. In addition, teachers who reported about an environmental sciences unit were excluded from the sample because a corresponding measure for subject matter knowledge (SMK) did not exist in the survey. Because an environmental science SMK measure was not included, a comparison of teachers’ SMK and topic specific professional knowledge (TSPK) could not be conducted for teachers who reported about an environmental sciences unit. The resulting sample included all elementary teachers who took the 2012 NSSME for science and reported about a physical science, life science, or Earth and space science unit. The cleaned data set included 731 elementary teachers.

As shown in Table 5, the sample consisted predominately of White, female elementary teachers. Most of the teachers worked in public schools and a majority of teachers worked in suburban schools in the South. Over half of the sample had between six and 20 years of experience teaching at the K-12 level. Although the sample may initially appear to underrepresent certain groups of teachers, it is important to remember that Horizon Research, Inc. went to great lengths to construct a national probability sample (Banilower et al., 2013). As such, the predominately White and female sample likely represents the demographics of elementary teachers in the United States.
Table 5

*Characteristics of the Sample*

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Percent of Teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>6</td>
</tr>
<tr>
<td>Female</td>
<td>94</td>
</tr>
<tr>
<td>Race</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>92.6</td>
</tr>
<tr>
<td>Non-White</td>
<td>7.4</td>
</tr>
<tr>
<td>Age</td>
<td></td>
</tr>
<tr>
<td>(\leq 30)</td>
<td>17.8</td>
</tr>
<tr>
<td>31-40</td>
<td>29</td>
</tr>
<tr>
<td>41-50</td>
<td>25.2</td>
</tr>
<tr>
<td>51-60</td>
<td>19.8</td>
</tr>
<tr>
<td>61+</td>
<td>8.2</td>
</tr>
<tr>
<td>Experience Teaching at the K-12 Level</td>
<td></td>
</tr>
<tr>
<td>0-2 years</td>
<td>10.6</td>
</tr>
<tr>
<td>3-5 years</td>
<td>15.9</td>
</tr>
<tr>
<td>6-10 years</td>
<td>20.5</td>
</tr>
<tr>
<td>11-20 years</td>
<td>33.2</td>
</tr>
<tr>
<td>(\geq 21) years</td>
<td>19.8</td>
</tr>
<tr>
<td>School Type</td>
<td></td>
</tr>
<tr>
<td>Public</td>
<td>90.2</td>
</tr>
<tr>
<td>Catholic</td>
<td>2.6</td>
</tr>
<tr>
<td>Non-Catholic Private</td>
<td>7.3</td>
</tr>
<tr>
<td>Community Type</td>
<td></td>
</tr>
<tr>
<td>Urban</td>
<td>26.1</td>
</tr>
<tr>
<td>Suburban</td>
<td>47.6</td>
</tr>
<tr>
<td>Rural</td>
<td>26.3</td>
</tr>
<tr>
<td>Region of the Country</td>
<td></td>
</tr>
<tr>
<td>Midwest</td>
<td>21.8</td>
</tr>
<tr>
<td>Northeast</td>
<td>14.8</td>
</tr>
<tr>
<td>South</td>
<td>50.6</td>
</tr>
<tr>
<td>West</td>
<td>12.9</td>
</tr>
</tbody>
</table>

*Note. n = 731.*
Large sample sizes are required for SEM to ensure accurate statistical estimates. The number of parameters in a structural model affects sample size requirements. Kline (2011) suggested that an ideal sample size would reflect the $N:q$ rule. The $N:q$ rule states that the ratio of cases ($N$) to the number of modeling parameters requiring statistical estimates ($q$) should be 20:1. The hypothesized model includes 10 modeling parameters requiring statistical estimates, so the sample size should be greater than $n = 200$. A sample size of 731 exceeds the requirements for sample size set forth by Kline (2011).

**Instrumentation**

All survey items were developed as part of the 2012 National Survey of Science and Mathematics Education (NSSME) (Weis & Banilower, 2013). Item development for the 2012 NSSME began with survey items that had been used in earlier versions of the survey. Survey items were reviewed by the project advisory board, which was comprised of experienced researchers in science and mathematics education. The project advisory board made recommendations about retaining and deleting items and adding new items relevant to the status of science and mathematics education at the time the survey was administered (Weis & Banilower, 2013). Preliminary drafts of the new items were sent to professional organizations for input. In science, these organizations included the National Science Teachers Association, the National Education Association, the American Federation of Teachers, and the National Catholic Education Association. The professional organizations provided feedback to Horizon Research, Inc. regarding content validity. Content validity is the degree to which the items used to measure an idea accurately represent that idea. By definition, content validity is not a statistical property, but rather a matter of expert judgement (Vogt & Johnson, 2011). Survey items were
subsequently revised, field tested, and revised again through an iterative process (Weis & Banilower, 2013).

Using factor analysis, Horizon Research, Inc. identified several sets of survey items in the 2012 NSSME that could be combined into composites (Weis & Banilower, 2013). Composites were calculated by summing the responses to the items associated with the composite and then dividing by the total points possible (Weis & Banilower, 2013). Composites were then placed on a 0-100 scale. Composite scores were not computed for respondents who responded to fewer than two-thirds of the items that formed the composite (Weis & Banilower, 2013). Two of the composites identified by Horizon Research, Inc. were used in this study. The first composite, originally called “perceptions of preparedness to implement instruction in a particular unit,” was used to measure topic specific professional knowledge (TSPK). The second composite, originally called “reform oriented instructional practices,” was used to measure three dimensional classroom practices. A detailed description of both composites and the use of both composites in the present study can be found in this Chapter. A third composite was developed as part of the present study to measure three dimensional beliefs about effective science instruction. The measure for SMK came from an individual item which asked teachers to respond to prompts about their preparedness to teach a particular subject in science.

Both SMK and TSPK were measured indirectly as teachers’ opinions about their content knowledge or preparedness to teach a particular unit. Measuring SMK and TSPK through self-report was deemed appropriate by the authors of the 2012 NSSME because the survey items can serve as a proxy for measuring knowledge (Banilower et al., 2013).
Fulkerson and Banilower (2014) argued that self-reports of preparedness to teach various science disciplines is an effective proxy for teachers’ SMK. The authors reported that data collected from items asking teachers about perceptions of preparedness to teach various science disciplines mirrored data collected from items asking teachers about college level content courses taken (Fulkerson & Banilower, 2014). Furthermore, Mayer (1999) documented evidence to support the claim that teachers generally report accurate estimates of their use of three dimensional classroom practices.

**Subject Matter Knowledge**

Subject matter knowledge (SMK) was measured using a one-item self-report of preparedness to teach various science disciplines. Teachers were asked to report how well prepared they felt to teach life science, Earth science, and physical science (see Table 6). Response options were rated on a four-point scale ranging from 1 – not adequately prepared to 4 – very well prepared. Teachers rated preparedness separately for life science, Earth science, and physical science. Responses for life science ($N = 860$, $M = 3.04$, $SD = .811$), Earth science ($N = 859$, $M = 2.97$, $SD = .807$), and physical science ($N = 857$, $M = 2.72$, $SD = .863$) were normally distributed and centered around an average of approximately 3. To allow for comparison of ratings across subject areas, ratings for preparedness to teach life science, Earth science, and physical science were standardized by calculating z-scores.

Because SMK is topic specific and because an individual elementary teacher’s SMK might vary for different science topics (Banilower et al., 2013; Gess-Newsome, 2015; van Driel et al., 2014), only one of the self-reported measures for SMK was used in this study. For instance, even though a teacher might have reported SMK for life science,
Earth science, and physical science, only the measure for one of the topic areas was used as that teacher’s measure of SMK. The topic area was selected based upon the teachers’ reported topic area for the topic specific professional knowledge (TSPK) items.

Table 6

*Items Used to Measure Subject Matter Knowledge (SMK)*

<table>
<thead>
<tr>
<th>How well prepared do you feel to teach each of the following subjects at the grade level(s) you teach, whether or not they are currently included in your teaching responsibilities?</th>
<th>Not adequately prepared</th>
<th>Somewhat prepared</th>
<th>Fairly well prepared</th>
<th>Very well prepared</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Life science</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>b. Earth science</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>c. Physical science</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
</tbody>
</table>


In responding to the TSPK items, teachers were asked to think about their most recent science unit. Teachers reported the specific science discipline for that unit. To determine SMK, the perceptions of preparedness z-score for the science discipline reported in the TSPK measure was used. For instance, if Teacher A responded to the TSPK items with an Earth science unit in mind, the SMK z-score for Earth science was used. If Teacher B responded to the TSPK items with a life science unit in mind, the SMK z-score for life science was used. This means that the science discipline for the SMK z-score matched each teachers’ TSPK science discipline and that every teacher’s SMK and TSPK scores were not based on the same discipline. After selecting the appropriate z-score for every teacher, the final score for SMK was standardized by calculating z-scores a second time.
Although it was not ideal to use a single item as the measure for SMK, the decision was made to use the single item measure because the item that was used was the best measure of SMK available in the 2012 National Survey for Science and Mathematics Education (NSSME). Other measures of SMK that were available in the 2012 NSSME included whether or not the teacher held a degree in science, the number of science courses that the teacher had taken, and how recently a teacher had taken a science course or engaged in science professional development. All of the aforementioned measures of SMK, however, are reflective of the SMK measures that were used prior to the 1980s (Druva & Anderson, 1983). In other words, measuring a teachers’ SMK using the number of courses taken or degrees earned reflects the view that teacher knowledge is a static component. Since Shulman (1986, 1987) presented the idea of pedagogical content knowledge (PCK), there has been a shift from viewing teacher knowledge as static to viewing the teacher as the ‘knower’ (van Driel et al., 2014). As such, the number of courses taken or degrees earned by a teacher does not necessarily equate to an accurate measure of SMK. Measuring SMK using a single item that asked teachers to respond to items about their preparedness to teach a particular topic allowed for the measurement of SMK to be reflective of the broad range of abilities within a particular topic area. Furthermore, the single item measurement for SMK allowed the measure for SMK to be topic specific. Topic specific SMK is a critical component of the consensus model, particularly as it relates to topic specific professional knowledge (TSPK).

**Topic Specific Professional Knowledge**

Topic specific professional knowledge (TSPK) was measured at the topic level rather than the subject level. Previous measures for constructs similar to TSPK have
been developed for specific topics (Ball et al., 2008; Mavhunga, 2012; Pitjeng, 2014). For instance, Mavhunga (2012) developed items related to specific topics within chemistry which required teachers to decide between specific representations of topics in chemistry. Although such measures provided a strong indication of TSPK for a particular topic, they would be difficult to use with teachers teaching a wide variety of topics. Rather than directly measuring TSPK using tools developed for specific topics, TSPK was measured in a more general way. In the 2012 National Survey of Science and Mathematics Education (NSSME), the authors created a composite that they referred to as “perceptions of preparedness to implement instruction in a unit” (Weis & Banilower, 2013). The authors of subsequent analyses using the same data suggested that this composite could be used as a proxy for pedagogical content knowledge (PCK) (A. A. Smith et al., 2013). Using the new definitions for PCK and TSPK outlined in the consensus model, the 2012 NSSME items for “preparedness to implement instruction in a unit” or PCK proxy (see Table 7) were likely better measures of TSPK than PCK. This is because the items included in this measure asked about preparedness to teach in a particular topic area but did not ask about preparedness to teach a particular group of students in a particular context. Because the 2012 NSSME items better aligned with the operational definition for TSPK than PCK, the composite score for the five PCK items was used to measure TSPK.

The TSPK measure asked teachers to think about teaching a particular unit of study and to report the topic area for the unit of study. Next, teachers responded to a series of items aimed to measure TSPK with the reported topic in mind. The items were generic in nature, so that they may apply to all topic areas. For instance, Item 1 asked
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teachers to rate how well prepared they felt to anticipate difficulties that students may have with particular science ideas and procedures in a particular unit. A teacher responding to this item could respond for a unit in chemistry topics or Earth science topics. In this way, TSPK could be measured across a variety of topics.

Table 7

*Items Used to Create the Topic Specific Professional Knowledge (TSPK) Composite*

<table>
<thead>
<tr>
<th>How well prepared did you feel to do each of the following as part of your instruction on this particular unit?</th>
<th>Not adequately prepared (1)</th>
<th>Somewhat prepared (2)</th>
<th>Fairly well prepared (3)</th>
<th>Very well prepared (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Anticipate difficulties that students may have with particular science ideas and procedures in this unit</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>2. Find out what students thought or already knew about the key science ideas</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>3. Implement the science textbook/module to be used during this unit</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>4. Monitor student understanding during this unit</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>5. Assess student understanding at the conclusion of this unit</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
</tbody>
</table>


In this study, TSPK was measured using a composite score on five items asking teachers to report how well prepared he or she felt to anticipate student difficulties, to find out what students know, to implement the science module, to monitor student understanding, and to assess student understanding. Respondents rated the items using a
four-point scale ranging from 1 – Not adequately prepared to 4 – Very well prepared.

The items used in the TSPK composite measured most of the components of TSPK related to student understanding, but did not necessarily address the components related to content representations. As such, the measure of TSPK in this study focused only on TSPK for student understanding. The items used to measure TSPK were identified through factor analysis and calculated as a composite in the 2012 NSSME (Weis & Banilower, 2013). The reliability and model fit for the composite were good ($\alpha = 0.88$, RMSEA < 0.01, SRMR < 0.01). To allow for comparison between TSPK and other measures, the score for TSPK was standardized by calculating the $z$-score.

**Three Dimensional Beliefs**

Teachers’ three dimensional beliefs about effective science instruction were measured by creating a composite of self-reported items asking about teachers’ three dimensional beliefs about effective science instruction. The composite for three dimensional beliefs about effective science instruction was the only newly constructed composite in the present study. Several items included in the 2012 National Survey of Science and Mathematics Education (NSSME) addressed teachers’ beliefs about effective science instruction (see Table 8), but in the preliminary factor analysis conducted by Weis and Banilower (2013), the authors did not identify a factor for teachers’ beliefs. One possible reason that a factor for teachers’ beliefs did not emerge during the preliminary factor analysis could be because many of the items on the survey addressed a variety of different types of beliefs, extending beyond three dimensional beliefs about effective science instruction.
Table 8

**Beliefs Items Included in the 2012 NSSME**

<table>
<thead>
<tr>
<th>Beliefs</th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>No opinion</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Students learn science best in classes with students of similar abilities.</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>B. Inadequacies in students’ science background can be overcome by effective teaching.</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>C. It is better for science instruction to focus on ideas in depth, even if that means covering fewer topics.</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>D. Students should be provided with the purpose for a lesson as it begins.</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>E. At the beginning of instruction on a science idea, students should be provided with definitions for new scientific vocabulary that will be used.</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>F. Teachers should explain an idea to students before having them consider evidence that relates to the idea.</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>G. Most class periods should include some review of previously covered ideas and skills.</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>H. Most class periods should provide opportunities for students to share their thinking and reasoning.</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>I. Hands-on/laboratory activities should be used primarily to reinforce a science idea that the students have already learned.</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>J. Students should be assigned homework most days.</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>K. Most class periods should conclude with a summary of the key ideas addressed.</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
</tbody>
</table>

TEACHERS’ KNOWLEDGE, BELIEFS, AND PRACTICES IN SCIENCE

Other items on the survey could have addressed beliefs about learning, self-efficacy beliefs, beliefs about students, beliefs about lesson structure, and beliefs about inquiry (Jones & Leagon, 2014). As such, it may have been difficult to detect relationships among all of the beliefs items. Rather, it was necessary to subdivide the beliefs items using a factor analysis on only the items relating to teachers’ beliefs in order to detect factors for the various different types of beliefs.

In an effort to identify the items that measured three dimensional beliefs about effective science instruction, an exploratory factor analysis was performed through IBM SPSS Version 23 on all 11 of the potential beliefs items from the 2012 NSSME. The goal of the factor analysis was to reduce the large number of items into a smaller number of beliefs factors and to identify a factor that aligned with the operational definition for three dimensional beliefs about effective science instruction.

*Data Screening.* The subset of elementary teachers who responded to the science survey focusing on a life science, physical science, or Earth and space science unit was identified. Prior to running the analysis, the data were screened with IBM SPSS Version 23 Frequencies, Explore, Plot, and Regression procedures for possible statistical assumption violations and to identify and treat any missing values and outliers. First, the data were screened for missing values on the 11 beliefs items (Items A-K). Between 4 and 10 values out of 766 were missing per item, which was less than 1.5% of the overall values for each item (see Table 9). The items were inspected for patterns in missing data. Two of the teachers did not respond to any of the beliefs items and a third teacher responded only to items A and B. Otherwise, there were no apparent patterns in the missing data. With fewer than 5% missing cases that were missing at random, the
solution of deleting the cases list wise was most appropriate (Tabachnick & Fidell, 2013). With the cases with missing values deleted list wise, the data set was narrowed to 732 cases.

Table 9

*Missing Values for Beliefs Items A-K*

<table>
<thead>
<tr>
<th>Item</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>4</td>
<td>5</td>
<td>10</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>5</td>
<td>9</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>%</td>
<td>0.52</td>
<td>0.65</td>
<td>1.31</td>
<td>0.52</td>
<td>0.78</td>
<td>0.91</td>
<td>0.91</td>
<td>0.65</td>
<td>1.18</td>
<td>0.91</td>
<td>0.52</td>
</tr>
</tbody>
</table>

*Note.* N = 766.

After narrowing the data set to 732 cases, univariate normality was examined using skewness and kurtosis values for all 11 items (see Table 10). For most items, either the skewness or the kurtosis value fell outside of the accepted ± |1| range (Meyers, Gamst, & Guarino, 2013). Furthermore, Q-Q and P-P plots suggested non-normality. Most of the items displayed a moderate negative skew. Tabachnick and Fidell (2013) recommended a reflected log transformation for variables with moderate negative skews. Given the results of the normality tests, all 11 items were reflected and log transformed to achieve normality. The resulting skewness and kurtosis values for the transformed items were within the accepted ± |1| range except for the kurtosis values for Items I and K, which were slightly over -1. Although the kurtosis values for Items I and K were not ideal, the reflected log transformation yielded the best result of any transformation technique for these items. Furthermore, Kline (2011) suggested that kurtosis values less than 10 were acceptable.
Table 10

Univariate Normality Tests for Original and Transformed Items A-K

<table>
<thead>
<tr>
<th>Item</th>
<th>Original Data</th>
<th>Transformed Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
</tr>
<tr>
<td>A</td>
<td>2.81</td>
<td>1.07</td>
</tr>
<tr>
<td>B</td>
<td>4.06</td>
<td>.661</td>
</tr>
<tr>
<td>C</td>
<td>3.74</td>
<td>.963</td>
</tr>
<tr>
<td>D</td>
<td>4.34</td>
<td>.764</td>
</tr>
<tr>
<td>E</td>
<td>4.14</td>
<td>.896</td>
</tr>
<tr>
<td>F</td>
<td>3.19</td>
<td>1.13</td>
</tr>
<tr>
<td>G</td>
<td>4.20</td>
<td>.728</td>
</tr>
<tr>
<td>H</td>
<td>4.54</td>
<td>.760</td>
</tr>
<tr>
<td>I</td>
<td>3.38</td>
<td>1.28</td>
</tr>
<tr>
<td>J</td>
<td>2.93</td>
<td>1.12</td>
</tr>
<tr>
<td>K</td>
<td>4.41</td>
<td>.621</td>
</tr>
</tbody>
</table>

*Note. N = 732. $M$ = mean; $SD$ = standard deviation. The original data were measured on a 1-5 scale. The transformed data were reverse log transformed.*

Pairwise linearity was deemed satisfactory using a scatterplot matrix of the 11 items. No univariate outliers were detected. Mahalanobis distance variable was created to identify multivariate outliers. Results indicated that the four cases with Mahalanobis distances greater than or equal to 34 had extreme values (df = 11, $p < .001$). The four cases were deleted from the data set. The resulting sample consisted of 728 participants. Using the guidelines for sample size set forth by Tabachnick and Fidell (2013), $n = 728$ was well over the required sample size of $n = 500$ for factor analysis.

Multicollinearity and singularity were assessed using a linear regression. Tolerance values, which ranged from .564 to .924, were deemed acceptable as they were much greater than .1 (Kline, 2011). Furthermore, VIF values were deemed acceptable as they were all less than 10 (Kline, 2011). Multicollinearity was not a threat in this data.
set. The correlation matrix revealed numerous signification correlations among the 11 items. Therefore, patterns in responses to variables were anticipated.

*Initial Solution.* An exploratory factor analysis with varimax rotation of the 11 beliefs items was performed on the data from 728 elementary science teachers who responded to the 2012 NSSME. The Kaiser-Meyer-Olkin measure of sampling adequacy was .815, indicating that the data were suitable for factor analysis. Similarly, Bartlett’s test of sphericity was significant ($p < .001$), indicating sufficient correlation between the variables to proceed with the analysis. A total of three factors had eigenvalues greater than 1.00, cumulatively accounting for 52.360% of the total variance. Two of the communalities, for Items B and J, were lower than the other communalities, but still greater than the cutoff of .2 identified by Tabachnick and Fidell (2013) (see Table 11). In addition, the rotated factor loadings for Items B, J, and E were lower than the cutoff of .55 established by Comrey and Lee (1992).

Table 11

<table>
<thead>
<tr>
<th>Factor</th>
<th>Item</th>
<th>Factor Loading</th>
<th>Communality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>K</td>
<td>.776</td>
<td>.624</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>.749</td>
<td>.561</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>.694</td>
<td>.528</td>
</tr>
<tr>
<td></td>
<td>G</td>
<td>.619</td>
<td>.523</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>.529</td>
<td>.550</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>.500</td>
<td>.332</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>.800</td>
<td>.662</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>.696</td>
<td>.513</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>.732</td>
<td>.644</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>.653</td>
<td>.609</td>
</tr>
<tr>
<td></td>
<td>J</td>
<td>.407</td>
<td>.212</td>
</tr>
</tbody>
</table>

*Note:* $n = 728$. Factor loadings <.600 and communalities <.500 are in boldface. Factor loading values are given for the rotated solution.
Three Factor Solution. A second factor analysis with varimax rotation was conducted to force a three factor solution. Given the low communalities and factor loadings of Items B and J and the low factor loading of Item E, these items were eliminated from the analysis. The Kaiser-Meyer-Olkin measure of sampling adequacy was .760, indicating that the data were suitable for principal components analysis. Similarly, Bartlett’s test of sphericity was significant ($p < .001$), indicating sufficient correlation between the variables to proceed with the analysis.

A total of three factors had eigenvalues greater than 1.00, cumulatively accounting for 63.02% of the total variance, which is an improvement over the initial solution. All items had communalities greater than .542 and all items had factor loadings on the rotated solution of greater than .646. According to Comrey and Lee (1992), factor loadings of greater than .63 are considered very good. Loadings of items on factors, communalities, and percent of variance are shown in Table 12. Items are ordered and grouped by size of loading to facilitate interpretation. Interpretive labels are suggested for each factor in the column labeled ‘description.’ Three factors were identified for the beliefs items on the 2012 NSSME. The factors identified included beliefs about lesson structure, three dimensional beliefs about effective science instruction, and beliefs about how students learn science. The internal consistency for beliefs about lesson structure was good ($\alpha = .756$), mediocre for three dimensional beliefs about effective science instruction ($\alpha = .573$), and poor for beliefs about how students learn science ($\alpha = .247$). Weis and Banilower (2013) accepted alpha levels of 0.6-0.8 as evidence of moderate reliability. Given the proximity of the reliability estimate for three dimensional beliefs about effective science instruction to the cutoff point established by Weis and Banilower
(2013), the reliability for three dimensional beliefs about effective science instruction was deemed acceptable. The lower reliability estimates for three dimensional beliefs about effective science instruction and beliefs about how students learn science was likely a result of including only two items for the composite.

Table 12

Factors, Variance, Loadings, and Communalities for the Three Factor Solution

<table>
<thead>
<tr>
<th>Factor</th>
<th>Description</th>
<th>% of Variance</th>
<th>Item</th>
<th>Item Description</th>
<th>Factor Loading</th>
<th>Communalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Beliefs about lesson structure</td>
<td>34.07</td>
<td>K</td>
<td>Most class periods should conclude with a summary of the key ideas addressed.</td>
<td>.815</td>
<td>.677</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>H</td>
<td>Most class periods should provide opportunities for students to share their thinking and reasoning.</td>
<td>.766</td>
<td>.588</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>D</td>
<td>Students should be provided with the purpose for a lesson as it begins.</td>
<td>.703</td>
<td>.542</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>G</td>
<td>Most class periods should include some review of previously covered ideas and skills.</td>
<td>.646</td>
<td>.560</td>
</tr>
<tr>
<td>2</td>
<td>Three dimensional beliefs about effective science instruction</td>
<td>16.16</td>
<td>F</td>
<td>Teachers should explain an idea to students before having them consider evidence that relates to the idea.</td>
<td>.820</td>
<td>.694</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>I</td>
<td>Hands-on/laboratory activities should be used primarily to reinforce a science idea that the students have already learned.</td>
<td>.730</td>
<td>.569</td>
</tr>
<tr>
<td>3</td>
<td>Beliefs about how students learn science</td>
<td>12.79</td>
<td>C</td>
<td>It is better for science instruction to focus on ideas in depth, even if that means covering fewer topics.</td>
<td>.781</td>
<td>.740</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td>Students learn science best in classes with students of similar abilities.</td>
<td>.694</td>
<td>.671</td>
</tr>
</tbody>
</table>

Note. n = 728. Factor loading values are given for the rotated solution.
Creating a Composite. The composite for three dimensional beliefs about effective science instruction was constructed using Items F and I. Item F (teachers should explain an idea to students before having them consider evidence that relates to the idea) and Item I (hands-on/laboratory activities should be used primarily to reinforce a science idea that students have already learned) both reflect traditional pedagogical perspectives. During the data cleaning, however, Items F and I were reflected, so scores on Items F and I should reflect the respondent’s three dimensional beliefs about effective science instruction. As such, a second transformation to reverse the scale was not necessary.

To construct the three dimensional beliefs about effective science instruction composite, the reflected log of Items F and I were added together. A z-score for the resulting score was calculated. A composite was not calculated for individuals who did not respond to at least one of the items. Rather, the value for the three dimensional beliefs about effective science instruction for individual who did not respond to at least one of the items was recorded as ‘missing.’ Further discussion about missing values analysis and handling for three dimensional beliefs about effective science instruction is included in Chapter 4.

Three Dimensional Classroom Practices

Three dimensional classroom practices were measured using six items that asked teachers to report how often they implemented various practices in their classroom (see Table 13). The composite used to measure three dimensional classroom practices was previously developed for the 2012 National Survey of Science and Mathematics Education (NSSME). In the 2012 NSSME, Weis and Banilower (2013) referred to this
composite as “reform oriented practices.” Even though the name is different, the composite measured three dimensional classroom practices. Teachers rated each item on a five-point scale ranging from 1 – Never to 5 – All or almost all science lessons. Weis and Banilower (2013) used factor analysis to determine that the six items measuring three dimensional classroom practices factored into the same construct ($\alpha = 0.72$, RMSEA = 0.06, SRMR = 0.03). The authors then combined all items into a composite. To allow for comparison to other measures, the score for practices was standardized by calculating the $z$-score.

Table 13
Items Used to Create the Three Dimensional Classroom Practices Composite

<table>
<thead>
<tr>
<th>How often do you do each of the following in your science instruction in this class?</th>
<th>Never (a few times a year)</th>
<th>Rarely (once or twice a month)</th>
<th>Sometimes (once or twice a week)</th>
<th>Often (once or twice a week)</th>
<th>All or almost all science lessons</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Have students work in small groups</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>2. Do hands-on/laboratory activities</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>3. Engage the class in project-based learning (PBL) activities</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>4. Have students represent and/or analyze data using tables, charts, or graphs</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>5. Require students to supply evidence in support of their claims</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>6. Have students write their reflections (e.g. in their journals) in class or for homework</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
</tbody>
</table>

Data Analysis

This study used structural equation modeling (SEM) with IBM SPSS AMOS Version 23 software. Prior to analysis, the data were checked for all of the assumptions associated with structural equation modeling. Missing data were examined and treated and the assumptions of multivariate normality, linearity, and the absence of multicollinearity and singularity were checked.

Kline (2011) identified six steps for structural equation modeling and the structure of the data analysis followed the suggested steps: (1) specification, (2) identification, (3) measure selection and data collection, (4) estimation, (5) re-specification, and (6) reporting results. First, the hypothesized model was specified using the consensus model and associated literature base (see Figure 19). Next, the hypothesized model was identified. A model can be identified if it is theoretically possible for the computer to derive a unique estimate for every model parameter (Kline, 2011). There are two general requirements for identification. First, every variable must be assigned a scale, and second, the model degrees of freedom must be at least zero. Every variable – SMK, TSPK, three dimensional beliefs about effective science instruction, and three dimensional classroom practices – was assigned a scale as described in the instrumentation section. To determine that the model degrees of freedom was greater than or equal to zero, the number of data points and number of parameters that were to be estimated were determined. In the hypothesized model, there were four measured variables, which meant that there were 10 data points (4 variances and 6 covariances), and there were 10 model parameters that were free to vary (Tabachnick & Fidell, 2013). This meant that there were zero degrees of freedom and that the model was “just
identified” (Kline, 2011). The third preparation step was to select measures and collect data. The selected measures and data collection have previously been described.

The fourth step was to estimate the model. In this step, it was necessary to evaluate model fit and to interpret parameter estimates. Using IBM SPSS AMOS Version 23, a structural equation model was constructed to examine the relationships among SMK, TSPK, three dimensional beliefs about effective science instruction, and three dimensional classroom practices. To examine model fit, Hooper, Coughlan, and Mullen (2008) advocated for use of the chi-square test statistic, its degrees of freedom and p value, the root mean square error of approximation (RMSEA) and its associated confidence interval, the standardized root mean square residual (SRMR), the comparative fit index (CFI), and the parsimonious normed fit index (PNFI). The chi-square test statistic was used to assess overall model fit. A non-significant chi-square test statistic (p > .05) indicates good model fit (Hoyle, 2012). Although the chi-square test has many

Figure 19. Hypothesized model for the relationships among science subject matter knowledge (SMK), topic specific professional knowledge (TSPK), three dimensional beliefs about effective science instruction, and three dimensional classroom practices.
problems associated with it, Hooper et al. (2008) recommended that the chi-square test and the associated degrees of freedom and \( p \) value should always be reported as it is an essential statistic. The RMSEA was used as an additional measure of overall model fit. The RMSEA is the average of the residuals between the observed correlation from the sample and the expected correlation for the population (Meyers et al., 2013). Hoyle (2012) recommended using a cutoff criterion of < .06 for the RMSEA. The SRMR is the standardized square root of the difference between the residuals of the sample covariance matrix and the hypothesized covariance matrix (Hooper et al., 2008). The SRMR was used as a third measure of overall model fit. Hoyle (2012) recommended a cutoff criterion of < .08 for the SRMR. The CFI was used as an incremental fit index. Hoyle (2012) recommended a cutoff criterion of > .95 for the CFI. Finally, the PNFI was used as a parsimony fit index. Meyers et al. (2013) recommended values of .5 or greater for PNFI.

The fifth and sixth steps recommended by Kline (2011) were model re-specification and reporting the results. The model was re-specified as needed and the results are reported in Chapter 4.

Each of the three research questions were addressed through the analysis. The first research question, which aimed to examine the adequacy of the hypothesized model in explaining theory was assessed by comparing the population covariance matrix with the sample covariance matrix. If the model is good, the parameter estimates produce an estimated matrix that is close to the sample covariance matrix (Tabachnick & Fidell, 2013). The chi-square test statistic and previously described fit indices were used to
evaluate the adequacy of the model. The second research question, which aimed to
determine the amount of variance in three dimensional classroom practices explained by
the combined effect of SMK, TSPK, and beliefs about effective science instruction was
assessed through square multiple correlation (SMC). The third research question, which
aimed to determine the nature of the relationships among SMK, TSPK, three dimensional
beliefs about effective science instruction, and three dimensional classroom practices was
assessed by examining parameter estimates. Alpha level of significance was set at .05,
which is customary for social science research (Tabachnick & Fidell, 2013).
CHAPTER 4: RESULTS

The authors of the Framework (National Research Council, 2012) and the NGSS called for shifts in science teaching and learning that are fundamentally different from teaching and learning within the traditional paradigm for science education. In the traditional paradigm for science teaching and learning, students learn about a set of science facts. In the three dimensional paradigm, outlined by the authors of the Framework (National Research Council, 2012) and the NGSS, students engage in investigations to construct understanding of science ideas using key science and engineering practices, core disciplinary ideas, and crosscutting concepts. Learning is centered around making sense of scientific phenomena. In order to successfully transition to the three dimensional paradigm, elementary science teachers must be supported as they attempt to implement three dimensional classroom practices. Teachers’ science subject matter knowledge (SMK), topic specific professional knowledge (TSPK), and three dimensional beliefs about effective science instruction may impact implementation of three dimensional classroom practices. Understanding the structure and nature of the relationships among SMK, TSPK, three dimensional beliefs about effective science instruction, and three dimensional classroom practices may provide insight into the types of supports needed to help teachers implement three dimensional teaching and learning in elementary science classrooms.

A consensus model for teacher knowledge and practice that was developed at a 2012 research summit was used as the conceptual framework for the present study (Gess-Newsome, 2015; Kind, 2015). The authors of the consensus model proposed a model
structure that can help explain the relationships among SMK, TSPK, three dimensional beliefs about effective science instruction, and three dimensional classroom practices. The structure of the consensus model has yet to be empirically tested. The goals of the present study were to: (1) empirically test one path embedded within the consensus model; (2) determine the amount of variance in three dimensional classroom practices that can be explained by the combined effect of science SMK, TSPK, and three dimensional beliefs about effective science instruction; and (3) examine the direct and indirect relationships among science SMK, TSPK, three dimensional beliefs about effective science instruction, and three dimensional classroom practices.

Data from the 2012 National Survey of Science and Mathematics Education (NSSME) were used to measure science SMK, TSPK, three dimensional beliefs about effective science instruction, and three dimensional classroom practices. Structural equation modeling was used to examine the overall model structure, the amount of variance in three dimensional classroom practices that can be explained, and the direct and indirect relationships among the variables. In this Chapter, the analysis from the structural equation modeling is presented.

**Assumptions**

Prior to the analysis, the variables for subject matter knowledge (SMK), topic specific professional knowledge (TSPK), three dimensional beliefs about effective science instruction, and three dimensional classroom practices were examined through various IBM SPSS Version 23 programs for accuracy of data entry, missing values, and fit between distributions and the assumptions of multivariate analysis. The results of the analysis are described in this Chapter.
Sample Size and Missing Data

The 2012 National Survey for Science and Mathematics Education (NSSME) public use data set included responses from teachers who taught kindergarten through twelfth grade. Because the present study was designed to focus specifically on elementary teachers, the subset of 766 elementary teachers who responded to the 2012 NSSME science survey about physical science, life science, or Earth and space science was selected. Data collected from the elementary teachers were screened for missing values on the four variables of interest: subject matter knowledge (SMK), topic specific professional knowledge (TSPK), three dimensional beliefs about effective science instruction, and three dimensional classroom practices. The number and percentage of missing values for each variable can be found in Table 14. For all four variables, there were between 0 and 17 missing values, which is less than 2.22% of the total values for each variable.

Table 14

<table>
<thead>
<tr>
<th>Measure</th>
<th>SMK</th>
<th>TSPK</th>
<th>Three Dimensional Beliefs</th>
<th>Three Dimensional Classroom Practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>17</td>
<td>3</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>%</td>
<td>2.22</td>
<td>0.39</td>
<td>1.57</td>
<td>0</td>
</tr>
</tbody>
</table>

*Note. N = 766. SMK = subject matter knowledge; TSPK = topic specific professional knowledge.*

The data were examined for patterns in missing values, none of which were detected. Because fewer than 5% of the values were missing at random on all variables,
cases with missing values on any of the four variables of interest were excluded list wise (Tabachnick & Fidell, 2013). After the cases with missing values were excluded, the subset of elementary teachers who responded to the 2012 NSSME about physical science, life science, or Earth and space science was reduced to 734 cases.

**Normality of Sampling Distributions**

All four variables—subject matter knowledge (SMK), topic specific professional knowledge (TSPK), three dimensional beliefs about effective science instruction, and three dimensional classroom practices—were screened for normality assumptions with IBM SPSS Frequencies, Explore, and Plot. As shown in Table 15, the skewness and kurtosis values for all four variables fell well inside the accepted ± |1| range (Meyers et al., 2013). Furthermore, the Q-Q and P-P plots revealed normal distributions. Given the results from these analyses, it was determined that univariate normality was not an issue for SMK, TSPK, three dimensional beliefs about effective science instruction, and three dimensional classroom practices, so transformations were not necessary.

**Table 15**

*Normality of Sampling Distributions for SMK, TSPK, Three Dimensional Beliefs, and Three Dimensional Classroom Practices*

<table>
<thead>
<tr>
<th>Measure</th>
<th>SMK</th>
<th>TSPK</th>
<th>Three Dimensional Beliefs</th>
<th>Three Dimensional Classroom Practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$SD$</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Skew</td>
<td>-.420</td>
<td>-.675</td>
<td>-.396</td>
<td>-.098</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>-.313</td>
<td>.118</td>
<td>-.712</td>
<td>-.050</td>
</tr>
</tbody>
</table>

*Note: $N = 734$. $M$ = mean; $SD$ = standard deviation; SMK = subject matter knowledge; TSPK = topic specific professional knowledge. Means and standard deviations were approximately 0 and 1, respectively, because $z$-scores were used and missing cases were deleted.*
Outliers

No univariate outliers were detected. Mahalanobis’ distance variable was created to identify multivariate outliers. Three cases were found to be multivariate outliers and were excluded from the analysis (df = 4, p < .001). The resulting dataset had no missing data and a final sample size of 731, which was an adequate sample size for structural equation modeling.

Multicollinearity and Singularity

Pairwise linearity was deemed satisfactory using a scatterplot matrix of the four variables. Bivariate correlations were examined for possible problems with multicollinearity or singularity. As shown in Table 16, problems with multicollinearity and singularity were not detected. Linear regression was also used to detect possible problems with multicollinearity and singularity. Tolerance values, which ranged from .800 to .989 were deemed acceptable as they were much greater than .1 (Kline, 2011). Furthermore, VIF values were deemed acceptable as they were all smaller than 10 (Kline, 2011). Multicollinearity was not a threat in this data set.

Table 16

Bivariate Correlations between SMK, TSPK, Three Dimensional Beliefs, and Three Dimensional Classroom Practices

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. SMK</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. TSPK</td>
<td></td>
<td>.405**</td>
<td></td>
</tr>
<tr>
<td>3. Three Dimensional Beliefs</td>
<td>.030</td>
<td>-.039</td>
<td></td>
</tr>
<tr>
<td>4. Three Dimensional Classroom Practices</td>
<td>.243**</td>
<td>.279**</td>
<td>-.084*</td>
</tr>
</tbody>
</table>

Note: N = 731. SMK = subject matter knowledge; TSPK = topic specific professional knowledge. *p < .05. **p < .01.
Analysis

After the data were screened, analysis using IBM SPSS AMOS Version 23 was conducted on a sample of 731. The analysis began with the first research question. After the model was modified, the second and third research questions were examined.

Research Question 1: Model Fit

The purpose of the first research question was to examine the model fit. The model fit was first examined for the consensus model (see Figure 20) and subsequently examined for the hypothesized model (see Figure 21). The paths in the consensus model directly represented the paths proposed by Kind (2015). Additional paths were included in the hypothesized model to reflect findings from the relevant literature base. In both models, rectangles represented variables measured using composite scores in the case of topic specific professional knowledge (TSPK), three dimensional beliefs about effective science instruction, and three dimensional classroom practices, and the variable measured using a single item response for subject matter knowledge (SMK). Arrows indicated hypothesized direct effects.

Consensus model. When the hypothesized model was developed, the paths within the model were informed by the consensus model that was developed at the PCK research summit (Kind, 2015). Two additional paths were added to the hypothesized model that did not exist in the consensus model. The first path was from SMK to three dimensional beliefs about effective science instruction and the second path was from SMK to three dimensional classroom practices. The paths were added based on the literature that supported the link between SMK and three dimensional beliefs about
effective science instruction and the link between SMK and three dimensional classroom practices.

Prior to testing the hypothesized model, the consensus model was tested to confirm that the additional paths in the hypothesized model were added appropriately. The model was examined for good model fit using the chi-square ($\chi^2$) test, root mean square error approximation (RMSEA), standardized root mean square residual (SRMR), comparative fit index (CFI), and parsimonious normed-fit index (PNFI) as recommended by Hooper et al. (2008). Cutoff criterion recommended by Hoyle (2012) were used to assess the chi-square test, RMSEA, SRMR, and CFI. Cutoff criterion recommended by Meyers et al. (2013) were used to assess the PNFI.

As shown in Table 17 and Figure 20, the standardized regression coefficients for three of the four paths were significant at the $p < .05$ level. As shown in Table 18, the chi-square test was significant $\chi^2 (2, n = 731) = 19.164, p = .000$. A significant chi-square test generally indicates poor model fit. Because the chi-square test is not considered to be a strong indicator of model fit, however, additional fit indices were assessed. The RMSEA was .108 with a 90% confidence interval of .068 to .155. The RMSEA fell outside of the target value of less than .08 (Hoyle, 2012). The CFI was .918, which was smaller than the cutoff criterion of greater than .95 (Hoyle, 2012). The results of the chi-square test, RMSEA, and CFI all indicated poor overall model fit. The SRMR was .015, which fell within the cutoff criterion of less than .08 (Hoyle, 2012). The PNFI was .165, which did not meet the criteria for parsimony. In sum, the consensus model demonstrated poor model fit. As such, it was determined that the additional paths in the hypothesized model were added appropriately.
Table 17

Path Coefficients for the Consensus Model

<table>
<thead>
<tr>
<th></th>
<th>SMK→TSPK</th>
<th>SMK→Beliefs</th>
<th>TSPK→Beliefs</th>
<th>Beliefs→Practices</th>
<th>TSPK→Practices</th>
<th>SMK→Practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>β</td>
<td>.405**</td>
<td>-</td>
<td>-.039</td>
<td>-.073*</td>
<td>.276**</td>
<td>-</td>
</tr>
<tr>
<td>p-value</td>
<td>&lt; .001</td>
<td>-</td>
<td>.293</td>
<td>.040</td>
<td>&lt; .001</td>
<td>-</td>
</tr>
</tbody>
</table>

*Note. n = 731. β = standardized regression coefficient; SMK = subject matter knowledge; TSPK = topic specific professional knowledge. *p < .05. **p < .001.

*Figure 20.* Consensus model regression coefficients.
Table 18

Model Fit for the Consensus Model

<table>
<thead>
<tr>
<th>Schematic Model</th>
<th>df</th>
<th>$\chi^2$</th>
<th>RMSEA</th>
<th>SRMR</th>
<th>CFI</th>
<th>PNFI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criterion</td>
<td>&gt; 0</td>
<td>$p &gt; .05$</td>
<td>&lt;.06</td>
<td>&lt;.08</td>
<td>&gt;.95</td>
<td>&gt;.5</td>
</tr>
<tr>
<td>Consensus Model</td>
<td>3</td>
<td>$p = .000$</td>
<td>.108</td>
<td>.015</td>
<td>.918</td>
<td>.165</td>
</tr>
</tbody>
</table>

Note. $n = 731$. df = degrees of freedom; $\chi^2$ = chi-square test statistic; GFI = goodness-of-fit index; NFI = normed fit index; CFI = comparative fit index; RMSEA = root mean square error of approximation; RMR = root mean square residual.

**Hypothesized model.** In the hypothesized model, it was hypothesized that SMK and TSPK directly and indirectly impact three dimensional classroom practices and that three dimensional beliefs about effective science instruction directly impacts three dimensional classroom practices. The hypothesized model was just-identified, meaning that the number of observations in the model equaled the number of free parameters in the model. A just-identified model has zero degrees of freedom so the model can perfectly reproduce the sample covariances (Kline, 2011). As a result, the model cannot be used to estimate model fit. However, the model can be used to estimate the values of the coefficients for the paths. As such, analysis of the hypothesized model did not include the model fit indices. Rather, the values of the coefficients for the paths were examined.

In the hypothesized model, six direct paths were tested. As displayed in Table 19 and Figure 21, four of the paths were significant at the $p < .05$ level. The remaining two paths were not significant. Because two paths in the model were not significant, modifications to the model were necessary.
Table 19

Path Coefficients for the Hypothesized Model

<table>
<thead>
<tr>
<th></th>
<th>SMK → TSPK</th>
<th>SMK → Beliefs</th>
<th>TSPK → Beliefs</th>
<th>Beliefs → Practices</th>
<th>TSPK → Practices</th>
<th>SMK → Practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
<td>.405**</td>
<td>.055</td>
<td>-.061</td>
<td>-.080*</td>
<td>.211**</td>
<td>.161*</td>
</tr>
<tr>
<td>$p$-value</td>
<td>&lt; .001</td>
<td>.173</td>
<td>.130</td>
<td>.022</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
</tr>
</tbody>
</table>

*Note. $n = 731$. $\beta$ = standardized regression coefficient; SMK = subject matter knowledge; TSPK = topic specific professional knowledge. *$p < .05$. **$p < .001$.  

Figure 21. Hypothesized model regression coefficients.

**Final model.** In order to improve the model, the two paths that were not significant at the $p < .05$ level were removed from the model. The model was examined for good model fit using the chi-square ($\chi^2$) test, RMSEA, SRMR, CFI, and PNFI as
recommended by Hooper et al. (2008). Cutoff criterion recommended by Hoyle (2012) were used to assess the chi-square test, RMSEA, SRMR, and CFI. Cutoff criterion recommended by Meyers et al. (2013) were used to assess the PNFI.

As shown in Figure 22 and Table 20, the standardized regression coefficients for all of the paths were significant at the $p < .05$ level. As shown in Table 21, the chi-square test statistic was not significant $\chi^2 (2, n = 731) = 2.96, p = .227$. Although a non-significant chi-square test statistic can indicate good model fit, the chi-square test is not considered to be a strong indicator of model fit. As a result, additional indices for model fit were considered. The RMSEA was .026 with a 90% confidence interval of .000 to .082, which fit within the target value of less than .06 (Hoyle, 2012). The SRMR was .016, which was below the cutoff value of less than .08 (Hoyle, 2012). The results of the chi-square test, RMSEA, and SRMR all indicated good overall model fit. The CFI value was .995, which well exceeded the target value of greater than .95 (Hoyle, 2012), indicating good model fit based on model comparisons.

The only fit index that did not suggest good model fit was the PNFI. The PNFI is a measure of parsimony. Model parsimony is desirable because having a nearly saturated model can result in a less rigorous theoretical model (Hooper et al., 2008). The revised model was nearly saturated, so the PNFI was lower than the accepted value of .5 or higher (Meyers et al., 2013). Parsimony is typically used to decide between two equivalent models, which was not necessary in this analysis. Despite the lack of parsimony, the revised model demonstrated good model fit on all other measures. Furthermore, all of the regression coefficients for all paths in the model were significant. As such, it was determined that the model would be accepted as the final model.
Table 20

Path Coefficients for the Final Model

<table>
<thead>
<tr>
<th></th>
<th>SMK→TSPK</th>
<th>SMK→Beliefs</th>
<th>TSPK→Beliefs</th>
<th>Beliefs→Practices</th>
<th>TSPK→Practices</th>
<th>SMK→Practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>β</td>
<td>.405**</td>
<td>-</td>
<td>-</td>
<td>-.080*</td>
<td>.211**</td>
<td>.161**</td>
</tr>
<tr>
<td>p-value</td>
<td>&lt; .001</td>
<td>-</td>
<td>-</td>
<td>.022</td>
<td>&lt; .001</td>
<td>&lt; .001</td>
</tr>
</tbody>
</table>

Note. \( n = 731 \). \( \beta \) = standardized regression coefficients; SMK = subject matter knowledge; TSPK = topic specific professional knowledge. 
\(* p < .05. \quad ** p < .001.\)

Figure 22. Final model regression coefficients.
Table 21

*Model Fit for the Final Model*

<table>
<thead>
<tr>
<th>Criterion</th>
<th>df</th>
<th>$\chi^2$</th>
<th>RMSEA</th>
<th>SRMR</th>
<th>CFI</th>
<th>PNFI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consensus Model</td>
<td>3</td>
<td>$p = .000$</td>
<td>.108</td>
<td>.015</td>
<td>.918</td>
<td>.165</td>
</tr>
<tr>
<td>Final Model</td>
<td>2</td>
<td>$p = .227$</td>
<td>.026</td>
<td>.016</td>
<td>.995</td>
<td>.329</td>
</tr>
</tbody>
</table>

*Note.* $n = 731$. $df =$ degrees of freedom; $\chi^2 =$ chi-square test statistic; RMSEA = root mean square error of approximation; SRMR = standardized root mean square residual; CFI = comparative fit index; PNFI = parsimonious normed fit index.

**Summary.** The hypothesized model needed to be modified to produce an estimated population covariance matrix consistent with the sample covariance matrix. In order to improve the model, the direct paths from SMK to three dimensional beliefs about effective science instruction and from TSPK to three dimensional beliefs about effective science instruction were dropped from the model. The resulting model, with direct paths from SMK to TSPK, TSPK to three dimensional classroom practices, SMK to three dimensional classroom practices, and three dimensional beliefs about effective science instruction to three dimensional classroom practices, produced an estimated population covariance matrix consistent with the sample covariance matrix.

**Research Question 2: Variance Explained**

The purpose of the second research question was to examine the amount of variance in three dimensional classroom practices that could be accounted for by the combined effect of subject matter knowledge (SMK), topic specific professional knowledge (TSPK), and three dimensional beliefs about effective science instruction. The amount of variance explained was determined using the squared multiple
correlations for both of the endogenous variables (Meyers et al., 2013). Based on the squared multiple correlations, 16.4% of the variance in TSPK was explained by SMK and 10.4% of the variance in three dimensional classroom practices was explained by the combined effect of SMK, TSPK, and three dimensional beliefs about effective science instruction.

**Research Question 3: Direct and Indirect Effects**

The purpose of the third research question was to examine the nature of the relationships among subject matter knowledge (SMK), topic specific professional knowledge (TSPK), three dimensional beliefs about effective science instruction, and three dimensional classroom practices. Standardized direct, indirect, and total effects were examined for each of the variables. The standardized direct effect of SMK on TSPK was $\beta = .405 (p < .001)$. The standardized direct effect of TSPK on three dimensional classroom practices was $\beta = .211 (p < .001)$. The standardized direct effect of three dimensional beliefs about effective science instruction on three dimensional classroom practices was $\beta = -.080 (p < .05)$. Finally, the standardized direct effect of SMK on three dimensional classroom practices was $\beta = .161 (p < .001)$. The standardized indirect effect of SMK on three dimensional classroom practices was $\beta = .085$ for a standardized total effect of SMK on three dimensional classroom practices of $\beta = .246$. The paths between SMK and three dimensional beliefs about effective science instruction and TSPK and three dimensional beliefs about effective science instruction were eliminated, so direct and indirect effects included in those paths were not detected.
In sum, the hypothesized model did not fit the data. The model was modified by eliminating the direct paths from subject matter knowledge (SMK) to three dimensional beliefs about effective science instruction and from topic specific professional knowledge (TSPK) to three dimensional beliefs about effective science instruction. The revised model was able to produce an estimated population covariance matrix consistent with the sample covariance matrix. The revised model demonstrated excellent model fit according to a variety of fit indices. In the revised model, 10.4% of the variance in three dimensional classroom practices was explained by the combined effect of SMK, TSPK, and three dimensional beliefs about effective science instruction. In addition, SMK and TSPK both had strong effects on three dimensional classroom practices. Three dimensional beliefs about effective science instruction also had a significant effect on three dimensional classroom practices.
CHAPTER 5: DISCUSSION

The purpose of this study was to examine the relationships among elementary teachers’ science subject matter knowledge (SMK), topic specific professional knowledge (TSPK), three dimensional beliefs about effective science instruction, and three dimensional classroom practices. The conceptual framework guiding this study was based on a consensus model for teacher knowledge, classroom practice, and student outcomes (see Figure 23) (Gess-Newsome, 2015; Kind, 2015). This study was designed to empirically test one path embedded within the consensus model (see Figure 24).

Figure 23. Consensus model for teacher knowledge, classroom practice, and student outcomes. Reproduced from “On the beauty of knowing then not knowing: Pinning down the elusive qualities of PCK,” by V. Kind, 2015, in A. Berry, P. Friedrichsen, & J. Loughran (Eds.), Re-examining pedagogical content knowledge in science education, p. 192. Copyright 2015 by Routledge. Reproduced with permission.
Figure 24. Hypothesized model for the relationships among science subject matter knowledge (SMK), topic specific professional knowledge (TSPK), three dimensional beliefs about effective science instruction, and three dimensional classroom practices.

Data from the 2012 National Survey of Science and Mathematics Education (NSSME) were analyzed using IBM SPSS AMOS Version 23 to answer each of the following research questions:

Research Question 1. Does the hypothesized model produce an estimated population covariance matrix consistent with the sample covariance matrix?

Research Question 2. How much of the variance in three dimensional classroom practices is accounted for by the combined effect of SMK, TSPK, and three dimensional beliefs about effective science instruction?

Research Question 3. What is the nature of the relationships among SMK, TSPK, three dimensional beliefs about effective science instruction, and three dimensional classroom practices?

Sub-Question A. What effect does SMK have on TSPK?

Sub-Question B. What effect does SMK have on three dimensional beliefs about effective science instruction?
Sub-Question C. What effect does SMK have on three dimensional classroom practices?

Sub-Question D. What effect does TSPK have on three dimensional beliefs about effective science instruction?

Sub-Question E. What effect does TSPK have on three dimensional classroom practices?

Sub-Question F. What effect does three dimensional beliefs about effective science instruction have on three dimensional classroom practices?

Sub-Question G. Does TSPK mediate the effect of SMK on three dimensional classroom practices?

Sub-Question H. Does three dimensional beliefs about effective science instruction mediate the relationship between TSPK and three dimensional classroom practices?

Sub-Question I. Does three dimensional beliefs about effective science instruction mediate the relationship between SMK and three dimensional classroom practices?

Sub-Question J. Do TSPK and three dimensional beliefs about effective science instruction mediate the relationship between SMK and three dimensional classroom practices?

Structural equation modeling analysis of the hypothesized model revealed that a modified model, with the direct effects from SMK to three dimensional beliefs about effective science instruction and from TSPK to three dimensional beliefs about effective science instruction removed from the model (see Figure 25), better fit the data than the
hypothesized model. The modified model that best fit the data will herein be referred to as the final model. In the final model, 16.4% of the variance in TSPK was explained by SMK and 10.4% of the variance in three dimensional classroom practices was explained by the combined effect of SMK, TSPK, and three dimensional beliefs about effective science instruction. Furthermore, SMK had a positive, direct effect on TSPK ($\beta = .405, p < .001$) and a positive, direct effect on three dimensional classroom practices ($\beta = .161, p < .001$). In addition, TSPK had a positive, direct effect on three dimensional classroom practices ($\beta = .211, p < .001$). Three dimensional beliefs about effective science instruction, however, had a negative direct effect on three dimensional classroom practices ($\beta = -.080, p < .05$). An interpretation of the research findings according to research question and sub-question is presented in this Chapter.

![Diagram](image)

*Figure 25.* Final model for the relationships among science subject matter knowledge (SMK), topic specific professional knowledge (TSPK), three dimensional beliefs about effective science instruction, and three dimensional classroom practices.
Research Question 1: Model Fit

The first research question was designed to examine the fit between the estimated population covariance matrix and the sample covariance matrix for the hypothesized model. The hypothesized model was constructed based on the paths included in the consensus model. Paths from subject matter knowledge (SMK) to three dimensional beliefs about effective science instruction and from SMK to three dimensional classroom practices were not included in the consensus model, but were added to the hypothesized model based on hypotheses informed by the relevant literature base. Analysis of the hypothesized model using IBM SPSS AMOS Version 23 revealed non-significant paths from SMK to three dimensional beliefs about effective science instruction and from topic specific professional knowledge (TSPK) to three dimensional beliefs about effective science instruction. Because the paths from SMK and TSPK to three dimensional beliefs about effective science instruction were not significant, the paths were dropped from the hypothesized model.

Analysis of the modified model, also referred to as the final model, revealed excellent model fit. Furthermore, all of the paths included in the model were significant. Because the model demonstrated excellent model fit and because the paths included in the model were all significant, it was determined that the modified model would be accepted as the final model. The final model produced an estimated population covariance matrix that was consistent with the sample covariance matrix.

In order to complete a thorough analysis, the consensus model was also tested. The structure of the consensus model was the same as the hypothesized model, but without the added paths from SMK to three dimensional beliefs about effective science
instruction and from SMK to three dimensional classroom practices. Analysis of the consensus model revealed poor model fit. It was determined that the final model better fit the data than the consensus model.

The findings from this study provided support for several of the existing paths in the consensus model and simultaneously provided evidence for a need to modify several paths in the consensus model. First, the existence of direct paths from SMK to TSPK, from TSPK to three dimensional classroom practices, and from three dimensional beliefs about effective science instruction to three dimensional classroom practices were supported by findings from the first research question. The direct relationships between SMK and TSPK, TSPK and three dimensional classroom practices, and three dimensional beliefs about effective science instruction and three dimensional classroom practices are discussed in more detail in relation to the third research question. Second, the findings from this study did not provide support for the existence of a path between SMK and three dimensional beliefs about effective science instruction or the path between TSPK and three dimensional beliefs about effective science instruction. Again, the absence of a direct path between SMK and three dimensional beliefs about effective science instruction and the direct path between TSPK and three dimensional beliefs about effective science instruction is discussed in more detail in relation to the third research question. Finally, the findings from this study provided support for the existence of a path from SMK to three dimensional classroom practices, a path that was not included in the consensus model.

Based on the findings from this study, a modified model for teacher knowledge and classroom practice was constructed (see Figure 26). In the modified model, a path
from SMK to classroom practices was added and the path from TSPK to teacher beliefs was removed. The modified model does not show recursive paths as illustrated in the consensus model because this study did not test recursive paths. In addition, the lower portion of the consensus model relating to student amplifiers and filters and student outcomes was not included in Figure 26 because the present study did not examine any student related variables.

Figure 26. Modified model for teacher knowledge and skill. The bolded arrow indicates a path that was added to the model. The dotted arrow with a cross over it indicates a path that was removed from the model. Modified from “On the beauty of knowing then not knowing: Pinning down the elusive qualities of PCK,” by V. Kind, 2015, in A. Berry, P. Friedrichsen, & J. Loughran (Eds.), Re-examining pedagogical content knowledge in science education, p. 192. Copyright 2015 by Routledge.

Subject Matter Knowledge and Three Dimensional Classroom Practices

The most significant modification to the consensus model was the addition of a direct path from science subject matter knowledge (SMK) to three dimensional classroom practices. Interestingly, the authors of the consensus model might have originally
intended to include the path from SMK to classroom practices. When the consensus model was originally published, it was published as part of a compilation of articles that resulted from the pedagogical content knowledge (PCK) research summit. Included in the compilation were two articles, each referring to a slightly different version of the consensus model (Gess-Newsome, 2015; Kind, 2015). The consensus model used to guide the present study was the consensus model presented by Kind (2015); this model did not include a path from SMK to classroom practices. The consensus model presented by Gess-Newsome (2015), however, included a path between SMK and classroom practices. The only other difference between the two models was that the model presented by Gess-Newsome (2015) indicated that student outcomes influence teachers’ beliefs through a recursive path. It was not clear why two different versions of the same consensus model were presented in the compilation, but both authors referred to the consensus model as the model that was developed during the PCK research summit (Gess-Newsome, 2015; Kind, 2015). In sum, although the addition of the path from SMK to classroom practices is a modification to the model presented by Kind (2015), it may not necessarily be a modification to the consensus model envisioned by the researchers involved in the PCK research summit.

The inclusion of a path between SMK and classroom practices has been supported by previous authors who have documented a relationship between SMK and three dimensional classroom practices (Gess-Newsome, 1999). For instance, Sanders et al. (1993) and Hashweh (1987) both documented a connection between SMK and three dimensional classroom practices, even when PCK remained partially constant. In both studies, the authors examined the relationship between SMK and three dimensional
classroom practices by having teachers plan lessons outside of their topic area of expertise. For example, a life science teacher might have been asked to plan a physics lesson and a physics teacher might have been asked to plan a life science lesson. It was assumed that teachers had higher levels of SMK in their content area of expertise. For instance, it was assumed that a life science teacher had higher life science SMK than a physics teacher and that a physics teacher had higher physics SMK than a life science teacher. Hashweh (1987) verified the differences in SMK using summary free recall, concept-map line labeling, and card sorting tasks.

Sanders et al. (1993) and Hashweh (1987) both concluded that when teachers planned within their topic area of expertise, they were better able to modify existing activities or investigations to incorporate additional concepts and science practices, reorganize instructional materials to improve coherence and flow, and add concepts to existing lessons or units to enhance student learning. On the other hand, when teachers planned outside of their topic area of expertise, they were more likely to emphasize the facts and procedures of an activity (Sanders et al., 1993). These findings not only supported the conclusion that SMK influences classroom practices, but they also provided support for the inclusion of topic specific professional knowledge (TSPK) as a mediating variable between SMK and classroom practices. In both studies, the participating teachers planned both within and outside of their subject area and planned with the same group of students in mind. Although it was not identified as such, having the same teachers plan for the same students served as a control for pedagogical knowledge and a partial control for PCK. When planning for different content areas, however, the teachers used very different classroom practices. Despite having the same
pedagogical knowledge, teachers planning within their content area of expertise employed more constructivist classroom practices. When planning outside of their content area, however, the same teachers tended to employ traditional classroom practices. Given these points, different levels of TSPK within and outside of the teachers’ content area of expertise could have accounted for the variations in classroom practices based upon the differing SMK levels.

Including a direct path from SMK to three dimensional classroom practices in combination with an indirect path from SMK to three dimensional classroom practices through TSPK suggests that SMK influences teachers’ classroom practices in multiple ways. Teachers’ SMK can directly influence classroom practices and can indirectly influence classroom practices in a relationship mediated by TSPK. These findings support Shulman’s (1987) hypothesis that teachers with equivalent levels of SMK may not be equally effective. A teacher with high levels of SMK but low levels of TSPK may not necessarily know how to translate SMK into practice, as might be the case with a high level content expert with low levels of TSPK. On the other hand, a teacher with low levels of SMK but high levels of TSPK may have the skills necessary to plan lessons, but the deficiency in SMK may limit the effectiveness of the teacher’s lesson planning. More specifically, a teacher with low levels of SMK may emphasize the facts or procedures of an activity (Hashweh, 1987; Sanders et al., 1993) and may fail to engage students in critical thinking and problem solving. As such, teachers with low levels of SMK may struggle to implement classroom practices that align with the three dimensional reforms because the reforms focus so heavily on critical thinking and problem solving. Findings from the present study demonstrated that it is not sufficient for a teacher to have only
strong TSPK or strong SMK, particularly as teachers shift to three dimensional classroom practices. Rather, teachers must have highly developed SMK and TSPK in the topic area to be taught in order to implement three dimensional classroom practices.

**Three Dimensional Beliefs**

A second major modification to the hypothesized model was the elimination of the direct relationships from subject matter knowledge (SMK) to three dimensional beliefs about effective science instruction and from topic specific professional knowledge (TSPK) to three dimensional beliefs about effective science instruction. This means that SMK and TSPK do not directly influence three dimensional beliefs about effective science instruction. As indicated in the final model, a teacher with high levels of SMK and TSPK may hold traditional beliefs about effective science instruction and a teacher with low levels of SMK and TSPK may hold three dimensional beliefs about effective science instruction.

Factors such as individual teacher differences, school context, or pre-service teacher training may play a greater role in impacting three dimensional beliefs about effective science instruction than SMK or TSPK. Jones and Leagon (2014) claimed that science teachers’ belief systems are embedded in contexts, experiences, and cultural frameworks. As such, individual teacher differences in values, traditions, and experiences may shape a teacher’s belief system. For instance, a teacher who has experienced success with science teaching and learning in the traditional or the three dimensional paradigm may hold beliefs about effective science instruction that are consistent with the paradigm in which the teacher experienced success. Alternatively, a teacher who has been exposed to three dimensional teaching and learning may either
develop three dimensional beliefs about effective science teaching if the teacher experienced success with the three dimensional paradigm or may regress to traditional beliefs about effective science instruction if the teacher experienced frustration in the three dimensional paradigm. The influence of teachers’ individual differences, school context, or pre-service teacher training on three dimensional beliefs about effective science instruction can be complex. For instance, Pilitsis and Duncan (2012) documented evidence that demonstrated that changes in pre-service teachers beliefs over the course of a methods class are not linear or consistent with pre-service teachers’ experiences and that pre-service teachers can regress to traditional beliefs even after partially developing three dimensional beliefs about effective science instruction. Additional research is needed to better understand the ways by which individual differences, school context, and pre-service teacher training influence three dimensional beliefs about effective science instruction.

Although factors such as individual differences, school context, or pre-service teacher training may influence three dimensional beliefs about effective science instruction more than SMK or TSPK, it is possible that SMK and TSPK are still filtered or amplified by three dimensional beliefs about effective science instruction. In the consensus model, teachers’ beliefs were included as an amplifier or filter between TSPK and classroom practices. Gess-Newsome (2015) argued teachers personalize knowledge before acting upon it and part of personalizing knowledge is filtering or amplifying knowledge through personal belief systems. When a teacher personalizes knowledge, the teacher assimilates or accommodates his or her existing schemes to include the new knowledge. Even though SMK and TSPK did not directly impact three dimensional
beliefs about effective science instruction, it is possible that SMK, TSPK, and three dimensional beliefs about effective science instruction interact in a more complex way so that a teacher can personalize knowledge to impact classroom practices.

Furthermore, although teachers’ beliefs were included in the consensus model as an amplifier or filter for knowledge, Gess-Newsome (2015) cited a long standing debate about whether teachers’ beliefs about effective science instruction needed to change before a change in practice could be observed. In the final model of the present study, teachers did not necessarily need to hold three dimensional beliefs about effective science instruction in order to implement three dimensional classroom practices. Rather, SMK and TSPK could impact three dimensional classroom practices despite the fact that teachers may hold traditional beliefs about effective science instruction. This finding provides initial support for the hypothesis that teachers may develop three dimensional beliefs about effective science instruction after they begin implementing three dimensional classroom practices. In other words, if a teacher has the knowledge and skill necessary, he or she may begin experimenting with three dimensional classroom practices. If teachers experience success with three dimensional classroom practices, their three dimensional beliefs about effective science instruction may change. In a recursive loop, three dimensional beliefs about effective science instruction may, in turn, strengthen three dimensional classroom practices.

In sum, results from the first research question suggested that although SMK and TSPK do not directly influence three dimensional beliefs about effective science instruction, SMK, TSPK, and three dimensional beliefs about effective science instruction can work together to influence three dimensional classroom practices. For
instance, a teacher with low levels of SMK and TSPK who holds three dimensional beliefs about effective science instruction may work with partial success to implement three dimensional classroom practices. Although the teacher may be partially successful in implementing three dimensional classroom practices, the teacher may require additional support to improve his or her SMK and TSPK in order to experience more success with three dimensional classroom practices. This teacher would benefit from professional learning experiences focused on improving SMK and TSPK. Similarly, a teacher with high levels of SMK and TSPK who holds traditional beliefs about effective science instruction may not implement three dimensional classroom practices, even if he or she has the skills and knowledge necessary to do so. Because this teacher is already primed with the SMK and TSPK necessary to implement three dimensional classroom practices, supporting this teacher’s transition to three dimensional classroom practices may require professional learning experiences aimed at shifting teachers’ beliefs about effective science instruction so that the beliefs align with the reforms called for by the authors of the Framework (National Research Council, 2012) and the NGSS. As previously mentioned, this teacher may benefit from experimenting with three dimensional classroom practices, which may, through a recursive loop, begin to change the teacher’s three dimensional beliefs about effective science instruction.

**Research Question 2: Variance Explained**

The second research question was designed to examine the amount of variance in three dimensional classroom practices that could be accounted for by the combined effect of subject matter knowledge (SMK), topic specific professional knowledge (TSPK), and three dimensional beliefs about effective science instruction. Analysis of the results
suggested that 10.4% of the variance in three dimensional classroom practices can be explained by the combined effect of SMK, TSPK, and three dimensional beliefs about effective science instruction. Furthermore, 16.4% of the variance in TSPK can be explained by SMK. The finding that 10.4% of the variance could be explained by the combined effect of SMK, TSPK, and three dimensional beliefs about effective science instruction provides support for the claim that changing teachers’ SMK, TSPK, and three dimensional beliefs about effective science instruction can positively impact the likelihood of successful implementation of three dimensional classroom practices. However, almost 90% of the variance in three dimensional classroom practices could not be explained by SMK, TSPK, and three dimensional beliefs about effective science instruction.

The unexplained variance in three dimensional classroom practices could be accounted for by including previously researched variables that have been associated with three dimensional classroom practices. For instance, Banilower et al. (2007), Jetty (2015), and A. A. Smith et al. (2013), used hierarchical linear modeling to identify variables that could predict three dimensional classroom practices. In addition, Weiss et al. (2003) qualitatively examined the variables that could predict three dimensional classroom practices. As shown in Table 22, the authors identified multiple variables beyond SMK, TSPK and three dimensional beliefs about effective science instruction that were related to three dimensional classroom practices. In Table 22, the variables are arranged in four categories: (a) teacher knowledge and beliefs, (b) extent of professional learning, (c) school demographics, and (d) professional culture and context.
Table 22

*Variables that Predict Three Dimensional Classroom Practices*

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Teacher Knowledge and Beliefs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMK</td>
<td>✓</td>
<td>✓</td>
<td>NS</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>PCK/TSPK</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>Three dimensional beliefs</td>
<td>✓</td>
<td>✓</td>
<td>NS</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Extent of Professional Learning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-service teacher training</td>
<td>-</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>In-service teacher training</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Teaching experience</td>
<td>-</td>
<td>✓</td>
<td>NS</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>School Demographics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of students enrolled</td>
<td>-</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Student Characteristics</td>
<td>-</td>
<td>✓</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Community type</td>
<td>-</td>
<td>✓</td>
<td>-</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>Resources available for science instruction</td>
<td>-</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Professional Culture and Context</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Principal support</td>
<td>-</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>✓</td>
</tr>
<tr>
<td>Professional autonomy</td>
<td>-</td>
<td>-</td>
<td>✓</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Professional culture of school context</td>
<td>-</td>
<td>-</td>
<td>✓</td>
<td>-</td>
<td>✓</td>
</tr>
<tr>
<td>Total Variance Explained</td>
<td>10.4%</td>
<td></td>
<td>38%</td>
<td>~33%</td>
<td>-</td>
</tr>
</tbody>
</table>

*Note:* SMK = subject matter knowledge; TSPK = topic specific professional knowledge; ✓ = significant predictor of three dimensional classroom practices; - = variable not investigated; NS = not significant.

Before proceeding, it is important to note that Banilower et al. (2007), Jetty (2015), and A. A. Smith et al. (2013) examined the relationships between the identified variables and three dimensional classroom practices, but the authors did not necessarily examine the interactions among the identified variables and the ways by which the variables work together to predict three dimensional classroom practices. As such, some
of the indirect effects that were identified by the present study were not detected by Banilower et al. (2007), Jetty (2015), and A. A. Smith et al. (2013). For instance, in the present study, 16.4% of the variance in TSPK could be explained by SMK and both SMK and TSPK contributed to explaining the total variance in three dimensional classroom practices. The importance of SMK to the structural model was not detected by Jetty (2015), likely because the author did not examine the overall structure of the relationships among the variables.

As demonstrated in the present study, SMK, TSPK, and three dimensional beliefs about effective science instruction accounted for 10.4% of the total variance in three dimensional classroom practices. Banilower et al. (2007), A. A. Smith et al. (2013), and Weiss et al. (2003) also provided evidence for the importance of SMK, TSPK, and three dimensional beliefs about effective science instruction in predicting three dimensional classroom practices. The remaining 89.6% of variance in three dimensional classroom practices can likely be explained by a combination of the variables identified by Banilower et al. (2007), Jetty (2015), A. A. Smith et al. (2013), and Weiss et al. (2003). For instance, school demographic variables such as number of students enrolled, percent of students classified as limited English proficient, prior achievement level of students, community type, and resources available, may account for some of the remaining unexplained variance.

In addition to school demographic variables, pre-service and in-service teacher training may account for some of the unexplained variance. Although the pre-service and in-service teacher training variables are likely closely related to SMK, TSPK, and three dimensional beliefs about effective science instruction, there may be more involved in
pre-service and in-service teacher training than simply increasing SMK, TSPK, and three dimensional beliefs about effective science instruction. For instance, the development of a supportive professional learning community focused on three dimensional classroom practices may contribute to implementation of three dimensional classroom practices. Jetty (2015) and Weiss et al. (2003) provided preliminary data to support the idea that professional culture, professional autonomy, and principal support may contribute to implementation of three dimensional classroom practices. Teachers who feel supported by their principal and colleagues and empowered to take risks and experiment with new pedagogies may be more likely to experiment with implementing three dimensional classroom practices. As teachers experiment with three dimensional classroom practices in supportive professional environments, they can learn from their mistakes and continually improve their practices. In addition, variables that have yet to be identified by the literature base may impact three dimensional classroom practices. Such variables may include teachers’ experience with scientific research or teachers’ experiences as a learner in three dimensional classroom settings.

Results from the present study and the studies published by Banilower et al. (2007), Jetty (2015), A. A. Smith et al. (2013), and Weiss et al. (2003) have indicated that a number of variables are associated with the implementation of three dimensional classroom practices. Continuing to identify and use key variables to predict three dimensional classroom practices may improve the amount of variance in three dimensional classroom practices that can be explained. In sum, 10.4% of the variance in three dimensional classroom practices can be explained by the combined effect of SMK, TSPK, and three dimensional beliefs about effective science instruction. The remaining
89.6% of the variance may be explained by variables related to school demographics, the extent of teacher training, and professional culture and context. It is possible that additional variables relating the three dimensional classroom practices such as research experience or teachers’ experiences as a learner in three dimensional classroom settings have yet to be explored in the literature base.

**Research Question 3: Direct and Indirect Effects**

The third research question was designed to examine the direct and indirect relationships among subject matter knowledge (SMK), topic specific professional knowledge (TSPK), three dimensional beliefs about effective science instruction, and three dimensional classroom practices. The third research question was divided into a series of sub-questions. The interpretation of the findings for each sub-question is listed in this section.

**Sub-Question A**

The goal of Sub-Question A was to determine the effect of subject matter knowledge (SMK) on topic specific professional knowledge (TSPK). In the final model, SMK had a positive, direct effect on topic specific professional knowledge (TSPK) ($\beta = .405, p < .001$). Furthermore, 16.4% of the variance in TSPK could be explained by SMK. This means that the relationship between SMK and TSPK is a strong relationship and that strengthening teacher’s SMK will likely strengthen teacher’s TSPK.

In defining TSPK, Gess-Newsome (2015) asserted that TSPK is the knowledge needed to determine effective instructional strategies, select multiple representations, organize content to use specific examples to build overarching ideas, understand incoming students’ developing conceptions, and integrate the three dimensions of the
Framework (National Research Council, 2012) and the NGSS. In order to engage in these activities, teachers must have knowledge of both content and pedagogy. Having knowledge of content and pedagogy, however, is not enough; teachers must be able to combine the two different types of knowledge. The authors of the consensus model referred to the combination of knowledge of content and pedagogy as a new type of knowledge called TSPK (Gess-Newsome, 2015). Although TSPK extends beyond a simple combination of SMK and pedagogical knowledge, it is clear that SMK impacts TSPK. Having higher levels of SMK likely facilitates a teacher’s ability to determine effective instructional strategies, select multiple representations, organize content, understand students’ developing conceptions, and integrate the three dimensions of the Framework (National Research Council, 2012) and the NGSS.

Because TSPK is a relatively new construct, few authors have documented relationships between TSPK and other types of teacher knowledge or skill. To date, the present study is one of the first studies to document a relationship between SMK and TSPK. It is important to note, however, that the TSPK construct grew out of a complicated definition for pedagogical content knowledge (PCK). Much of the knowledge that was labeled as TSPK in the present study was previously included as a component of PCK. The strong relationship between PCK and SMK has been well documented (Abell, 2007; Kind, 2009; van Driel et al., 2014), so a positive, direct effect of SMK on TSPK was expected.

**Sub-Question B**

The goal of Sub-Question B was to determine the effect of subject matter knowledge (SMK) on three dimensional beliefs about effective science instruction. The
hypothesized model included a direct path from SMK to three dimensional beliefs about effective science instruction. This path was not included in the consensus model, but was added to the hypothesized model to test the hypothesis that three dimensional beliefs about effective science instruction could mediate the relationship between SMK and three dimensional classroom practices. Analysis of the hypothesized model revealed that the path from SMK to three dimensional beliefs about effective science instruction was not significant. As a result, the path was dropped from the model. The final model, which demonstrated excellent model fit, did not include a path from SMK to three dimensional beliefs about effective science instruction. In sum, SMK had neither a direct, nor an indirect effect on three dimensional beliefs about effective science instruction.

The findings from this research question indicated that SMK does not influence three dimensional beliefs about effective science instruction. This means that teachers with very high levels of SMK may have very traditional beliefs about effective science instruction, and teachers with very low levels of SMK may have three dimensional beliefs about effective science instruction. Although the path from SMK to three dimensional beliefs about effective science instruction was added to examine the potential mediating effect of three dimensional beliefs about effective science instruction, a direct relationship between SMK and three dimensional beliefs about effective science instruction was not documented in the literature. For instance, Saad and BouJaoude (2012) were unable to detect consistent relationships between teachers’ knowledge and beliefs. As such, the failure to detect a direct relationship between SMK and three dimensional beliefs about effective science instruction was consistent with the existing literature base.
Sub-Question C

The goal of Sub-Question C was to determine the effect of subject matter knowledge (SMK) on three dimensional classroom practices. As previously discussed, the version of the consensus model used as the conceptual framework for the present study did not include the path from SMK to three dimensional classroom practices (Kind, 2015). A second version of the consensus model, however, did include the path from SMK to three dimensional classroom practices (Gess-Newsome, 2015). Although the direct path from SMK to three dimensional classroom practices was not included in the consensus model that was used as a conceptual framework to guide the present study, it was added to the hypothesized model because of the strong connection between SMK and three dimensional classroom practices that was documented in the literature.

Analysis of the final model revealed that SMK had a positive, direct effect on three dimensional classroom practices ($\beta = .161$, $p < .001$). This means that SMK plays an important role in predicting implementation of three dimensional classroom practices.

In order to implement three dimensional classroom practices, teachers must be able to successfully integrate the three dimensions of science teaching and learning that were identified by the Framework (National Research Council, 2012) and the NGSS: (a) disciplinary core ideas, (b) science and engineering practices, and (c) crosscutting concepts. This requires teachers to carefully design, plan, and implement units that fluidly connect the three dimensions. Teachers must be able to work with developing student conceptions as students work to make sense of phenomena. To be successful with this type of teaching and learning, teachers must be able to comfortably draw from a large body of highly developed knowledge and understanding.
The connection between highly developed SMK and three dimensional classroom practices was documented by Bartos, Lederman, and Lederman (2014) in a study that explored teachers’ SMK structures. SMK structures are the ways by which teachers structure and organize their SMK. For instance, teachers may connect certain concepts within a topic to other concepts, create overarching thematic elements, or organize ideas based in similarities and differences. Content experts’ SMK structures differ from the SMK structures of novices; content experts’ SMK structures contain more cross-linking, interconnections, and overarching thematic elements (Bartos et al., 2014). In the study conducted by Bartos et al. (2014), teachers diagrammed their own SMK structures and the researchers diagrammed inferred SMK structures from teachers’ classroom practices. Bartos et al. (2014) documented a high level of congruence between teachers’ diagrammed SMK structures and the SMK structures that were inferred from teachers’ classroom practices. This means that teachers with expert SMK structures were better able to translate their SMK structures to classroom practices. In other words, teachers were better able to draw upon a complex network of SMK in order to implement three dimensional classroom practices. The findings from the present study substantiated the connection between SMK and classroom practices by uncovering a positive, direct path from SMK to 3D classroom practices.

Additional work examining teachers’ implementation of three dimensional classroom practices has documented a relationship between teachers’ SMK and the ability to plan for and implement constructivist classroom practices. For example, Hashweh (1987), Lee (1995), and Sanders et al. (1993) concluded that when teachers had higher levels of SMK, they were better able to modify existing activities or investigations
to incorporate additional concepts and science practices, reorganize instructional materials to improve coherence and flow, and add concepts to existing lessons or unit plans to enhance student learning. Teachers with high levels of SMK were likely able to plan more complex and coherent units of study because their SMK structures were more complex and highly developed. Coherence and flow are essential to promoting the progressive building of understanding across grade bands and topic areas that is integral to the reforms called for by the Framework (National Research Council, 2012) and the NGSS. It follows, then, that SMK is essential to successful implementation of three dimensional classroom practices because SMK can help teachers improve coherence and flow.

As demonstrated by the present study, high levels of SMK are essential for the successful implementation of three dimensional classroom practices. Expert SMK structures can help teachers draw from a complex network of highly developed knowledge and understanding in science in order to support students as they progressively build ideas and make sense of phenomena. Furthermore, high levels of SMK can help teachers build coherence and flow when designing and implementing science units of study.

Sub-Question D

The goal of Sub-Question D was to determine the effect of topic specific professional knowledge (TSPK) on three dimensional beliefs about effective science instruction. The results indicated that TSPK had neither a direct, nor an indirect effect on three dimensional beliefs about effective science instruction.
The path from TSPK to three dimensional beliefs about effective science instruction was included because the authors of the consensus model hypothesized that teachers’ beliefs acted as an amplifier or filter between TSPK and classroom practices (Gess-Newsome, 2015; Kind, 2015). As previously mentioned Gess-Newsome (2015) hypothesized that teachers’ beliefs could help teachers personalize knowledge to ultimately impact classroom practices. Results from the present study, however, indicated that TSPK does not directly influence three dimensional beliefs about effective science instruction, and thus, the mediating effect of three dimensional beliefs about effective science instruction was not detected. This means that although teachers may personalize TSPK, teachers’ TSPK does not directly influence teachers’ three dimensional beliefs about effective science instruction. As such, the interaction between TSPK and three dimensional beliefs about effective science instruction may be more complex than a relationship in which the path from TSPK to three dimensional classroom practices is mediated by three dimensional beliefs about effective science instruction.

Overall, the findings indicated that teachers’ beliefs act independently from teachers’ TSPK. This means that teachers may have high levels of TSPK but traditional beliefs about effective science instruction or low levels and TSPK and three dimensional beliefs about effective science instruction.

**Sub-Question E**

The goal of Sub-Question E was to determine the effect of topic specific professional knowledge (TSPK) on three dimensional classroom practices. As previously mentioned, TSPK is a new construct that was introduced to the field by the authors of the consensus model (Gess-Newsome, 2015; Kind, 2015). The authors of the consensus
model hypothesized that TSPK had a direct effect on classroom practices. The results indicated that TSPK had a positive, direct effect on three dimensional classroom practices ($\beta = .211, p < .001$).

The finding that TSPK has a positive, direct effect on three dimensional classroom practices indicates that TSPK is an important component of teacher knowledge and that it plays an important role in influencing three dimensional classroom practices. The TSPK construct was designed to reflect the knowledge need to determine effective instructional strategies, organize content to highlight overarching ideas, understand developing student conceptions, and integrate the three dimensions of the Framework (National Research Council, 2012) and the NGSS. Given the close relationship between TSPK and classroom practices, it was expected that TSPK would impact classroom practices. Furthermore, an extensive literature base investigating pedagogical content knowledge (PCK), the construct from which TSPK was developed, has documented a strong relationship between PCK and classroom practices. For instance, Park et al. (2011) documented strong correlations between knowledge of student understanding and three dimensional classroom practices in addition to knowledge of instructional strategies and three dimensional classroom practices. The knowledge components documented by Park et al. (2011) were also knowledge components of TSPK, so the finding that these knowledge components influenced three dimensional classroom practices was consistent with the results from the present study. In the study conducted by Park et al. (2011), however, the knowledge components were referred to as components of PCK.

Prior to the present study, publications examining the relationship between the newly identified TSPK construct and classroom practices were not readily available,
although the relationship between components of PCK and classroom practices had been well documented (Abell, 2007; van Driel et al., 2014). This study was one of the first to document a relationship between the newly developed TSPK construct and three-dimensional classroom practices. In sum, the findings from this study support the hypothesis that TSPK is an important knowledge component for three-dimensional classroom practices.

Sub-Question F

The goal of Sub-Question F was to examine the effect of three-dimensional beliefs about effective science instruction on three-dimensional classroom practices. In the consensus model, teachers’ beliefs about effective science instruction was included as an amplifier or filter between topic specific professional knowledge (TSPK) and classroom practices. As indicated in the final model, three-dimensional beliefs about effective science instruction had a negative, direct effect on three-dimensional classroom practices ($\beta = -.080, p < .05$).

The findings from Sub-Question F indicated that three-dimensional beliefs about effective science instruction impacts three-dimensional classroom practices, but that the effect is a negative one. This means that if teachers hold three-dimensional beliefs about effective science instruction, they are less likely to successfully implement three-dimensional classroom practices. This finding conflicts with previous findings that documented a positive relationship between three-dimensional beliefs about effective science instruction and three-dimensional classroom practices (Anderson, 2015; Crawford, 2007; Roehrig & Luft, 2004b).
The conflicting findings may have resulted from the use of inadequate instrumentation for the measurement of three dimensional beliefs about effective science instruction in the present study. The composite used to measure three dimensional beliefs about effective science instruction was the only newly constructed composite for the present study. The composite was constructed based upon a factor analysis of survey items related to beliefs about teaching and learning. The results of the factor analysis indicated that two items on the survey factored together and both were related to three dimensional beliefs about effective science instruction. The two items were: (Item F) teachers should explain an idea to students before having them consider evidence that relates to the idea, and (Item I) hands on/laboratory activities should be used primarily to reinforce a science idea that the students have already learned. Both items, as stated, reflect traditional views of effective science instruction. In three dimensional teaching and learning, students should consider evidence to help them figure out the explanation for a phenomenon. In addition, students should engage in laboratory investigations to help them figure out core science ideas.

During the construction of the composite, it was assumed that the opposite of traditional beliefs about effective science instruction was three dimensional beliefs about effective science instruction. As such, during the data cleaning process, both items were reverse log transformed. After being reverse log transformed, it was determined that values that were previously high on traditional beliefs were now low on three dimensional beliefs and values that were previously low on traditional beliefs were now high on three dimensional beliefs. The items were then added together to create a composite score. The composite score was then normalized by calculating a $z$-score. The
resulting composite was used to measure three dimensional beliefs about effective science instruction.

Despite the careful construction of the composite used to measure three dimensional beliefs about effective science instruction, it is possible that the items used to construct the composite did not accurately measure three dimensional beliefs about effective science instruction. The items used to construct the three dimensional beliefs composite were phrased as items that reflected traditional beliefs about effective science instruction. During the construction of the composite, it was assumed that the opposite of traditional beliefs about effective science instruction was three dimensional beliefs about science instruction. Upon examination of the results from the present study, however, it was determined that it may be the case that the opposite of traditional beliefs is not three dimensional beliefs about effective science instruction. Rather, the opposite of traditional beliefs about effective science instruction could be weak traditional beliefs about effective science instruction. If this is the case, it would follow that weak traditional beliefs about effective science instruction would have a negative impact on three dimensional classroom practices. As a result, the composite used to measure three dimensional beliefs about effective science instruction may have lacked construct validity.

Given the complexity of the measurement of three dimensional beliefs about effective science instruction and the conflicting findings regarding the negative effect of three dimensional beliefs about effective science instruction on three dimensional classroom practices, it is difficult to draw meaningful conclusions about the three dimensional beliefs construct.
Sub-Question G

Sub-Question G was designed to examine whether topic specific professional knowledge (TSPK) mediated the effect of subject matter knowledge (SMK) on three dimensional classroom practices. As indicated by the final model, TSPK mediated the effect of SMK on three dimensional classroom practices. SMK had a standardized indirect effect on classroom practices that was mediated by TSPK ($\beta = .085$) for a standardized total effect of SMK on three dimensional classroom practices of $\beta = .246$.

The findings from Sub-Question G indicated that TSPK plays an important role in mediating the relationship between SMK and three dimensional classroom practices. This means that teachers’ SMK informs TSPK, which in turn informs classroom practices. This finding may help explain previously documented relationships between SMK and three dimensional classroom practices. For instance, Gess-Newsome and Lederman (1995) detected varied relationships between SMK and classroom practices after interviewing and observing five male high school teachers. More specifically, a direct relationship between SMK and classroom practices was detected for one of the teachers, but there was limited translation of SMK to classroom practices for the other teachers. Adding the TSPK construct could have helped account for the differences in the findings. The teacher for which a direct relationship between SMK and classroom practices was detected may have had highly developed TSPK. The other teachers, however, may have had lower levels of TSPK, thus limiting the translation of SMK to classroom practices.

Similarly, Alonzo (2002) noted that after engaging in a professional learning experience most teachers were able to increase their SMK, but few teachers were able to
translate their increased SMK to classroom practices. Again, including the TSPK construct may help explain the difficulties with translating improved SMK to classroom practices. Although the teachers in the study improved their levels of SMK, teachers’ TSPK may have remained the same, thus limiting the translation of SMK to classroom practices. In sum, the findings from the present study demonstrated that TSPK is an important mediating variable between SMK and classroom practices. In order to promote three dimensional classroom practices, teachers must improve both SMK and TSPK.

**Sub-Questions H and I**

Sub-Question H was designed to determine if three dimensional beliefs about effective science instruction mediated the relationship between topic specific professional knowledge (TSPK) and three dimensional classroom practices. Sub-Question I was designed to determine if three dimensional beliefs about effective science instruction mediated the relationship between subject matter knowledge (SMK) and three dimensional classroom practices. Because the two sub-questions are similar, the discussion of both sub-questions was combined. The final model did not include a relationship between TSPK and three dimensional beliefs about effective science instruction, nor did it include a relationship between SMK and three dimensional beliefs about effective science instruction. As such, three dimensional beliefs about effective science instruction did not mediate the relationship between SMK and three dimensional classroom practices or between TSPK and three dimensional classroom practices.

The mediating effect of three dimensional beliefs about effective science instruction was included because the authors of the consensus model proposed that teachers’ beliefs act as an amplifier or a filter between TSPK and classroom practices.
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(Gess-Newsome, 2015). As indicated in the discussion of the first research question, it is still possible that three dimensional beliefs about effective science instruction helps teachers personalize SMK and TSPK through a more complex relationship, though three dimensional beliefs do not directly filter or amplify SMK and TSPK.

**Sub-Question J**

Sub-Question J was designed to determine if topic specific professional knowledge (TSPK) and three dimensional beliefs about effective science instruction mediated the relationship between subject matter knowledge (SMK) and three dimensional classroom practices. The final model did not include a relationship between SMK and three dimensional beliefs about effective science instruction, nor did it include a relationship between TSPK and three dimensional beliefs about effective science instruction. As previously described in the discussion of Sub-Questions H and I, three dimensional beliefs about effective science instruction did not mediate the relationship between SMK and three dimensional classroom practices, nor did it mediate the relationship between TSPK and three dimensional classroom practices. Sub-Question J was designed to examine the combination of the mediating effects, but three dimensional beliefs about effective science instruction did not play a mediating role.

**Limitations**

There were several limitations of the present study. The major limitation of this study was that the instrument used to measure three dimensional beliefs about effective science instruction may have lacked construct validity. As noted in the discussion of Sub-Question F, the inclusion of three dimensional beliefs about effective science instruction in the model posed a challenge. Although it was hypothesized that three
dimensional beliefs about effective science instruction would have a positive effect on three dimensional classroom practices, the effect was negative. Furthermore, the hypothesized paths between three dimensional beliefs about effective science instruction and both subject matter knowledge (SMK) and topic specific professional knowledge (TSPK) did not exist. As mentioned in the discussion of Sub-Question F, the items used to measure three dimensional beliefs about effective science instruction may have actually measured weak traditional beliefs about effective science instruction. Future studies investigating three dimensional beliefs about effective science instruction need to use a better measure than the one used in the present study.

An additional limitation of this study was that the data were restricted to a single point in time prior to the release of the Framework (2012) and the NGSS. As three dimensional reforms are implemented, additional insights or variables may emerge as important to the model. In addition, the data collection was limited to pre-existing items included in the 2012 National Survey for Science and Mathematics Education (NSSME). Using the 2012 NSSME allowed for examination of a large sample size, however analysis was restricted to existing measures. In addition to the problems with measuring three dimensional beliefs about effective science instruction, the measures for subject matter knowledge (SMK) and topic specific professional knowledge (TSPK) were limited to self-reports. Self-reports can sometimes be problematic because self-reports are indirect measures. This means that teachers gauge their own levels of SMK and TSPK, but there is not a direct measure of SMK or TSPK to confirm that the teacher’s self-report is valid. Furthermore, the instrument used to measure SMK was limited to one item.
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Improving this study will require the development and use of more refined instruments to measure SMK and three dimensional beliefs about effective science instruction.

The sample used in this study may have also been a limitation. Although Horizon Research, Inc. conducted careful sampling to assemble a nationally representative sample of teachers (Weis & Banilower, 2013), the sample consisted of mostly White women. The findings from this study may hold true for this particular sample, but as the elementary teaching population grows and diversifies, differences in the relationships among the variables may be detected. The final limitation of this study was that it was designed to test only one path within the consensus model in the context of three dimensional classroom practices. Adding additional paths or examining the relationships among the variables in different pedagogical contexts may yield different results.

Implications for Professional Practice

Several implications for professional practice exist based on the findings from this study. The finding that subject matter knowledge (SMK) and topic specific professional knowledge (TSPK) work together to impact three dimensional classroom practices has implications for both pre-service and in-service learning. In addition, the finding that SMK has a significant impact on three dimensional classroom practices has implications for the structure of science teaching at the elementary level.

Implications for Pre-Service Teacher Education

In many pre-service training programs, elementary teachers enroll in content area courses separately from teaching methods courses. This means that pre-service elementary teachers may take a life science course in the science department during their first year of pre-service teacher training, but may not address science teaching methods
until their third or fourth year of pre-service teacher training. By taking content area courses separately from teaching methods courses, pre-service elementary teachers develop their subject matter knowledge (SMK) in life science separately from their topic specific professional knowledge (TSPK). Findings from the first research question in the present study, however, indicated that SMK and TSPK work together to influence three dimensional classroom practices. As such, it is important for pre-service teachers to engage in learning experiences that integrate SMK and TSPK.

Science content courses designed specifically for elementary education majors could be designed to promote growth in both SMK and TSPK. Previous researchers investigating science content courses designed specifically for elementary education majors have demonstrated that such courses have a positive effect on elementary education majors’ attitudes toward science instruction (Minger & Simpson, 2006) and self-efficacy beliefs (Bergman & Morphew, 2015). Beyond improving attitudes toward science instruction and self-efficacy, science content courses for elementary education majors could simultaneously improve SMK and TSPK. Matthews, Rech, and Grandgenett (2010) demonstrated that a mathematics content course designed for elementary education majors significantly improved mathematics content knowledge. The mathematics content course designed for elementary education majors was designed to focus specifically on mathematics content that is taught at the elementary level. Given the success in the mathematics content course, a similar effect of a science content course for elementary education majors on science SMK is expected. Designing science content courses that focus on science that is taught at the elementary level and that model three dimensional pedagogy may promote growth in pre-service teachers’ SMK and TSPK.
In an analysis of a life science course designed specifically for elementary education majors, Weld and Funk (2005) demonstrated that participation in the course led to improved self-perceived subject matter command, curriculum development competence, and pedagogical skills. It is important to note, however, that Weld and Funk (2005) assessed the change in intentions of the elementary education majors, but did not compare the changes in the elementary education majors who were enrolled in the course to elementary education majors who were enrolled in a general science content course. In sum, engaging in a science content course designed for elementary education majors may help pre-service teachers simultaneously improve science SMK and TSPK, thus leading to improved implementation of three dimensional classroom practices.

**Implications for In-Service Teacher Learning**

In-service teachers often engage in professional learning experiences during which teachers learn to use specific classroom activities or curricula. Such professional learning experiences rarely include an emphasis or focus on subject matter knowledge (SMK) or topic specific professional knowledge (TSPK). Other professional learning experiences are designed to expose teachers to certain pedagogical or instructional strategies, but again, such learning experiences often fail to include an emphasis on SMK. Because SMK and TSPK work together to promote three dimensional classroom practices, it is important for in-service teachers to continually advance both SMK and TSPK through professional learning experiences. As such, it is recommended that in-service professional learning experiences be designed to help teachers to explicitly develop SMK in combination with TSPK.
Recently, authors investigating professional learning experiences have drawn similar conclusions. For example, after investigating the effects of a professional learning experience focused on developing teachers’ SMK and pedagogical knowledge, Alonzo (2002) drew the conclusion that professional learning experiences must also focus on pedagogical content knowledge (PCK) in order to successfully impact classroom practices. In the study conducted by Alonzo (2002), the SMK of teachers engaged in the professional learning experience improved, yet the teachers struggled to translate their learning to impact classroom practices. Alonzo (2002) suggested that this was likely because the professional learning experiences did not explicitly focus on developing teachers’ PCK.

Professional learning experiences that combine SMK and TSPK should have several key characteristics. Moon, Passmore, Reiser, and Michaels (2014) and Reiser (2013) argued that professional learning experiences designed to support teachers through the transitions called for by the authors of the Framework (National Research Council, 2012) and the NGSS should be: (a) embedded in subject matter, (b) involve active sense-making and problem solving, and (c) be connected to issues of teachers’ own practice. This recommendation is significant because embedding professional learning in subject matter and involving active sense-making help teachers improve their SMK and connecting professional learning to teachers’ practice helps teachers improve their TSPK. Further, Wilson (2013) argued that professional learning needs to be embedded in the context of school reform. This means that professional learning experiences should fit within the larger framework of school, district, and state reform initiatives. Finally, Covay Minor, Desimone, Caines Lee, and Hochberg (2016) suggested that professional
learning experiences should be differentiated based upon teachers’ SMK levels in order to have the greatest effect on teacher learning. The resulting professional learning experiences would aim to improve SMK and TSPK by: (a) embedding professional learning in subject matter, (b) involving active sense-making and problem solving, (c) connecting professional learning to teachers’ classroom practices, (d) embedding professional learning in the context of school reform, and (e) differentiating professional learning based upon teachers’ SMK and TSPK. Such professional learning experiences could contribute to the simultaneous improvement of both SMK and TSPK, thus leading to successful implementation of three dimensional classroom practices.

**Implications for Elementary Science Teaching**

The finding that subject matter knowledge (SMK) influences three dimensional classroom practices directly and indirectly has significant implications for elementary teachers. Unlike high school teachers, elementary teachers cover a broad range of subject areas and topics. Elementary teachers are expected to be content experts in reading, writing, mathematics, science, and social studies. In science, elementary teachers are expected to have expertise in physical science, life science, and Earth and space science. For instance, the NGSS call for second grade teachers to have expertise in the following disciplinary core ideas: (a) matter and its interactions, (b) ecosystems, (c) biological evolution, (d) Earth’s place in the Universe, (e) Earth’s systems, and (f) engineering design. A second grade teacher, then, must have high levels of both topic specific SMK and topic specific professional knowledge (TSPK) for all six of the aforementioned disciplinary core ideas to have the greatest impact on three dimensional classroom practices.
It is an enormous ask for elementary teachers to have high levels of SMK and TSPK in all of the required science topic areas in addition to the required SMK in reading, writing, mathematics, and social studies. In order to better support teachers and students, schools might consider utilizing a science content specialist. Science content specialists can take on many responsibilities to support teachers and students. The responsibilities may include, but are not limited to, teaching science classes, co-teaching science classes, providing teachers with content support when necessary, and leading professional learning experiences to strengthen teachers’ SMK in grade specific topic areas. If it is not possible to utilize a science content specialist, teachers could be supported through professional learning experiences targeted at topics within their grade level. For instance, it is important for a second grade teacher to have high levels of SMK and TSPK in ecosystems, but they do not necessarily need to have high levels of expertise in cellular biology. As such, professional learning experiences can be designed to focus on the specific topics that the grade level teacher will encounter.

In sum, both pre-service and in-service professional learning experiences need to focus specifically on supporting teachers’ simultaneous growth in SMK and TSPK. In pre-service teacher education, this can be accomplished by offering science content courses designed specifically for elementary education majors. For in-service teachers, professional learning experiences that combine SMK and TSPK may lead to successful implementation of three dimensional classroom practices. Finally, elementary schools should consider hiring science content specialists to support teachers as they implement three dimensional classroom practices.
In addition to implications for professional learning, there are also several important implications for future research. First, additional work will need to be conducted to explore alternative paths within the consensus model. In this study, the goal of the first research question was to examine one path within the consensus model in the context of three dimensional science reforms. Many additional paths, including recursive paths, still remain to be tested. Furthermore, the entire consensus model needs to be tested in various educational contexts. Additional studies are needed to test the other paths in the consensus model for teacher knowledge and skill in a variety of different contexts (Gess-Newsome, 2015; Kind, 2015).

Second, additional research is needed to develop and use an instrument that can effectively measure three dimensional beliefs about effective science instruction. One such instrument, called the Teacher Beliefs about Effective Science Teaching (TBEST) questionnaire, was developed by P. S. Smith, Smith, and Banilower (2014). This instrument included items used to measure beliefs about (a) learning-theory-aligned science instruction, (b) confirmatory science instruction, and (c) all hands-on all the time. In the report that detailed the development of the TBEST, the operational definition for learning-theory-aligned science instruction matched the operational definition for three dimensional classroom practices that was used in the present study. Unfortunately, the TBEST was developed and published after the administration of the 2012 National Survey of Science and Mathematics Education (NSSME), so the TBEST was not used on the 2012 NSSME. Future investigations are needed to build upon the present study by using the TBEST or other similar tools to measure three dimensional beliefs about
effective science instruction. In addition, future research will be needed to elucidate the relationships between three dimensional beliefs about effective science instruction and other variables related to teacher knowledge and skill.

Results from the present study also demonstrated that topic specific professional knowledge (TSPK) is an important construct in predicting three dimensional classroom practices. Because TSPK is a relatively new construct, few researchers have specifically investigated TSPK. The findings from the present study indicated that TSPK is an important construct that should be further investigated. A series of research programs focusing on TSPK may strengthen the literature base and contribute to the overall understanding of teacher knowledge and skill.

Finally, additional work could focus on developing and refining pre-service and in-service learning experiences to support teachers in simultaneously improving subject matter knowledge (SMK) and TSPK. Results from the present study indicated that both SMK and TSPK contribute to the implementation of three dimensional classroom practices. As discussed in the Implications section, some initial work on pre-service and in-service teacher training has indicated that professional learning experiences should focus on both SMK and TSPK (Alonzo, 2002; Bergman & Morphew, 2015; Matthews et al., 2010; Minger & Simpson, 2006; Weld & Funk, 2005). Further work can be done to develop and refine such courses or professional learning experiences.

Conclusion

The goal of this study was to examine the relationships among elementary teachers’ science subject matter knowledge (SMK), topic specific professional knowledge (TSPK), three dimensional beliefs about effective science instruction, and
three dimensional classroom practices. A hypothesized model was generated based on a consensus model developed at a 2012 research summit (Gess-Newsome, 2015; Kind, 2015). One path within the consensus model was empirically tested, and the relationships among the variables were examined. Data for this study were from the 2012 National Survey of Science and Mathematics Education (NSSME).

The analyses indicated that SMK, TSPK, and three dimensional beliefs about effective science instruction impact three dimensional classroom practices, but that SMK may be more important in promoting three dimensional classroom practices than the other constructs. In addition, the results demonstrated that SMK and TSPK do not impact three dimensional beliefs about effective science instruction. A revised model for teacher knowledge and skill was proposed. These findings demonstrate that focusing on elementary teachers’ science SMK in combination with TSPK in professional learning experiences may promote three dimensional classroom practices. Future research is needed to more thoroughly examine the three dimensional beliefs construct and to further test the consensus model for teacher knowledge and skill.
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APPENDIX A: INSTRUMENTATION

**Subject Matter Knowledge (SMK)**
How well prepared do you feel to teach each of the following subjects at the grade level(s) you teach, whether or not they are currently included in your teaching responsibilities?

<table>
<thead>
<tr>
<th>Subject</th>
<th>Not adequately prepared</th>
<th>Somewhat prepared</th>
<th>Fairly well prepared</th>
<th>Very well prepared</th>
</tr>
</thead>
<tbody>
<tr>
<td>d. Life science</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>e. Earth science</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>f. Physical science</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>g. Engineering</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
</tbody>
</table>

**Topic Specific Professional Knowledge (TSPK)**
How well prepared did you feel to do each of the following as part of your instruction on this particular unit?

<table>
<thead>
<tr>
<th>Task</th>
<th>Not adequately prepared</th>
<th>Somewhat prepared</th>
<th>Fairly well prepared</th>
<th>Very well prepared</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Anticipate difficulties that students may have with particular science ideas and procedures in this unit</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>2. Find out what students thought or already knew about the key science ideas</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>3. Implement the science textbook/module to be used during this unit</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>4. Monitor student understanding during this unit</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>5. Assess student understanding at the conclusion of this unit</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
</tbody>
</table>

**Three Dimensional Beliefs**
Please provide your opinion about each of the following statements. [Reverse scored]

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>No opinion</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Teachers should explain an idea to students before having them consider evidence that relates to the idea.</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>2. Hands-on/laboratory activities should be used primarily to reinforce a science idea that the students have already learned.</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
</tbody>
</table>

**Three Dimensional Classroom Practices**
How often do you do each of the following in your science instruction in this class?

<table>
<thead>
<tr>
<th>Task</th>
<th>Never</th>
<th>Rarely</th>
<th>Sometimes</th>
<th>Often</th>
<th>All or almost all lessons</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Have students work in small groups</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>2. Do hands-on/laboratory activities</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>3. Engage the class in project-based learning (PBL) activities</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>4. Have students represent and/or analyze data using tables, charts, or graphs</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>5. Require students to supply evidence in support of their claims</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>6. Have students write their reflections (e.g. in their journals) in class or for homework</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
</tbody>
</table>
DATE: March 02, 2016

TO: Katahdin Cook Whitt, PI, Student
    LDR
    Suzanne Franco, Ph.D., Faculty Advisor

FROM: Robyn Wilks
      Coordinator, IRB-WSU

SUBJECT: SC# 6143
         'A Structural Model of Elementary Teachers' Knowledge, Beliefs and Practices for Next Generation Science Teaching'

The above-listed project does not meet the Federal definition for human subjects research, specifically "a systematic investigation designed to contribute to generalizable knowledge". Therefore, the project does not require approval from the Wright State University Institutional Review Board.

If you have any questions or require additional information, please contact me at 775-4462.

Best wishes for a successful project.