PRESERVICE TEACHERS AND THEIR PRECONCEPTIONS OF THE *NGSS* SCIENCE AND ENGINEERING PRACTICE OF DEVELOPING AND USING MODELS IN ELEMENTARY SCIENCE EDUCATION

By

Lizette A. Burks

Submitted to the graduate degree program in Curriculum and Teaching in the School of Education and the Graduate Faculty of the University of Kansas in partial fulfillment of the requirements for the degree of Doctor of Education.

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Dr. Douglas Huffman, Chair

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Dr. Laurie Cleavinger

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Dr. James Ellis

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Dr. Melinda Leko

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Dr. Kelli Thomas

Date Defended: May 1, 2017

The Dissertation Committee for Lizette A. Burks certifies that this is the approved version of the following dissertation:

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Abstract

The science and engineering practice of developing and using models is a new science practice identified to achieve the vision of three-dimensional teaching and learning and as such should be an important new component of teacher preparation programs (NRC, 2012). Developing and using models is a high-leverage practice in teacher preparation because of the use of discourse in its implementation that is also used in other practices utilized within the *NGSS* (NGSS Lead States, 2013) science classroom. Additionally, the overlap between the other seven identified *NGSS* (NGSS Lead States, 2013) practices and the development and use of models along with the use of models represented in two of the overall three dimensions of the new vision for science education (NRC, 2012) contribute to its high leverage nature. The intent of this study was to examine elementary science preservice teachers' understandings and preconceptions about the practice of developing and using models. This study provides important information for teacher preparation to use this high-leverage practice. The study examined preservice teachers' preconceptions about the practice of developing and using models including discourse patterns the preservice teachers identified as being critical to the success of this practice in the classroom. Data were gathered through a written survey in which preservice teachers described their initial understanding about different components of modeling instruction. A video was used to elicit their initial understandings about certain components of modeling instruction. A sample of the preservice teachers were interviewed to elaborate on their responses to the survey. The results of the study indicated that when preservice teachers initially described how this practice might look in the classroom, only two of the six categories described in *A Science Framework for K-12 Science Education* (NRC, 2012) for this practice were described by most participants. Of those two categories described by most participants, the majority were at a novice level.

When noticing critical student-student and student-teacher discourse patterns in a video, preservice teachers were better able to identify more components described in the Talk Science Primer (Michaels & O'Conner, 2012) at slightly higher levels. These results emphasize the necessity for elementary teacher education to provide opportunities for preservice teachers to better understand the practice of developing and using models (some components more than others) to use this practice as a high-leverage practice during teacher preparation programs.

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Chapter 1: The Research Problem

Introduction

"On a snowy day in December, just over a century ago, John Dewey stood before dignitaries and onlookers" in order "to plead for a rethinking of what science education should aim to accomplish" (Rudolph, 2014, p. 1). John Dewey (1910) would go on to publish that students have not flocked to study science due to complex reasons. He said he could single out one influential cause, "science has been taught too much as an accumulation of readymade material with which students are to be made familiar, not enough as method of thinking, an attitude of mind, after the pattern of which mental habits are to be transformed" (Dewey, 1910, p. 121-122). Joseph Krajcik and Joi Merritt (2012) highlight that the issues brought up by Dewey in 1910 are still plaguing science education in America today. "U.S. science curriculum has long suffered from being disconnected and presenting too many ideas too specifically, often leaving students with disconnected ideas that cannot be used to solve problems and explain phenomena they encounter in their everyday world" (p. 4). The work of the National Science Foundation, the American Association for the Advancement of Science, and the National Research Council are a few examples of organizations that began a wave of reform for science education starting in the late 1980s to resolve concerns about the way students learn science (Berns & Sandler, 2009). In 1996 this reform, the *National Science Education Standards* (NRC, 1996), created the first national science education standards that sought to bring coherence that would improve science education. About twenty years later after trial and error from implementing the *National Science Education Standards* (NRC, 1996), a second set of national standards, the *Next Generation Science Standards (NGSS)*, was released (NGSS Lead States, 2013) to work on issues of keeping content and inquiry separate (Pruitt, 2014). *A Science Framework for K-12 Science Education* (NRC, 2012) was the blueprint for the *NGSS* and "expresses a vision in science education that requires students to operate at the nexus of three dimensions of learning: Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas" (NGSS Lead States, 2013, Appendix F p.1). The way the *NGSS* focus on practices, deeper applications, and content is not a new idea. What is new about the *NGSS* is the attempt to bring evidence-based approaches to achieving science literacy into practice through the standards themselves and the way the standards describe students engaging in integrated three-dimensional learning in order to make better sense of science phenomena. "Standards provide a vision for teaching and learning, but the vision cannot be realized unless the standards permeate the education system" including teacher preparation and professional development (NRC, 2012, p. 241). As implementation of the *NGSS* is underway, how do we know our efforts in teacher preparation are effective in meeting the full integration of the new standards and the implications they have on teaching science in this revisited way?

Rationale

The *Next Generation Science Standards* (NGSS Lead States, 2013) were released in 2013, and their precursor, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (the *Framework*) (NRC, 2012) was released in 2012. A main goal in their development was to use the lessons learned from past evidence-based practices on how students best learn science, as well as problems identified in realizing this vision in recent reform. The development of mathematics and English language arts national *Common Core State Standards* (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010) in 2009 inspired a similar focus for science (NRC, 2012). Although the committee and framework for the *Common Core State Standards* (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010) was different than the newly developed *NGSS*, the idea of revisiting what is essential for student learning across the nation was the same (NRC, 2012). The *NGSS* (NGSS Lead States, 2013) focus on three dimensions: disciplinary core ideas (science content), science and engineering practices (application of science), and cross cutting concepts (ideas that connect the disciplines in science) that are intended to be integrated for student learning.

"Teachers must meld all three of the dimensions together to build effective science lessons, but before they can do that, they need to understand each dimension and the shifts in emphasis around each that are central to the definition and structure of the *NGSS*" (Duncan et al., 2017, p. vii). The idea of using models in the science classroom appears in two of the three dimensions of the *NGSS* (NGSS Lead States, 2013). Developing and using models is one of the eight identified practices in the science and engineering practices dimension. Similarly, in the dimension of crosscutting concepts, systems and system models is one of seven identified concepts (NGSS Lead States, 2013). The practice of developing and using models is the focus for this study and has the potential to have a significant impact on teacher preparation because this practice also utilizes several of the other seven practices and modeling has been identified in two of the three dimensions in this new vision for science education (i.e. science and engineering practices, and cross-cutting concepts) (NRC, 2012). The inception of this dissertation study came from first hand observations of the missing practice of developing and using models in K-12 education as described in the *NGSS* (NGSS Lead States, 2013) during work with educators and students as a curriculum science specialist for a school district. This practice will have the greatest impact alone within the *NGSS* (NGSS Lead States, 2013) in changing science education because it is identified in two of the three dimensions. "The emphasis on modeling is also new and will need to be an explicit element of teacher preparation" (NRC, 2012, p. 258). Modeling instruction is the term used by researchers when using models in sense making processes within the science classroom (Campbell, Oh, Maughn, Kiriazis, & Zuwallack, 2014). This term, modeling instruction, will be used in this study to refer to the application of using models as discussed in the developing and using models practice within the *NGSS* (NGSS Lead States, 2013). Further description of the practice as described by the *NGSS* (NGSS Lead States, 2013) will be clarified in chapter two.

Statement of the Problem

As a science curriculum specialist, I have observed that the practice of developing and using models is complex work for current teachers. We need to understand pre-service teachers' current level of understanding regarding modeling instruction. Success in implementing modeling instruction will need to be developed from the beginning with preservice teachers and preparatory programs to implement key components of these new national standards. For that reason, elementary preservice teachers were chosen as the focus population for this study. The implications of the study include a better understanding of where teachers begin in the implementation of modeling instruction. This can in turn help to serve the shift that will be needed in teacher preparatory programs to bridge the gap between current levels of knowledge about modeling instruction and the greater role that modeling will play in the *Next Generation Science Standards* (NGSS Lead States, 2013).

The *NGSS* (NGSS Lead States, 2013) were released in 2013 and Kansas adopted the Kansas College and Career Ready Standards that same year that included the same shifts that were in the *NGSS*. The *NGSS* (NGSS Lead States, 2013) list criteria students need to be able to accomplish by the end of each grade band throughout K-12, but they do not give the pedagogy needed by teachers to achieve what needs to be learned by students. The *Framework* (NRC, 2012), the important document that guided the creation of the *NGSS* (NGSS Lead States, 2013), only *suggests* instructional methods will be needed to accomplish the *NGSS*. The instructional methods involved to teach the performance expectations in the *NGSS* (NGSS Lead States, 2013) will rely on evidence-based practices to achieve the standards. Teachers will need support to teach the integrated three-dimensional approach to learning in these standards. Standards prior to 2013 were often interpreted and implemented by science programs and science teachers as one dimensional, primarily focusing on the disciplinary core idea. It is important for teachers to understand the components of all three dimensions and to use them to work together for student learning. It will be critical for teachers to develop a strong knowledge of the practices to help their students engage in three-dimensional learning. Likewise, improving support with educators for the science and engineering practices will be needed. Because models appear in two of the three dimensions (i.e. science and engineering practices, and cross-cutting concepts) and the practice of developing and using models utilizes several of the other practices, it is a topic that holds great impact in teacher preparation. In a recent study of 19 preservice teachers, ideas about scientific practices, including modeling instruction, were examined. Ricketts (2014) identified elementary teachers as those that will need the most support due to their lack of a strong science background. Supporting elementary teachers in preservice teacher preparation is particularly important. Success in implementing modeling instruction will need to be developed from the beginning with preservice teachers and preparatory programs to implement key components of these new national standards. For that reason, elementary preservice teachers have been chosen as the focus population for this study.

Purpose of the Study

As the science community continues to implement the *Next Generation Science Standards*, preservice teachers will need to reconstruct their previous knowledge with shifts identified in the *NGSS*. With models occurring in two of the three dimensions, and being a newer component in the *NGSS*, this area provides a great way to impact this reconstruction in a way that will be needed. Professional learning experiences in undergraduate studies for science education will need to make shifts seen from the *NGSS* for preservice elementary science teachers. The purpose of this study was to examine the level of beginning knowledge (preconceptions) elementary preservice teachers have about developing and using models.

Research Questions

This study focused on preservice teachers' preconceptions of the *NGSS* (NGSS Lead States, 2013) science and engineering practice developing and using models. The study also included their preconceptions of the role of student-student and student-teacher discourse in the development of modeling instruction in the classroom, concepts that are described as fundamental to this practice (Campbell et al., 2014). The following research questions guided the study:

1. What are elementary preservice teachers' preconceptions about developing and using models in the classroom?
2. What student-student and student-teacher interactions are identified by elementary preservice teachers as critical to developing and using models in the classroom?
3. What teaching strategies do preservice elementary teachers identify as critical to developing and using models in the classroom?

Definitions of Terms

The following definitions were used to conduct this study. They are further clarified in Chapter 2, the literature review.

Science Inquiry. "The diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (NRC, 1996, p. 23).

Framework. "Beginning in January of 2010, the Carnegie Corporation of New York funded a two-step process to develop a new set of state developed science standards intended to prepare students for college and career readiness in science" (Pruitt, 2014, p. 145). The first phase ended with Achieve creating *A Framework for K-12 Science Education* (the *Framework*). "The goal of the Framework was to articulate the vision for science education in the twenty first century and to articulate what students need to know in their K-12 experience to be considered scientifically literate" (Pruitt, 2014, p. 146).

NGSS. The second phase, also privately funded, was led by twenty-six states and facilitated by Achieve. to take the *Framework* and develop student PEs that could be adopted by states. These new internationally benchmarked science standards, the Next Generation Science Standards (*NGSS*) were completed in April of 2013. The *NGSS* represent a change in how states have traditionally approached their science standards. In embracing science education research, the *NGSS* represent performance expectations (PEs) that require all students have a deep understanding of a smaller number of disciplinary core ideas (DCIs), are able to show evidence of that knowledge through scientific and engineering practices, and connect crosscutting concepts across disciplines" (Pruitt, 2014, p. 145).

Science and Engineering Practice. There are eight practices that make up the first dimension of the *NGSS* and they are described as "(a) the major practices that scientists employ as they investigate and build models and theories about the world and (b) a key set of engineering practices that engineers use as they design and build systems. We use the term "practices" instead of a term such as "skills" to emphasize that engaging in scientific investigation requires not only skill but also knowledge that is specific to each practice. Similarly, because the term "inquiry," extensively referred to in previous standards documents, has been interpreted over time in many different ways throughout the science education community, part of our intent in articulating the practices in Dimension 1 is to better specify what is meant by inquiry in science and the range of cognitive, social, and physical practices that it requires" (NRC, 2012, p. 30).

Crosscutting Concepts. These concepts are Dimension 3 of the *NGSS* and are described as "concepts that bridge disciplinary boundaries, having explanatory value throughout much of science and engineering. These crosscutting concepts were selected for their value across the sciences and in engineering. These concepts help provide students with an organizational framework for connecting knowledge from the various disciplines into a coherent and scientifically based view of the world" (NRC, 2012, p. 83).

Disciplinary Core Idea. "The continuing expansion of scientific knowledge makes it impossible to teach all the ideas related to a given discipline in exhaustive detail during the K-12 years. An important role of science education is not to teach "all the facts" but rather to prepare students with sufficient core knowledge so that they can later acquire additional information on their own. An education focused on a limited set of ideas and practices in science and engineering should enable students to evaluate and select reliable sources of scientific information and allow them to continue their development well beyond their K-12 school years as science learners, users of scientific knowledge, and perhaps also as producers of such knowledge. The committee developed its small set of core ideas in science and engineering. We grouped disciplinary ideas into four major domains: the physical sciences; the life sciences; the earth and space sciences; and engineering, technology, and applications of science" (NRC, 2012, p. 31).

Models. "Models include diagrams, physical replicas, mathematical representations, analogies, and computer simulations. Although models do not correspond exactly to the real world, they bring certain features into focus while obscuring others. All models contain approximations and assumptions that limit the range of validity and predictive power, so it is important for students to recognize their limitations" (NGSS Lead States, 2013, p. 386).

System and System Models. One of the seven crosscutting concepts in dimension two of the *NGSS* to help students deepen their knowledge of the disciplinary core ideas (NGSS Lead States, 2013). This crosscutting concept is described as "defining the system under study-specifying its boundaries and making explicit a model of that system-provides tools for understanding and testing ideas that are applicable throughout science and engineering" (NRC, 2012, p. 84).

Developing and Using Models. Listed as one of the practices in dimension one of the *NGSS* (from a science and engineering lens) to help students engage in work that is derived from what scientists and engineers actually practice (NGSS Lead States, 2013). "In science, models are used to represent a system (or parts of a system) under study, to aid in the development of questions and explanations, to generate data that can be used to make predictions, and to communicate ideas to others. Students can be expected to evaluate and refine models through an iterative cycle of comparing their predictions with the real world and then adjusting them to gain insights into the phenomenon being modeled. As such, models are based upon evidence. When new evidence is uncovered that the models can't explain, models are modified. In engineering, models may be used to analyze a system to see where or under what conditions flaws might develop, or to test possible solutions to a problem. Models can also be used to visualize and refine a design, to communicate a design's features to others, and as prototypes for testing design performance" (NGSS Lead States, 2013, p. 386).

Modeling Instruction. "Instruction that is centered around models, so that students explore, create, test, evaluate, and revise models in singular or iterative cycles in sense making processes within science classrooms" (Campbell et al., 2014, p. 160). This term was created to encompass all previous definitions, such as model-based inquiry and model-based reasoning, developed by other researchers when referring to using models as a teaching strategy in the classroom (Campbell et al., 2014, p.160). A full review of the literature is in chapter two.

Assumptions, Limitations, and Delimitations

In the fall semester of 2016, the students in this study were receiving instruction in a science methods course for a couple of weeks before this study took place. This course was the first science methods course the preservice teachers had taken and the assumptions of this study include the *NGSS* (NGSS Lead States, 2013) and the practice of developing and using models were not used for instruction the first two weeks of class. It is assumed that the participants in this study had little to no knowledge of the NGSS and specifically the practice of developing and using models.

This study focused on the science and engineering practice of developing and using models described in the *Framework* (NRC, 2012) and the *NGSS* (NGSS Lead States, 2013). The practices are one of the three dimensions (disciplinary core ideas, science and engineering practices, and crosscutting concepts) described in the new vision for science education (NGSS Lead States, 2013). Although the focus of the study is on one of the eight science and engineering practices, elementary teachers will need to integrate all three dimensions to form learning experiences for students. To achieve the vision of the *Framework* (NRC, 2012), elementary preservice teachers will need to understand each of the dimensions and this study aims to address one component of one of those three dimensions. This study conducted by the researcher exposed the preconceptions of the science and engineering practice of developing and using models for a population of elementary science preservice teachers. This knowledge can be used to strengthen greater areas of deficiencies for this practice. This study did not examine the implementation of the practice of developing and using models and frameworks (including discourse) that are specific to the goals for the elementary grade band using the specification in the *NGSS* (NGSS Lead States, 2013).

While the results of this study are encouraging, there are some limitations. First, the findings relate to the preservice elementary science teachers' ability to have understandings about the basic idea of the science practice of developing and using models. There are specific, grade appropriate criteria for elementary teachers and this practice. In order to meet the vision of the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013) with this practice of developing and using models, both an overall understanding of this practice (focus of this study) and ability to instruct based on grade appropriate criteria for this practice will be needed. Second, the preservice teachers were asked about their preconceptions of this practice and a video was analyzed during one phase of the study. The video was not intended to be an intervention, but instead to give teachers context to respond to the survey questions. The video may have provided some unintentional intervention, but better context was needed and identified through a previous pilot of the study. Third, analysis of written responses and interviews was conducted by one person and a more robust study would include more evaluators for inter-rater reliability. Efforts were made to use tools that previously existed to create validity in the study. Fourth, the study focused on preconceptions, but more impact could have been created to provide an intervention to help preservice teachers progress their understandings of how to use this practice to reach the vision of the *NGSS*. The implications of this study can serve to inform interventions for future studies. Last, the results are of two groups of elementary preservice science teachers in Kansas and although the implications of the study cannot be generalized to a larger context they can provide further insight about this practice and the support needed.

Summary of Chapter 1

The first chapter in this study provides the background and significance to the problem that was investigated. Chapter two will present a review of the literature that includes the science education wave of reform seen in this study, the role of the teacher and student in the reform-based classroom, information about our knowledge of the preservice teacher, and further clarifications of modeling instruction. Chapter three gives a description of the methodology that includes the participants, instruments, procedure, and data analysis methods for this study. The fourth chapter presents the findings of the surveys and interviews. The fifth chapter presents the findings and conclusions of the study as well as implications and future research for teacher education.

Chapter 2: Review of the Literature

Introduction

A recent reform in science curriculum began with a framework that developed expectations for all students in science and with an overarching goal (NRC, 2012, p. 1).

> By the end of 12th grade, all students have some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are careful consumers of scientific and technological information related to their everyday lives; are able to continue to learn about science outside school; and have the skills to enter careers of their choice. (NRC, 2012, p. 1)

A major difference between the older science standards and the *NGSS* is that students now work simultaneously with "how science is done (practice), and its practical value (applications), along with mastering content (facts)" (Mervis, 2013, p. 1391). The *NGSS*, released by the National Research Council (NRC), uses four key ideas: "(1) a limited number of core ideas of science, (2) the integration or coupling of core ideas and scientific and engineering practices, (3) crosscutting concepts, and (4) the development of the core ideas, scientific practices, and crosscutting concepts over time" (Krajcik & Merritt, 2012, p. 1). The last of these four key ideas is calling for the development of the other three, making the *NGSS* three dimensional in nature. In order for instructional resources to meet the vision of the standards they are required to be three dimensional and integrate the three dimensions in instruction (Achieve, 2016a).

> Pairing practices with DCIs is necessary to define a discrete set of blended standards, but should not be viewed as the only combinations that appear in instructional materials. In fact, quality instructional materials and instruction must allow students to learn and apply the science practices, separately and in combination, in multiple disciplinary contexts.

The practical aspect to science instruction is that the practices are inextricably linked. (NGSS Lead States, 2013, p. xvii)

Modeling appears in two of these three dimensions. In the dimension of science and engineering practices, developing and using models is one of the eight identified science and engineering practices. Similarly, in the dimension of crosscutting concepts, systems and system models is one of the seven identified concepts. “Modeling can begin in the earliest grades, with students’ models progressing from concrete “pictures” and/or physical scale models (e.g., a toy car) to more abstract representations of relevant relationships in later grades, such as a diagram representing forces on a particular object in a system” (NRC, 2012, p. 58). “Increasingly, more science education researchers and U. S. national standards documents have noted the importance of models in science and engineering and have subsequently called for an increased role for models in K-12 science teaching and learning” (Campbell et al., 2014, p. 159-160). Children before entering elementary school ask about the natural/designed world around them and if students develop the practices of science and engineering, they can ask better questions and improve how they define problems (Bybee, 2011, p. 34). “Because science and engineering practices are basic to science education and the change from inquiry to practices is central, this innovation for the new standards will likely be one of the most significant challenges for the successful implementation of science education standards (Bybee, 2011, p. 34). The science and engineering practices build on prior reforms of inquiry in science classrooms and better articulate “what successful inquiry looks like when it results in building scientific knowledge” as a “kind of Inquiry 2.0-not a replacement for inquiry” (Schwarz, Passmore, & Reiser, 2017, p.5)

With the implementation of the *NGSS*, specifically the science and engineering practices, shifts in science preservice professional learning will be needed. “Considering that preservice elementary teachers have little to no experience participating in a scientific community, it is not surprising that their knowledge of scientific practices is often limited" (Ricketts, 2014, p. 2110). Combining preservice teacher's previous knowledge of the practices with awareness of their collective renewed meaning will help them reach the new vision for science education.

A Reform in Science Education

"Beginning in the early 1980s, a report by the Commission on Excellence in Education, *A Nation at Risk*, stimulated an era of standards-based reform, which we are in the midst of today" (Lederman & Abell, 2014, p. 568). *A Nation at Risk* (National Commission on Excellence in Education, 1983) warned of the risks in general education, but also gave warnings in science education if we as a nation neglected to improve public school quality of teaching. In the late 1980s and early 1990s, standards began to be used in the science community (Bybee, 2014, p. 212). It is important to note that Roger Bybee was a *NGSS* writing team leader and has been a strong voice in science education holding director roles in the Biological Sciences Curriculum Study and National Research Council Center for Science, Mathematics, and Engineering Education while contributing to the development of science education standards since the 1980's (Bybee & Pruitt, 2017). Based on a scientific literacy initiative (Project 2061) that was sponsored by the American Association for the Advancement of Science (AAAS), *Science for All Americans (SFAA)* reported what necessary steps were needed to begin reformations for education in science, math, and technology (Rutherford & Algren, 1989). The name "Project 2061" came from an idea that science reform requires a long-term vision (Nelson, 1999, p. 15). In *SFAA*, authors claim, "most Americans are not science-literate" (Rutherford & Algren, 1989, p. 32). These authors argued the need for science literacy and used international studies of poor U.S. performance, America's future, and global problems among the reasons to produce science literate students (Rutherford & Algren, 1989, p. 30-32). They saw the U.S. as a prosperous nation able to do more and provided examples where education was lacking including teacher knowledge in science, textbooks, and over packed curricula (Rutherford & Algren, 1989, p. 35-36). The AAAS described the purpose of the *SFAA* as follows:

> The terms and circumstances of human existence can be expected to change radically during the next human life span. Science, mathematics, and technology will be at the center of that change—causing it, shaping it, responding to it. Therefore, they will be essential to the education of today's children for tomorrow's world. (American Association for the Advancement of Science (AAAS), 1993)

The recommendation of the authors for the *SFAA* asked for more content not to be taught, but instead a focus to be placed on the essentials that made someone literate in science (Rutherford & Algren, 1989, p. 37). The writings from the *SFAA* sought to represent a wide-ranging definition of what it means to be literate in science including habits of mind, the world through the lens of science, and the nature of science. Although the definitions were broad, this work helped produce another important document in the reform for science education. *Science for All Americans* "intended to present a compelling vision of achieving learning goals, that of the *Benchmarks for Science Literacy* was to chart territory that is necessary to reach the goals issued in *Science for All Americans"* (Rutherford & Algren, 1989, p. 17-18).

The *Benchmarks for Science Literacy (Benchmarks)* were written in 1993, four years after *SFAA,* and identified "how students should progress toward science literacy, recommending what they should know and be able to do by the time they reach certain grade levels" (AAAS, 1993). The *Benchmarks* were created with progress checkpoints for the end of grades 2, 5, 8, and 12 (AAAS, 1993). Groups of district teams comprised of teachers with consulting help from science specific specialists wrote the *Benchmarks*. They focused on twelve topics and were designed with an introductory section to create meaning for the topic. The grade level bulleted checkpoints also included a shorter introductory section that specified the topic more at the grade level of the checkpoints for the K-2, 3-5, 6-8, and 9-12 grade bands (AAAS, 1993). In 1995, the Trends in International Mathematics and Science Study (TIMSS) gathered data on the "quality of precollege education in science and mathematics in the United States and other countries" (Schmidt & McKnight, 1998, p. 1830-1831). Cross-national tests measuring achievement in each of the three grade bands, K-5, 6-8, and 9-12 were used as well as other variables that can affect quality of education (Schmidt & McKnight, 1998, p. 1830-1831). "The goal was to develop a map of the structure of each national education system, both to inform study of that system and to guide sampling for achievement testing" (Schmidt & McKnight, 1998, p. 1830-1831). The study showed that U.S. students are not learning what is most useful in science, math, and technology (Schmidt & McKnight, 1998, p. 1830-1831). In "Science literacy for all in the 21st century" (Nelson, 1999), the use of the TIMSS study helped create a greater need to use the work by the AAAS, *Benchmarks*, to continue a path to bring quality science literacy to our pre-college education in the U.S. (p. 14-17). "In a joint statement issued in February 1996, AAAS, the National Academy of Sciences, and the National Science Teachers Association affirmed their commitment to science literacy" (Nelson, 1999, p. 15).

In 1996, the National Research Council (NRC) published the *National Science Education Standards* (NRC, 1996). The *National Science Education Standards (NSES)* (NRC, 1996) recognized the established goals that the nation created to bring quality science education to the U.S. by helping students achieve scientific literacy (NRC, 1996, p. ix). These standards "emphasized a new way of teaching and learning about science that reflect how science itself is done, emphasizing inquiry as a way of achieving knowledge and understanding about the world" (NRC, 1996, p. ix). The *Benchmarks* (AAAS, 1993*)* and the *NSES* (NRC, 1996) differed in form and purpose. The *Benchmarks* served as a tool to help design curriculum to promote science literacy by specifying levels of understanding and ability to become literate in science (AAAS, 1993). The *NSES* do not rewrite the *Benchmarks* (AAAS, 1993*)*, but instead complement them by going further and describe, for the first time, criteria to judge the quality of teaching, professional development for educators, assessment systems, and science education programs (NRC, 1996). These standards began development when national support for education standards by state governments occurred in 1989 through endorsement by the National Governors Association (NRC, 1996, p. 13). Although these standards were a science education national effort, they are not federally mandated and states are free to use these standards or any others to create their own standards and assessments. Many works including those by the AAAS had influence over the call to action for these national standards to be written.

> The National Research Council of the National Academy of Sciences gratefully acknowledges its indebtedness to the similar work by the American Association for the Advancement of Science's Project 2061 and believes that use of *Benchmarks for Science Literacy* by state framework committees, school and school-district curriculum committees, and developers of instructional and assessment materials complies fully with the spirit of the content standards. (NRC, 1996, p.15)

The standards provide a set of "criteria that people at the local, state, and national levels can use to judge whether particular actions will serve the vision of a scientifically literate society" (NRC, 1996, p. 3). These standards provided a finer grain size of content specification than the *Benchmarks* (AAAS, 1993) and included a set of criteria for judging science teaching, professional development, assessment, science content, science education programs, and science education systems (NRC, 1996). The central idea in creating science education standards "is to describe clear, consistent, and comprehensive science content and abilities" (Bybee, 2014, p. 212).

In 2010, new science standards, *The Next Generation Science Standards (NGSS)* (NGSS Lead States, 2013), began their development that sought to create a different vision of standards (Pruitt, 2014, p. 146).

> Not only has science progressed, but the education community has learned important lessons from 10 years of implementing standards-based education, and there is a new and growing body of research on learning and teaching in science that can inform a revision of standards and revitalize science education. (NRC, 2012, p. ix)

Previously, states were using the *NSES* or the *Benchmarks* to create their own standards that often "kept inquiry and content standards separate" (Pruitt, 2014, p. 146).

> While each of them called for inquiry to be integrated into classrooms, state standards have traditionally kept inquiry and content standards separate. As a result, state assessment has tended to keep them separate and focused almost solely on content, which has also led to a greater focus on content in classrooms. While the previous efforts in science education reform did not intend science to be discrete pieces of knowledge, state standards often reduced it to just that. The *NGSS* were developed by states to be adopted directly by states in a manner that will realize the vision of quality science education. (Pruitt, 2014, p. 146)

The first phase of creating these contemporary standards involved "The National Research Council (NRC), the operational arm of the National Academy of Sciences, developing

A Framework for K -12 Science Education (henceforth the *Framework*) (NRC, 2012)" (Bybee, 2014, p. 212). The *Framework* (NRC, 2012) embodied a vision of design specifications to achieve science literacy for all that "values a learning progression of scientific content, scientific and engineering practices, and the crosscutting ideas that connect the various disciplines of science" (Pruitt, 2014, p. 146). It is important to note that Stephen Pruitt has an extensive background with local, state, and national levels of science education and served as senior vice president for Achieve leading one of the biggest science education reforms efforts with the *NGSS* while also being a member of the writing team for the *Framework* (Bybee & Pruitt, 2017). There are three parts to the *Framework*.

> The first part presents a vision for science education, which includes the guiding assumptions and organization. Part two provides the content for science and engineering education. Finally, part three addresses the means to realize the vision by addressing the integration of content, implementation, equity, and guidance for the *NGSS*. The *Framework* describes three dimensions for standards: science and engineering practices, crosscutting concepts, and core ideas in science disciplines. (Bybee, 2014, p.212-213)

The *Framework* gave guidance for the second phase of this science education reform. There are similarities between this document and *Science for All Americans* (Rutherford & Algren, 1989), which was written over thirty years before the *Framework.* Both documents were written to establish science literacy and gave guidance to preceding national standards.

The second phase, creation of the *Next Generation Science Standards*, was led by the efforts of twenty-six states and directed by Achieve (Bybee, 2014). There were twenty-six lead state partners that provided leadership in the writing team making a commitment to give serious consideration to adopting the *NGSS* and Kansas was one of the twenty-six lead states (NGSS Lead States, 2013). Each of the twenty-six states created a state team that included teachers, industry experts, and education leaders (Bybee, 2014). Kansas created a team of sixty that included K-12 science educators, post-secondary science professors, post-secondary science education professors, and business and industry representation. The state teams created a different development process than the *National Science Education Standards* created over fifteen years ago (NRC, 1996). The *National Science Education Standards* (NRC, 1996) development process utilized district teams instead of state teams. These state teams gave feedback and created drafts with Achieve for the final development of the *NGSS* (Bybee, 2014). "The final *NGSS* document was developed through the collaborative effort of 26 lead states in cooperation with stakeholders in science, science education higher education, and business and industry" (Bybee, 2014, p. 213). These new standards are different than the previous approaches mentioned in this wave of reform that began in the late 1980s. The three dimensions in the *NGSS* (disciplinary core ideas, science and engineering practices, crosscutting concepts) are meant to be interconnected and were directly written this way (Bybee, 2014). This integration will form "deeper experiences with, and understanding of, science concepts and practices" (Bybee, 2014, p. 215). The standards are not called standards, but instead performance expectations (NGSS Lead States, 2013). The performance expectations are presented in progressions for grade bands each building on the previous (NGSS Lead States, 2013). Previous standards focused on content and practices, the *NGSS* include crosscutting concepts and engineering components (Bybee, 2014). The *NGSS* (NGSS Lead States, 2013) also coordinate with Common Core State Standards for English Language Arts and Mathematics (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010). "Changes implied by the *Framework* for K-12 Science Education (NRC, 2012) and *NGSS* (NGSS Lead States, 2013) imply dramatic changes in teacher education programs" (Bybee, 2014, p. 217). Teaching and learning will require a different process than what has been applied in the past. The differences in these standards will have an impact on Kansas science classrooms in four key areas. First, the term science inquiry and scientific method have led to a separation of content and process that contrast with the emphasized idea in the *NGSS* that "science content is best learned by engaging in practices" (Bell, Shouse, & Peterman, 2014, p. 2). The *NGSS* offer a tighter integration in the standards themselves related to learning disciplinary core ideas while making connections to cross-cutting concepts (NGSS Lead States, 2013). Second, "previously science teachers were encouraged to identify children's misconceptions and design instruction to unsettle and replace these" (Bell et al., 2014). We have a better understanding that science ideas and identities are grounded in their personal experiences and should be leveraged as they learn (Bell et al., 2014). Third, the *NGSS* (NGSS Lead States, 2013) make explicit that these are standards for all students and not those that have often been marginalized from quality science instruction better attending to equity and calling for ambitious science for all (Bell et al., 2014). The last key area of impact includes modern science ideas for learning. The *NGSS* have learning goals across K-12 related to engineering, technology, and applications of science that include engineering practices (NGSS Lead States, 2013). "Engineering, technology and applications of science are central to science education" and "students should learn about engineering, technology, and applications of science" across K-12 including iterative design in engineering (Bell et al., 2014).

The *NGSS* Science Classroom

A key difference between the older national standards and the *NGSS* is that the "*NGSS* were written with the intention that states adopt them *as written* as opposed to the *NSES* which states had to modify to make them fit the requirements for state standards" (Pruitt, 2014, p. 154-155). This type of adoption will aid in creating the three-dimensional integration as opposed to keeping content and practice separate as in previous years (NRC, 2012). The new vision for science is intended to have students "engage in science and engineering practices and use disciplinary core ideas and crosscutting concepts to explain phenomena and solve problems" (Krajcik et al., 2014, p. 158). "The more connections developed, the greater the ability of students to solve problems, make decisions, explain phenomena, and make sense of new information" (Krajcik et al., 2014, p. 158). "Students are not just learning the disciplinary core ideas but are also engaging in science and engineering practices and understanding and applying a set of crosscutting concepts" (Duncan, Krajcik, & Rivet, 2017, p. vii). This section of the paper will describe the types of learning that can be seen in the newly reformed classroom.

"The vision of the *Framework* and the *NGSS* is to use scientific and engineering practices as a means for students to show evidence they are able to apply knowledge" (Pruitt, 2014, p.149). The ability for students to "show a deeper level of understanding of content is critical" (Pruitt, 2014, p. 149). In previous standards, it was enough for students to simply understand content (Pruitt, 2014). The verbs in the older standards used those from Bloom's taxonomy leading to separation of content and practice (Pruitt, 2014). The *NGSS* uses the science and engineering practices as verbs (Pruitt, 2014). Pruitt (2014) gives an example of an older 1998 California high school standard and the newer version from the *NGSS*.

> The following is an example from the 1998 California State Standards, High School Chemistry 8.b: Students know how reaction rates depend on such factors as concentration, temperature, and pressure. Consider this PE from the *NGSS* dealing with the same content, HS-PS1-5: Apply scientific principles and evidence to provide an

> explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. (Pruitt, 2014, p. 149)

Pruitt (2014) makes a comparison between the verb use in the California standard to simply know, but in the *NGSS* standard students are still expected to know but now must “provide evidence that support those rules” (p. 149). Instead of using the term “skills” in the *Framework* (NRC, 2012), developers chose to use the term “practice” instead (Pruitt, 2014). “An important change in how the practices will affect science classrooms is the realization that practices are not merely pedagogical strategies” (Pruitt, 2014, p. 150). In previous years, educators were using inquiry in the classroom as a teaching strategy (Pruitt, 2014). This often didn’t lead students to make connections in their knowledge “of how scientists work with how the science works” (Pruitt, 2014, p. 150). Research in science teaching and learning has shown that teaching content separate from how to use it has resulted in disconnected ideas that students find difficult to use and apply (NRC, 2007). Also, using a science process in isolation of core ideas leads to learning how to carry out a specific science procedure without knowing the meaning of why it exists or when to be able to use it (Duncan et al., 2017). “You cannot learn the ideas of science apart from the doing, and you cannot learn the practices of science apart from the core ideas” (Duncan et al., 2017, p. 5). An analogy is used to describe three-dimensional learning.

> Think of knowing how to do various techniques in the kitchen, such as kneading bread, cutting tomatoes, beating an egg, frying or roasting meat, and so on. These kitchen practices are like the science and engineering practices. You could know how to do all of these and still not be able to prepare a good meal. Now think about picking out great ingredients and knowing how those ingredients work together to form a delicious dish.

> You want a top-shelf piece of fish or poultry, some fresh vegetables, and well-made pasta. These are like your disciplinary core ideas (DCIs). DCIs are essential to explaining a number of phenomena; your main ingredients are essential to preparing a fantastic dinner. But just as the DCIs work with practices to help students make sense of phenomena and design solutions, the main ingredient is not as good if you don't use proper cooking techniques. But, even with these two elements, something is still missing. The food tastes bland. To make it really stand out, spices and herbs are needed. Crosscutting concepts are like your seasonings because they work across and are essential to all the disciplines. Cooking techniques, quality of the main ingredients, and condiments work together to make a delectable meal. Similarly, to make sense of phenomena and design solutions to problems, all three dimensions need to work together. (Duncan et al., 2017, p. 5)

"Making sense of the world, or sense-making for short, is the fundamental goal of science and should be at the core of what happens in science classrooms" (Schwarz et al., 2017, p. 6). Students engage in the science and engineering practices when they are making sense of the world and trying to figure out the way it works (Schwarz et al., 2017). "The emphasis on the science and engineering practices attempts to build on prior reforms and take advantage of what research has revealed about the successes and limitations on inquiry in classrooms" (Schwarz et al., 2017, p. 5). The *Framework* identify eight science and engineering practices and are the "different parts of the sense-making process" (Schwarz et al., 2017, p. 6).

1. Asking questions and defining problems.
2. Developing and using models
3. Planning and carrying out investigations

4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Schwarz, Passmore, and Reiser (2017) paint a picture of the vision of three-dimensional learning in a classroom by exploring the differences in two classroom case vignettes. The two vignettes are classroom descriptions of middle school students learning about the phases of the moon. One classroom is integrating the three dimensions as described in the analogy described in this section. The other classroom is focused more on “learning about” instead of “figuring out” that the shifts in the *NGSS* are moving away from (Schwarz et al., 2017). An excerpt from case one is described below.

> The students come into Ms. Sheridan’s class and find that the topic for the day is Moon phases. The day before this class, students had reviewed the order of the planets from the Sun. They had also made a chart of key characteristics of each planet. After she introduces the topic of the day, Ms. Sheridan asks the students to raise their hands and when called on tell the class one thing they know about the Moon. Students offer ideas such as “I know we’ve sent rockets to the Moon” and “Isn’t the Moon involved in tides?” After three or four students have shared, Ms. Sheridan asks them if they have ever noticed that the Moon has different shapes at different times. She explains that the different shapes are called the “phases of the Moon” and puts up a list naming eight phases of the Moon. Next, she explains that today they are going to learn why the Moon’s shape appears to change. She starts with the main facts about Moon phases: The phases

occur in a cycle. The cycle is one revolution of the Moon around the Earth, about 28 days. She explains that the Sun is relatively far away from the Earth and the Moon. She shows the class how light from the Sun falls on the Moon, always lighting up exactly half of it. Then she explains that the part of the lit Moon you can see varies depending on where the Moon is in its orbit around the Earth. She shows the class a diagram on the smart board, walks them through the different steps in the Moon's orbit, and describes the phase that can be seen at that point in the orbit, along with telling students the name of each Moon phase that she expects them to learn. Ms. Sheridan then tells the class that they can now try it out for themselves to see each phase of the Moon. (Schwarz et al., 2017, p. 8-9)

Most of the questions in case one come from the teacher and not the students. The teacher also has the master plan on how to investigate the question instead of students doing the sense making. Students are getting to an explanation by learning content in isolation from the practices. This is the type of learning that the *Framework (NRC, 2012)* describes as leading to disconnected ideas. An excerpt from case two is described below.

The students in Ms. Lee's class have been working on near-Earth astronomy for a few weeks. They have been pursuing the overarching question "Why do the Sun, Moon, and stars move in our sky and change in appearance over time?" Recently, the students have been investigating the appearance of the Moon. They wonder why it is visible in the sky at different times of day and appears some nights and not others. For over a month they have been spending a few minutes each day recording the appearance of the Moon on that day in a data table in their notebooks. As the Moon goes through the cycle of phases, the students learn the technical name of each phase. Prior to this lesson, they used moonrise time data to figure out that the Moon orbits the Earth in the same direction as the Earth spins, and it takes about a month to complete one orbit. Ms. Lee begins class on this day with a discussion to help the students summarize what they have figured out so far and what questions remain about their observations. Ms. Lee draws their attention to the main question about the Moon that started them off on their investigation: “Why does the Moon change shape during the month?” The students have collected data about the Moon’s appearance with the observations made throughout the month. Based on what they have discovered so far, the class refines its original question to “Why does the appearance of the Moon change as it orbits the Earth?” In the discussion, Ms. Lee raises the question of how it is even possible to see the Moon from Earth. Students draw on what they know about light sources and how light allows us to see and generally agree that it must be the light from the Sun reflecting off the Moon that makes part of the Moon visible from the Earth (since the Moon is not a light source). But students are not in agreement about why this would change as the Moon revolves around the Earth. Ms. Lee suggests they try to picture what is happening as the Moon goes around the Earth and recommends they use physical props to see for themselves why the shape might appear to change. In discussion, students decide they need to represent the Earth, the Moon, and the Sun. Ms. Lee gives each group of students a Styrofoam ball and says that they can use the ball to represent the Moon. Since the goal of the activity is to see what the Moon looks like from Earth, Ms. Lee helps the students come up with the idea of using the ball and their own bodies to simulate the Moon’s orbit around Earth (recalling what they had already figured out about that from the moonrise times). (Schwarz et al., 2017, p. 10-12)

The questions in case two come from students and they are actively involved in figuring out the phenomena of the changing moon shape in the night sky. Students can get to an explanation by using phenomena to drive their learning and are engaged in learning about the content by using the science and engineering practices simultaneously to make sense of their questions. This classroom case is making the shifts described in the *Framework* (NRC, 2012) and integrates the three dimensions better creating connected learning ideas for students. Schwarz et al. (2017) describe the eight practices working together to help students make sense of the world and this diagram represents how they achieve this to answer the four main questions in sense making (p. 18).

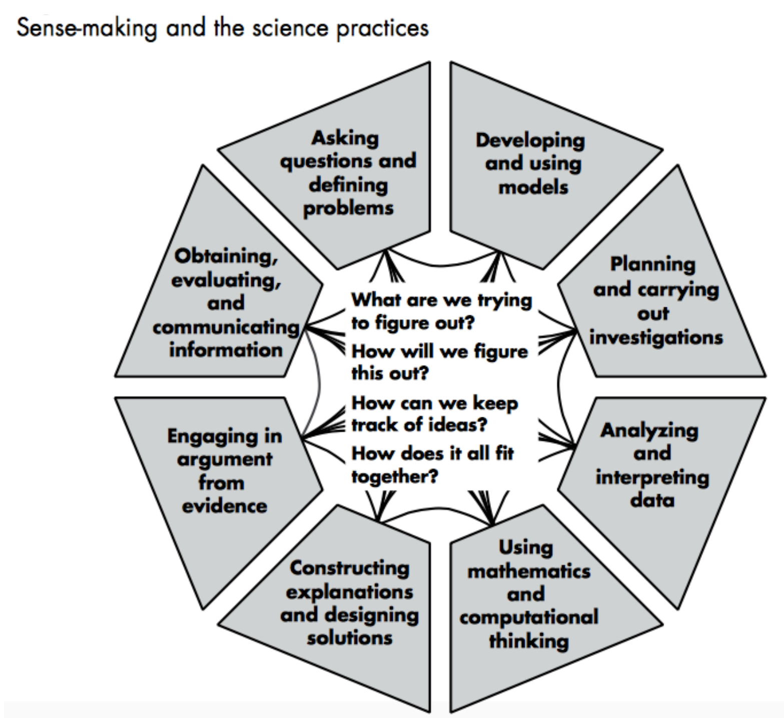

Figure 1. Sense-making and the science practices

(Schwarz et al., 2017, p. 18)

Science learning "is an inherently social and cultural process that requires mastery of specialized forms of discourse and comfort with norms of participation in the scientific community of the classroom (NRC, 2007, p. 203). Engagement in practices is language intensive and requires students to participate in classroom science discourse. The practices offer rich opportunities and demands for language learning while advancing science learning for all students (Lee, Quinn, & Valdés, 2013). “Each of the eight practices, as it is introduced and elaborated and experienced in the classroom, requires that students externalize their reasoning” (Schwarz et al., 2017, p. 311). Talk and discursive practices are fundamental to all the science practices in the classroom and mimic that of experienced scientists and engineers (Schwarz et al., 2017). “Researchers in a variety of fields relating to education have begun to converge on the finding that when teachers open up the conversation and get student to participate actively in reasoning with evidence and building and critiquing academic arguments, students make dramatic learning gains” (Schwarz et al., 2017, p. 312). In *Taking Science to School: Learning and Teaching Science in Grades K-8 (NRC, 2007)*, authors describe scientific discourse as different from that of everyday life and support is needed to engage in this type of discourse. Ogborn, Kress, Martins, and McGillicuddy (1996) found that most of the talk in science classrooms come from teachers and is mostly persuading talk about science topics. Eichinger, Anderson, Palinscar, and David (1991) found that students are more likely to engage in academically productive talk like argumentation when they are able to do this by working directly with each other instead of through teacher mediated talk. This talk needed to be supported by the teacher working to create classroom norms for this student mediated talk to occur and students were not successful without teacher intervention (Eichinger et al., 1991). In *Helping Students Make Sense of the World Using Next Generation Science and Engineering Practices*, Schwarz et al. (2017) devote a whole chapter to science discourse and base many of their recommendations on the work of Michaels and O’Connor (2012). Michaels and O’Connor

(2012) describe four teacher goals for academically productive talk through their findings from research. These four goals were used to create a scale for qualitative data coding in this study and is later described in chapter three.

1. Help individual students share, expand, and clarify their own thoughts.
2. Help students orient to and listen carefully to one another.
3. Help individual students deepen their own reasoning.
4. Help students engage with others' reasoning

These four teacher-centered goals apply to each of the *NGSS* science and engineering practices (Schwarz et al. 2017). There are five reflection questions that Michaels and O'Connor (2012) describe for educators to use as indicators that students are having quality meaning making discussions. These five questions were also used to create a scale for qualitative data coding in this study and will be further clarified in chapter three.

1. Did students propose answers? Did their answers address the main discussion question?
2. Did students use evidence to support their answers?
3. Did they critique their own and others' answers?
4. Did students merge their own and other's ideas to develop an explanation?
5. Did students apply their learning to a new context?

These four goals and five reflective questions for academically productive talk come from talk science research "investigating how teachers develop their capacity at leading productive science discussions to foster students' scientific reasoning" (Technical Education Research Centers (TERC), n.d). The framework is "rooted in sociological, linquistic, and anthropological approaches to classroom research going back over 30 years" (Michaels & O'Connor, 2015, p. 335). The tools and professional development program from this research are web-based and findings included shifts that teachers had in their perspectives on classroom discussions and their capacity to lead those discussions. The aim of the project was to enhance elementary science teachers' facilitation of productive science discussion in classrooms to promote scientific reasoning (TERC, n.d.). This research draws upon a body of research promoting academically productive talk in math classrooms that include the same four learning goals (Chapin, Anderson, & O'Connor, 2009).

The Teacher in an *NGSS* Classroom

Roger Bybee (2013) describes the instructional core "as a way to direct attention to the essentials of improving student learning- content, curriculum, and teachers' knowledge and skills for teaching content" (p. 9). In 2009 Richard Elmore introduced the term *instructional core*.

> There are only three ways to improve student learning at scale: You can raise the level of content that students are taught. You can increase the skill and knowledge that teachers bring to the teaching of that content. And you can increase the level of students' active learning of the content. (Elmore 2009, p. 24)

Bybee (2013) uses the instructional core graphic in Figure 2 below to direct attention to the essentials of improving student learning. As the levels of science content and practices have changed with the *NGSS* science teacher knowledge and skills along with science curriculum and instruction will need to change. This section of the literature review will focus on how the *NGSS* (NGSS Lead States, 2013) change science teacher knowledge and skills as well as science curriculum and instruction.

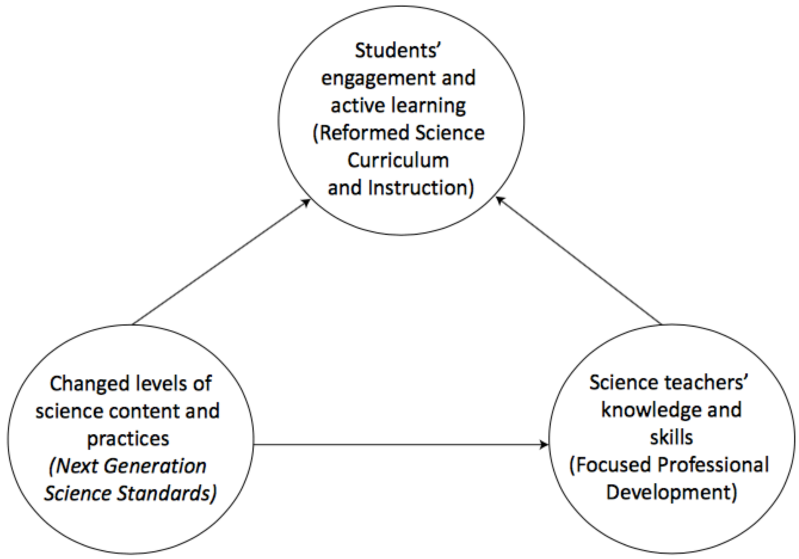

Figure 2. Instructional core of practice for science teaching

(Bybee, 2013)

The instructional shifts have been described differently by various authors, though these definitions have generally fallen into five main categories. Marshall and Alston (2014) write, "[t]he implementation of the *NGSS* represents a fundamental shift from the past standards for two significant reasons: (a) The degree of higher-order skills that all students are expected to master has increased dramatically, and (b) the level to which scientific practices and scientific content are integrated has dramatically increased" (p.808). Marshall and Alston (2014) indicate the integration of content and practice as a shift, but Bybee (2014) includes a critical third dimension that was intended to be integrated with the content and practices from the developers of the *NGSS*. This third dimension consists of crosscutting concepts that serve to deepen student understanding of the content (NRC, 2012). The integration of these three dimensions (content, practices, and crosscutting concepts) for science instruction is different from the way states were creating recommendations for curriculum. This integration will form "deeper experiences with, and understanding of, science concepts and practices" (Bybee, 2014, p. 215). In his description of the instructional shifts in the *NGSS*, Bybee (2014) indicates three additional topics separate from those mentioned by Marshal and Alston (2014): there are learning progressions in the *NGSS* that build coherence across K-12, the inclusion of engineering design in the standards, and an integration with the Common Core State Standards for English Language Arts and Math that were written into the *NGSS*. "The *NGSS* represent a fundamental change in the way science is taught and, if implemented well, will ensure that all students gain mastery over core concepts of science that are foundational to improving their scientific capacity" (National Academies of Sciences, Engineering, and Medicine, 2015, p.1). While these additional topics described by Bybee (2014) are integral to the implementation of *NGSS*, the two shifts identified by Marshall and Alston (2014) are foundational shifts that will be more difficult to accomplish than the others mentioned by Bybee (2014).

The instructional shift of combining separately taught content and practice is expanded by Marshall and Alston (2014). They analyzed one state's standards, that was indicated publicly as being strong, and found that 82% of the high school life science standards called for lower level thinking skills. The *NGSS* high school life science standards have only 6% of performance expectations at a remembering and understanding, lower thinking level (Marshall & Alston, 2014). The higher-level thinking in the *NGSS* stem from the inclusion of not just content, but also the other two dimensions (science and engineering practices and crosscutting concepts) that add depth to the standards. "For many years state science education standards have focused more on discrete facts, such as names and order of the planets, phases of mitosis" and not using those "facts to understand bigger concepts such as the Earth-Sun-Moon system and survival of an organism" (Pruitt, 2014). The *NGSS* were written with the intent for states to adopt them directly so the content and practices would be kept intact at the state level (Pruitt, 2014). This integration of the content, practice, and crosscutting concepts will be a shift for teachers, both in curriculum planning and in classroom instruction.

How can teachers better acclimate to these shifts in regard to curriculum planning? The *NGSS* (NGSS Lead States, 2013) are written in grade banded performance expectations. Along with studying the eight practices, teachers will need to study what aspects of the disciplinary core ideas are newly emphasized or de-emphasized (Duncan et al., 2017). After the release of the standards, developers of the NGSS met to discuss implementation and the role of instructional materials was a key focus (Roseman & Koppal, 2015). The authors of a *Guide to Implementing the Next Generation Science Standards* say, “full sequences of curriculum materials developed explicitly for the *NGSS* have not yet been developed” (NRC, 2015, p.4). “You won’t find much now, and it’s going to take time” (Roseman & Koppal, 2015). The demand for new curricular materials will be significant as more states continue to adopt *NGSS*, adding to the states which have already adopted and make up 26 percent of the U.S. student population (Roseman & Koppal, 2015). The *NGSS* “are in a position to exert significant influence on the design and use of science curriculum materials” (Roseman & Koppal, 2015).

Roseman and Koppal (2015) also note two major differences that come with the new standards that will likely affect development of curricular materials. First there is the integration and coherence of the three-dimensional learning that combines practice, content, and crosscutting concepts (Roseman & Koppal, 2015). “Engaging in science and engineering practices helps students learn science content, and learning the content helps students engage in the practices” (Roseman & Koppal, 2015, p. 24). If the practices or the content is left out, students may not develop ability in the other (Roseman & Koppal, 2015). The integration of these three dimensions also calls for coherence of these three dimensions to build across lessons, units, and grade bands (Roseman & Koppal, 2015). This coherence will "require that materials take into account essential science ideas, common student misconceptions, and basic ideas to build on" (Roseman & Koppal, 2015, p. 25). "Curriculum developers will need classroom data to select phenomena-based activities for students, refine the sequencing of student experiences into a coherent content storyline, and provide the instructional scaffolding necessary for ensuring student learning" (Roseman & Koppal, 2015, p. 25).

Second, the standards are now listed as performance expectations instead of learning goals (Roseman & Koppal, 2015). Performance expectations are descriptions of the integration of the three dimensions and show what students should be able to demonstrate at the end of instruction (NGSS Lead States, 2013). Older learning goals in previous standards used knowledge or skill statements that were used to directly build curriculum (Roseman & Koppal, 2015). NGSS Lead States (2013) make it explicit that the performance expectations are not a curriculum, but instead they should be used to know what students should be able to demonstrate at the end of instruction. The challenge for developers will be to create materials that provide the learning experiences along the way (integrated to the three dimensions) to meeting the performance expectations for all of our students (Roseman & Koppal, 2015).

The *Report of 2012 National Survey of Science and Mathematics Education* examined a survey given to 7,752 science and math teachers across the U.S. (Banilower, Smith, Weiss, Malzahn, & Campbell, 2013). In this survey, teachers were asked to answer questions about their instructional resources (Banilower et al., 2013). Over three-fourths of middle and high school science teachers reported use of published textbooks or programs (Banilower et al., 2013). "Textbooks appear to exert substantial influence on instruction, from the amount of class time spent using the textbook to the ways teachers use them to plan for and organize instruction"

(Banilower et al., 2013, p. 108). Although the study indicated heavy use of textbooks, there were findings from the survey that conclude "teachers deviate from their textbooks substantially when designing instruction" by incorporating other sources of activities (Banilower et al., 2013). "Science classes are more likely than mathematics classes to use multiple textbooks (or programs or modules), especially at the elementary level" (Banilower et al., 2013). The importance of continuing to develop aligned instructional materials can be seen from this report.

In order for teachers to shift their instruction, materials to support the new learning will be needed and teachers should not be expected to develop their own curriculum (NRC, 2015). While this is the case, there are current research-based units and materials that somewhat support the vision of the *NGSS* which are not fully aligned, but which can be adapted (NRC, 2015). Achieve Inc. (2016a) released version three of the *Educators evaluating the quality of instructional products for lessons and units (EQuIP)* in science that make use of the anatomy of the performance expectations for translation into teaching and learning. Not only do teachers need to have a better understanding of the practices, disciplinary core ideas, and the cross cutting concepts teachers will need to pay close attention to the specific elements that better describe how the dimensions are differentiated for their grade level. Without this specificity, having a general understanding of the three dimensions does not lead to progressions of learning throughout K-12 science learning. These elements are in the foundation boxes housed within the structure of the *NGSS* (NGSS Lead States, 2013) performance expectations. A fifth-grade performance expectation from the *NGSS* (NGSS Lead States, 2013) shows the three foundation boxes in the middle and when looking at an individual performance expectation you will find bulleted statements in each of these three boxes that specify grade level appropriate use of the indicated three dimensions for this performance expectation.

Students who demonstrate understanding can:

5-PS1-1. **Develop a model to describe that matter is made of particles too small to be seen.** [Clarification Statement: Examples of evidence supporting a model could include adding air to expand a basketball, compressing air in a syringe, dissolving sugar in water, and evaporating salt water.] [*Assessment Boundary: Assessment does not include the atomic-scale mechanism of evaporation and condensation or defining the unseen particles.*]

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 3–5 builds on K–2 experiences and progresses to building and revising simple models and using models to represent events and design solutions. • Use models to describe phenomena.	**PS1.A: Structure and Properties of Matter** • Matter of any type can be subdivided into particles that are too small to see, but even then the matter still exists and can be detected by other means. A model showing that gases are made from matter particles that are too small to see and are moving freely around in space can explain many observations, including the inflation and shape of a balloon and the effects of air on larger particles or objects.	**Scale, Proportion, and Quantity** • Natural objects exist from the very small to the immensely large.

Connections to other DCIs in fifth grade: N/A

Articulation of DCIs across grade-levels:
2.PS1.A ; **MS.PS1.A**

Common Core State Standards Connections:
ELA/Literacy -

RI.5.7	Draw on information from multiple print or digital sources, demonstrating the ability to locate an answer to a question quickly or to solve a problem efficiently. *(5-PS1-1)*

Mathematics -

MP.2	Reason abstractly and quantitatively. *(5-PS1-1)*
MP.4	Model with mathematics. *(5-PS1-1)*
5.NBT.A.1	Explain patterns in the number of zeros of the product when multiplying a number by powers of 10, and explain patterns in the placement of the decimal point when a decimal is multiplied or divided by a power of 10. Use whole-number exponents to denote powers of 10. *(5-PS1-1)*
5.NF.B.7	Apply and extend previous understandings of division to divide unit fractions by whole numbers and whole numbers by unit fractions. *(5-PS1-1)*
5.MD.C.3	Recognize volume as an attribute of solid figures and understand concepts of volume measurement. *(5-PS1-1)*
5.MD.C.4	Measure volumes by counting unit cubes, using cubic cm, cubic in, cubic ft, and improvised units. *(5-PS1-1)*

Figure 3. Performance expectation 5-PS1-1

(NGSS Lead States, 2013)

The *EQuIP* rubric (Achieve Inc., 2016a) emphasizes the need to look at the specific elements (bulleted statements) in the foundation boxes for instruction to align to the performance expectations teachers are building instruction from. As teachers reconstruct their ideas about science teaching and learning, three major science related *NGSS* shifts are identified in the *NGSS Lesson Screener Tool* that gives a quick approach for looking at the major shifts in a lesson compared to the *EQuIP* rubric (Achieve Inc., 2016b).

NGSS Shifts

A. **Explaining Phenomena or Designing Solutions**: The lesson focuses on supporting students to make sense of a phenomenon or design solutions to a problem.

B. **Three Dimensions**: The lesson helps students develop and use multiple grade-appropriate elements of the science and engineering practices (SEPs), disciplinary core ideas (DCIs), and crosscutting concepts (CCCs), which are deliberately selected to aid student sense-making of phenomena or designing of solutions.

C. **Integrating the Three Dimensions for Instruction and Assessment:** The lesson requires student performances that integrate elements of the SEPs, CCCs, and DCIs to make sense of phenomena or design solutions to problems, and the lesson elicits student artifacts that show direct, observable evidence of three-dimensional learning.

Features of Quality Design

D. **Relevance and Authenticity:** The lesson motivates student sense-making or problem-solving by taking advantage of student questions and prior experiences in the context of the students' home, neighborhood, and community as appropriate.

E. **Student Ideas:** The lesson provides opportunities for students to express, clarify, justify, interpret, and represent their ideas (i.e., making thinking visible) and to respond to peer and teacher feedback.

F. **Building on Students' Prior Knowledge**: The lesson identifies and builds on students' prior learning in all three dimensions in a way that is explicit to both the teacher and the students.

Figure 4. Shifts and features noted in the NGSS Lesson Screener Tool

(Achieve Inc., 2016b)

In the first major *NGSS* shift within the *NGSS Lesson Screener Tool* (Achieve Inc., 2016b), explaining phenomena or design solutions is a major key area. The *Framework* (NRC, 2012) describes phenomena as natural observable events that occur in the universe and students can use these phenomena to explain or predict. The *NGSS Lesson Screener Tool* (Achieve Inc., 2016b) describes how phenomena in *NGSS* designed lessons will look and what characteristics to move away from. A key area is the purpose and focus of a lesson to support students in making sense of phenomena, learning along the way, as opposed to lessons that develop science ideas first, then allow students to apply what they learned by introducing phenomena after the learning has taken place (Achieve Inc., 2016b). This key idea was demonstrated in the two classroom cases (Schwarz et al., 2017) in the previous section when students were introduced to the moon phases after learning had taken place as opposed to case two where student learning was driven by phenomena. Another key area emphasized in the tool (Achieve Inc., 2016b) that will require shifts in reconstructing science learning by educators includes using the grade-banded specific elements within the foundation boxes in the performance expectations themselves. For instruction to be designed to meet the performance expectation or a bundle of performance expectations, they must meet each of the elements within each foundation box. The tool (Achieve Inc., 2016b) describes lessons that use specific grade-appropriate elements of the science and engineering practices, cross cutting concepts, and disciplinary core ideas should be used to make sense of phenomena in the instruction. Lessons are not moving towards this key idea if the lesson focuses on colloquial definitions of the practices or crosscutting concepts instead of using the grade-appropriate learning elements for each dimension. The last *NGSS* key shift in the tool (Achieve Inc., 2016b) requires lessons to integrate the three dimensions for instruction and assessment. Lessons are not making this shift if students are learning the three dimensions in isolation from each other (Achieve Inc., 2016b). This idea was also demonstrated in case one (Schwarz et al., 2017) in the previous section where students were focusing on the disciplinary core idea in their learning for too long of a period without the integration of a practice or crosscutting concept to better make sense of the phenomena. The *NGSS Lesson Screener Tool* (Achieve Inc., 2016b) not only is intended to quickly look for the three major science areas describes, but there are three other categories that ask those designing lessons to make sure relevance and authenticity, student ideas, and building on students' prior knowledge are in the lesson for it to be making progress towards *NGSS* lesson design. The *EQuIP* (Achieve Inc., 2016a) rubric is intended to look at a full lesson or unit in more depth and has more categories than the tool.

Teachers will need to become familiar with the newer terminology and components of the *NGSS* (NGSS Lead States, 2013) not only for curriculum planning, but also in regard to instruction. In the development of the *NGSS*, "deliberate language was used as the standards were written" (Pruitt, 2014, p. 150). Teachers will need a better understanding of the practices to understand some of the distinctions (Pruitt, 2014). Pruitt (2014) uses the practice of developing and using models as an example to show phrases like “develop a model that describes” and “develop a model that predicts” as ways that teachers need to study the practices so they are aware of the multiple ways models can be used (p. 150). Another example of studying the nuances seen in the *NGSS* can be see with the difference between argument and explanation (Pruitt, 2014). “Building a good scientific argument means students know how to assemble data into evidence to support a claim” (Pruitt, 2014, p. 150). Being able to study the eight practices and have working knowledge of them in the classroom can help teachers utilize multiple practices throughout instruction (Pruitt, 2014). “Because science and engineering practices are basic to science education and the change from inquiry to practice is central, this innovation for the new standards will likely be one of the most significant challenges for the successful implementation of science education standards” (Bybee, 2011, p. 15).

The following studies give insight into current classroom practice. Bybee (2011) states that contemporary classrooms, prior to *NGSS*, have not implemented inquiry practices as widely as hoped even with a progression of reports indicating their need. A study surveying 1,222 K-12 math and science teachers from the largest school districts in the southeastern United states found that all teacher groups “reported believing in an ideal percentage of time devoted to inquiry instruction that was significantly greater than their reported percentage of time actually spent on inquiry instruction” (Marshall, Horton, Igo, & Switzer, 2009, p.575). The *NGSS* call for the content that students learn in the class to be coupled with the practice of inquiring about science as well as crosscutting concepts (NGSS Lead States, 2013). The study by Marshall et al. (2009) shows inquiry practices alone will need to be increased to achieve the vision set forth by the *NGSS*. In a study by Marshall and Alston (2014), a five-year professional development study including eleven schools and 74 middle school teachers found that when inquiry-based instruction was linked to learning with key concepts, learning gains could be seen in both the science practices and the science concepts. This study also found gains for all groups that included male, female, Caucasian, African-Americans, and Hispanic students on achievement tests compared to non-participating classrooms (Marshall & Alston, 2014). The non-participating classrooms were not observed, but the authors suggest their intervention of coupling the content with practices was not being used in the non-participating classes thus yielding higher gains of achievement (Marshall & Alston, 2014). This is a clear indicator of the importance of integrating the content and science practices in education.

Further insight into current science classroom practice can be found in the *Report of the 2012 National Survey of Science and Mathematics Education* (Banilower et al., 2013). In this national survey given to science teachers, explaining an idea to the whole class was a frequent activity in science classrooms (88-96 percent use this practice every week) (Banilower et al., 2013). Across all grade levels, "roughly 50 percent of classes include the teacher explaining science ideas in all or nearly all lessons" and teachers reported this as happening in most recent lessons (Banilower et al., 2013, p. 74). In a *Guide to Implementing the Next Generation Science Standards* (2015), the new vision for science should involve less of the teacher providing information to the whole class. Instead students need to be conducting investigations, engaging in classroom discourse, and solving problems (NRC, 2015). Currently elementary classroom teachers reported using classroom discussion in nearly every lesson and this was less common in secondary grade levels (Banilower et al., 2013). Also, only a quarter of K-12 science teachers (7,792 science and math teachers surveyed) create opportunities for students to work together in groups in almost all science lessons (Banilower et al., 2013). Often, the practices in the *NGSS* call for interaction with other students for productive classroom discourse (NRC, 2012). "Over half of K-12 science classes also include hands-on/laboratory activities and require students to supply evidence in support of their claims on a weekly basis" with this occurring more in high school than elementary (Banilower et al., 2013, p. 75). Although this survey was conducted before the release of the *NGSS*, the hands-on survey question can give insight into the practices defined in the *Framework*. The science and engineering practices include developing and using models, planning and carrying out investigations, and more that involve possible hands-on learning (NRC, 2012). The report (Banilower et al., 2013) indicated only half of teachers reported using hands-on learning once a week and this will need to increase due to the number of science and engineering practices (NRC, 2012) that require inquiry learning from students. Also, more specification in research for the eight different science practices (NRC, 2012) and their use in the classroom will need to happen in the future for there to be more progress on the new vision for science education instead of using terms like hands-on or inquiry.

Another recommendation to move away from the older practices in science education as noted by the NRC (2015), is a focus on literacy skills in the science classroom. Banilower et al. (2013) report that "nearly half of elementary classes focus on literacy skills at least once a week, compared to only one-fourth of high school classes" (p. 75). The NRC (2012) mimic this same sentiment when addressing teacher development and state there is a difference between high school teachers and elementary teachers in regards to literacy practices.

> The practices of obtaining, representing, communicating, and presenting information pose a particular challenge. Although elementary science teachers are usually also teachers of reading and writing and have experience in that realm, this is not the case for most secondary science teachers. Even for elementary teachers, their experience as

> literacy teachers rarely stresses science-specific issues, such as developing understanding based on integrating text with pictures, diagrams, and mathematical representations of information. For science teachers to embrace their role as teachers of science communication and of practices of acquiring, evaluating, and integrating information from multiple sources and multiple forms of presentation, their preparation as teachers will need to be strong in these areas. (NRC, 2015, p. 259)

The Guide to Implementing the Next Generation Science Standards (NRC, 2015) also states the new vision for science education will involve less of "rote memorization of facts or terminology" and "reading textbooks and answering questions at the end of the chapter" (p.8-9). Instead the facts and terminology should be "learned as needed while developing explanations and designing solutions supported by evidence-based arguments and reasoning" and reading should include "multiple sources including science-related magazines, journal articles, and web-based resources" to develop summaries of information (NRC, 2015, p. 8-9). Banilower et al. (2013) reported that in the most recent lessons, 59 percent of high school teachers said students were completing textbook/worksheet problems with middle school (51 percent) and elementary (43 percent) following closely in those numbers. This report (Banilower et al., 2013) was conducted one year prior to the release of the *NGSS*. This report gives the most recent national data and was intended to provide the most up-to-date information about trends in science and math across the United States (Banilower et al., 2013). *The National Survey of Science and Mathematics Education* (Banilower et al., 2013) has been conducted five times since 1977 and their survey methods provide reliable data about current trends in the science classroom.

McNeill, Katsh-Singer, and Pelletier (2015) describe the shift that educators will need to make towards prioritizing the science practices will need to move away from "science as a body of memorized facts to science as a way of thinking, talking, and acting that students need to engage in to make sense of the natural world" (p. 22). As educators make those shifts McNeill et al., (2015) have noted in their experiences the challenges educators have in thinking about the eight distinct practices and instead have grouped the practices as a way of introduction to help educators make appropriate shifts in using them in classroom instruction. Table 1 below groups the practices into three categories (investigating practices, sensemaking practices, and critiquing practices) based on how they were presented in the *Framework* (McNeill et al., 2015, p. 23). "The idea is that science is fundamentally about making sense of the natural world" (McNeill et al., 2015, p. 22).

Table 1

Grouping the Eight Science Practices into Investigating, Sensemaking, and Critiquing (McNeill et al., 2015)

	Investigating practices	**Sensemaking practices**	**Critiquing practices**
Science practices	1. Asking Questions 3. Planning and Carrying Out Investigations 5. Using Mathematics and Computational Thinking	2. Developing and Using Models 4. Analyzing and Interpreting Data 6. Constructing Explanations	7. Engaging in Argument from Evidence 8. Obtaining, Evaluating, and Communicating Information

"The investigating practices focus on asking questions and investigating the natural world" and the products of these investigation are usually data (McNeill et al., 2015, p. 22). "The sensemaking practices focus on analyzing that data by looking for patterns and relationships to develop explanation and models" (McNeill et al., 2015, p. 23). "The critiquing practices emphasize that students need to compare, contrast, and evaluate competing explanations and models as they make sense of the world around them" (McNeill et al., 2015, p. 23). Table 1 is one way to group the practices and it is important to note that McNeill et al. (2015) indicate that the practice developing and using models, the focus of this study, can fit into all three categories, depending on how it is integrated in lessons. A scale used to code qualitative data in the study was based upon the three categories presented by McNeill et al. (2015) and will be further clarified in chapter three. “Our three groupings allow us to think about which science practices occur in classroom instruction” and is an “important first step in assessing science practices” (McNeill et al., 2015, p. 23). McNeill et al. (2015) indicate in their professional development work with teachers, they found most existing curricular resources to focus on the investigating practices that lead to collecting data about the natural world and the critiquing practices are the rarest. Developing a class culture that will promote learning that prioritizes the practices will need to grow over time and these tools can help with those shifts educators will need to make with the practices (McNeill et al., 2015).

As teachers are learning more about the shifts in the *NGSS* (NGSS Lead States, 2013), instruction will become more and more like the teaching and learning described in the *Framework* (NRC, 2012).

> To help ensure that the intent of the *NGSS* and the *Framework* are enacted in the classroom, we need curriculum materials and professional development to support teachers, and we need research that extends over time to determine their effectiveness. We have much work in front of us, but like vista we see when we climb a tall mountain, our efforts will be worth it. (Krajcik et al., 2014, p. 174)

The Preservice Science Teacher

“Ultimately, the interactions between teachers and students in individual classrooms are the determining factor in whether students learn science successfully” (NRC, 2012, p. 255). The importance of the teacher as the linchpin for instruction and implementation of the new standards is stressed in the *Framework* (NRC, 2012). "Teachers at all levels must understand the scientific and engineering practices, crosscutting concepts, and disciplinary core ideas; how students learn them; and the range of instructional strategies that can support their learning" (NRC, 2012, p. 256). Preservice teachers will need help with the following: science pedagogical content knowledge for the disciplinary core ideas in the *NGSS*, help understanding how students think to build experiences, experiencing the science and engineering practices for themselves in investigations in order to help students develop those practices, facilitating productive classroom discourse, and how to make the crosscutting concepts a focus when teaching the content (NRC, 2012). The *Framework* (NRC, 2012) describes the need for preservice science teachers to engage in experiences that integrate the three dimensions so they can understand in depth what the three dimensions are. The current state of science teacher preparation will need reform to meet the challenges that come with the *NGSS* (NGSS Lead States, 2013).

"Across the country, teachers are prepared in more than 1,300 large and small, public and private colleges and universities, as well as through alternative programs offered by districts and states" (Wilson, Floden, & Ferrini-Mundy, 2001).

> Program designs and teacher preparation vary widely. Although the population of the U.S. school-age children is becoming increasingly diverse, our pool of potential teachers is not, furthering the need to prepare teacher to work with students different from themselves. The challenges in improving teacher education programs and practices in the U.S. are enormous, and a qualified teaching force is an unquestionable necessity. Research can help us make these improvements and build this qualified teaching force. (Wilson et al., 2001, p. i)

Wilson, Floden, & Ferrini-Mundy (2001) summarized in a comprehensive report of relevant literature about teacher preparation and what it can tell us about key issues. They found overall that research concerning teacher preparation “is relatively thin” (Wilson et al., 2001, p. i). Relating to how much subject matter preparation do prospective teachers need, there was a positive connection between teachers’ preparation in their subject matter and their performance and impact in the classroom. “There is little definitive research on the kinds or amount of subject matter preparation; much more research needs to be done before strong conclusions can be drawn” (Wilson et al., 2001, p. i). “Some researchers have found serious problems with the typical subject matter knowledge of preservice teachers, even those who have completed majors in academic disciplines” (Wilson et al., 2001, p. ii). This lack of deep understanding may impede effective teaching and research suggests that “changes in teachers’ subject matter preparation may be needed, and that the solution is more complicated than simply requiring a major or more subject matter courses” (Wilson et al., 2001, p. ii). Regarding pedagogical preparation (e.g. instructional methods, learning theories, foundations of education, classroom management), some evidence suggests “that coursework in content methods matter for teacher effectiveness” (Wilson et al., 2001, p. ii). “Studies that have looked across several of the pedagogical parts of teacher preparation programs reinforce the view that the pedagogical aspects of teacher preparation matter, both for their effects on teaching practice and for their ultimate impact on student achievement” (Wilson et al., 2001, p. ii). The content and arrangement of these types of courses vary widely so the results of the report do not give insight on which aspects of pedagogical preparation are critical (Wilson et al., 2001). Research in clinical experiences reveals significant shifts in the attitude of teacher candidates as they work in real classroom with students (Wilson et al., 2001). The quality of the field experience lies with the specific intent and characteristics of the experience (Wilson et al., 2001). "Research shows some promising practices can be developed: prospective teachers' conceptions of the teaching and learning of subject matter can be transformed through their observations and analysis of what goes on in real classrooms" (Wilson et al., 2001, p. ii). Focused and well-structured field experiences create significant learning experiences for the preservice teacher (Wilson et al., 2001). These are findings about general teacher preparation and the next section describes findings about science teacher preparation specifically.

In 1998, the National Research Council established a committee charged with identifying critical issues that exist in practices and policies for K-12 math and science teacher preparation (NRC, 2001). Their findings include five key areas that present challenges with science teacher preparation. Research demonstrates that good teaching does matter, but numerous studies demonstrate that many teachers, especially grades K-8, do not have enough content knowledge and adequate skills to teach (NRC, 2001). Currently elementary teachers only "take a limited number of science courses and a single science methods course" (NRC, 2012, p. 259). Teachers with greater content knowledge may ask more demanding questions and are "more likely to engage in sophisticated teaching practices" (Davis, Petish, and Smithey, 2006, p. 622). Davis et al. (2006) in their review of literature about *Challenges New Science Teachers Face* reported "preservice elementary teachers found that past experience (e.g., in science classes) was the most important factor in deciding whether they would concentrate in science" (p. 614). Davis et al. (2006) said "in almost all the studies reviewed here, the teachers were found to have unsophisticated understandings of science" when reporting about literature on the substantive knowledge of science content topic. Next, teachers are not equipped to teach using standards based approaches and in ways that bolster student learning and achievement even though standards exist through national organizations or state specific frameworks (NRC, 2001). Science teacher education programs vary widely from each other and there are few opportunities to engage in evidence-based teaching methods (Adams & Krockover, 1997; Clift & Brady, 2005). “Expert teachers need to be able to understand their students as learners so they can help them develop understandings and participate in the learning communities of classrooms” (Davis et al., 2006). Davis et al. (2006) report that new teachers in general “do not have very clear ideas about what to do with regard to students’ ideas or backgrounds” (p. 620). Third, “the preparation of beginning teachers by many colleges and universities does not meet the needs of the modern classroom” (NRC, 2012). Most preservice science teachers experience little authentic scientific experiences during their preservice training and instead experience step-by-step predetermined labs and didactic lectures (Gess-Newsome & Lederman, 1993). “To teach inquiry-oriented science as recommended by current reforms in science education, a teacher must also hold strong understandings of and abilities with regard to science inquiry” (Davis et al., 2006). Overall Davis et al. (2006) found that preservice teachers have unsophisticated understandings of inquiry and related skills. “The studies indicate that new science teachers tend to teach less reform oriented science than many science educators would hope” (Davis et al., 2006, p. 627). Fourth, accreditation education standards for programs may not reflect what is needed for modern classroom teaching expectations (NRC, 2001). The last concern is that teacher licensure exams do not always reflect the recommended standards for teacher education or what states expect K-12 students to know and do (NRC, 2001). The authors of *Taking Science to School* (NRC, 2007) found that students’ thinking about a given topic grows in sophistication over time and that instruction has generally not accounted for this. Research about elementary preservice science teachers reveal that they are in most need of professional development support because they have weak knowledge of science content and practices (Davis, Petish, & Smithey, 2006; Smith & Anderson, 1999; Zembal-Saul, Munford, Crawford, Friedrichsen, & Land, 2002). This study focuses on the elementary preservice science teacher.

Bybee (2014) presents the idea that the *NGSS* are a "significant departure from past approaches to science education" and will affect curriculum, instruction, and assessments (p. 213). With the U.S. education system being as complex as it is, Bybee (2014) brings a focus to colleges and universities in their decisions to prepare future teachers. Bybee (2014) uses the NRC report, *Investigating the Influence of Standards: A Framework for Research in Mathematics, Science, and Technology Education* (NRC, 2002) as a document to understand the influence education of science teachers can have. Bybee's (2014) figure below in Figure 5 shows the "channels of influence within the education system" (p. 214).

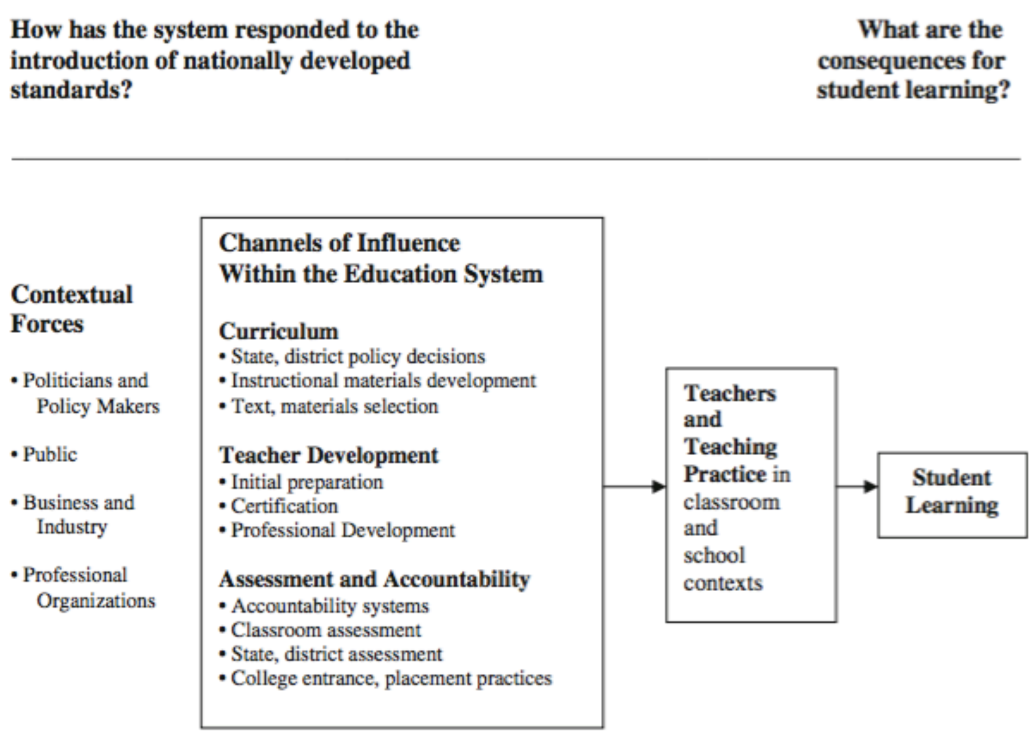

Figure 5. Channels of influence within the education system

(Bybee, 2014, p. 214)

"The primary channels through which the *NGSS* will influence the educational system are: curriculum, teacher development, and assessment and accountability" (Bybee, 2014, p. 214). Bybee (2014) says the *NGSS* presents "an opportunity to improve teacher development" (p. 215). The modifications within the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013) "imply dramatic changes in teacher education programs" (Bybee, 2014, p. 2017). Even though the research base for strategies related to science teacher preparation is growing, little is known about is offered across states (NRC, 2012). In the previous two sections about the *NGSS* teacher and classroom, there is complexity in the educational shifts presented and these shifts will require challenges for those responsible for educating future science educators. For preservice science teachers, the *Framework* (NRC, 2012) says these teachers will need experiences that integrate the three dimensions that will require them to understand in depth what the three dimensions are. Preservice teachers will need help with the following: science pedagogical content knowledge for the disciplinary core ideas in the *NGSS*, help understanding how students think in order to build experiences, experiencing the science and engineering practices for themselves in investigations in order to help students develop those practices, facilitating productive classroom discourse, and how to make the crosscutting concepts a focus when teaching the content (NRC, 2012). Bybee (2014) summarizes the educational shifts and describes the implications that these shifts have for teacher development in Table 2 below (p. 217).

Table 2

Educational Shifts Based on NGSS and Their Implications for Science Teacher Education (Bybee, 2014, p. 217)

From	To	Implications
Learning facts (e.g. parts of the cell)	Explaining natural phenomena (e.g. how cell structures relate to cell functions)	Students develop models and make sense of the natural world by using evidence to develop explanations
Single dimensions of science (e.g. disciplinary core ideas for physical science)	Interconnections of three dimensions of science (e.g. science and engineering practices, crosscutting concepts, disciplinary core ideas)	Students use the practices to gather data and form explanations using crosscutting concepts and disciplinary core ideas
Grade level content (e.g. middle school life science)	Progression of core ideas and practices across K-12 (e.g. coherent horizontal and vertical development of concepts and practices)	Students learn concepts below and above a grade-level
Science as a single discipline (e.g. biology)	Science and Engineering (e.g. practices of engineering design incorporated with science)	Students learn and apply the practices of engineering design
Science as a body of knowledge (e.g. conceptual structure of a discipline)	Science as a way of knowing (e.g. nature of science as an extension of practices and crosscutting concepts)	Students understand the nature of scientific knowledge
Science as a stand-alone discipline (e.g. separate time or course in curriculum)	Science connected with common core (e.g. English language arts and mathematics incorporated with science)	Students' science education program includes experiences that incorporate reading, writing, and mathematics

Bybee (2014) describes three ways that science teacher educators can approach the reform. Revising elements of the current program may be one way to approach the reform by making incremental changes to begin evolving the program to better meet state requirements (Bybee, 2014). "Further, the responsible individuals have their ideas about teaching and learning and those ideas do not necessarily align with *NGSS*" so smaller revisions may be a first step (Bybee, 2014, p. 218). In 2017 K-6 Kansas higher education preparation program standards were changed to reflect the shifts housed within the *NGSS*. Some secondary higher education program standards were changed in the fall of 2016 to include those shifts as well. The Kansas

Department of Education formed a committee to include higher education science teacher educators and current educators to make these changes. A second approach to make shifts in teacher preparation programs may be to replace components of the current program (Bybee, 2014). This may include creating short units that are based on the *NGSS* and give preservice teachers experience with essential features of the shifts to apply to their learning (Bybee, 2014). This approach could help educators experience the integrated three-dimensional learning, but may not include all of the educational shifts of the *NGSS* (Bybee, 2014). This approach could be taken to still meet current program requirements for graduation, certification, and licensure if those are standing in the way of a complete overhaul. The last approach to the reform would be a complete overhaul of the current program (Bybee, 2014). This approach would start with *NGSS* and "design a program that would provide undergraduates opportunities to learn the science content and practices in contexts that would be aligned with their future work as teachers" (Bybee, 2014, p. 218).

> Reforming science teacher education should begin with the innovations of *NGSS*: for example, the integration of science and engineering practices and crosscutting concepts. The integration centers on the need for activities and investigations as the context for integration. For states that adopt the *NGSS* (or variations) as the state standards, reforming science teacher education programs would be a direct implication of the adoption. It would be an opportunity to think about the NGSS and the unique needs of elementary, middle, and high school science teachers. Then, design a program for them. (Bybee, 2014, p. 219)

There are new challenges for those preparing science educators and the knowledge of life, earth, and physical sciences are still a requirement of effective science teaching (Bybee, 2014). “Relative to basic abilities, the *NGSS* places a new emphasis on science and engineering practices” (Bybee, 2014, p. 219). Science teachers will need to develop basic competencies for the practices (Bybee, 2014). Because the performance expectations require students to integrate the three dimensions in their learning, this significant requirement will need basic preservice teacher competencies “of the science content, practices, and their pedagogical implications” (Bybee, 2014, p. 219).

Though the demands of the *NGSS* (NGSS Lead States, 2013) will impact preservice preparation and reform is needed, there is little consensus in education research about what makes one teacher more effective than another (Goldhaber & Anthony, 2004). There is consensus around the importance that teachers need to be able to critically analyze their practice (Little & Horn, 2007; Windschitl, Thompson, & Braaten, 2008). “Teachers who have opportunities to rigorously reflect on their work and connect it to research and theory during their professional preparation are better able to identify and respond to dilemmas of practice, more likely to take an analytic stance toward their work, and demonstrate a willingness to take risk and explore alternative pedagogical approaches” (Barnhart & van Es, 2015, p. 83). In a review of literature titled *Challenges New Science Teachers Face* (Davis et al., 2006), authors recommend several ways teacher educators can support new science teachers in overcoming the challenges they discussed with multiple cycles of planning, teaching, and reflection occurring in one strategy. Research on teacher expertise shows that expert teachers are better able to distinguish between what is important and unimportant when evaluating a complex situation, they are then able to reason about what they observed, and can use this information to make better informed decisions for instruction (Berliner, 2001). “The preconceptions preservice teachers bring into the profession can interfere with what they choose to reflect on and how they reason about the effectiveness of their teaching; and preservice teachers may lack the observation skills and pedagogical content knowledge required for sophisticated analyses of teaching and learning" (Barnhart & van Es, 2015, p. 84). Barnhart and van Es (2015) conducted a study to investigate how a support influenced science preservice teachers' ability to analyze and reflect on teaching and learning. The analysis required the science preservice teacher to "attend to student thinking and learning and the interactions that unfold among students and between teachers and students," "interpret student understanding from these interactions," and "decide next steps based on this analysis" (Barnhart & van Es, 2015, p. 84). They also wanted to study how the level of sophistication one skill may or may not relate to the level of sophistication on another skill (Barnhart & van Es, 2015). Recent research in math education call these skills "teacher noticing" (Jacobs, Lamb, & Philipp, 2010). "The range of what we think and do is limited by what we fail to notice. And because we fail to notice *that* we fail to notice, there is little we can do to change until we notice how failing to notice shapes our thoughts and deeds" (Goleman, 1985, p. 24). "Noticing is a common activity of teaching, but, as Goleman suggested, noticing effectively is both complex and challenging" (Jacobs, Lamb, & Philipp, 2010, p. 169). Jacobs, Lamb, & Philipp (2010) (based on a growing body of research in math education) defined professional noticing of children's mathematical thinking as "(a) attending to children's strategies, (b) interpreting children's understandings, and (c) deciding how to respond on the basis of children's understandings (p. 169). "This construct was assessed in a cross-sectional study of 131 prospective and practicing teacher" and "findings help to characterize what this expertise entails; provide snapshots of those with varied levels of expertise; and document that, given time, this expertise can be learned" (Jacobs, Lamb, & Philipp, 2010, p. 169). Barnhart and van Es (2015) used the findings of patterns from the growing research on teacher noticing, lesson analysis, and teacher reflection to develop a framework (See Table 3) in order to characterize preservice teacher responses in their study. They applied the framework to cases and through an iterative process with members on their research team were able to assign numerical value to reflect the ordinal nature of the data and ensured inter-rater reliability with 86% agreement across the three skills (Barnhart & van Es, 2015). This scale was used to code qualitative responses in the study and will be further clarified in chapter three.

Table 3

Levels of Sophistication for Noticing Skills (Barnhart & van Es, 2015)

Skill	Low sophistication	Medium sophistication	High sophistication
Attending	Highlights classroom events, teacher pedagogy, student behavior, and/or classroom climate. No attention to student thinking.	Highlights student thinking with respect to the collection of data from a scientific inquiry (science procedural focus).	Highlights student thinking with respect to the collection, analysis, and interpretation of data from a scientific inquiry (science conceptual focus)
Analyzing	Little or no sense-making of highlighted events; mostly descriptions. No elaboration or analysis of interactions and classroom events; little or no use of evidence to support claims.	Begins to make sense of highlighted events. Some use of evidence to support claims.	Consistently makes sense of highlighted events. Consistent use of evidence to support claims.
Responding	Does not identify or describe acting on specific student ideas as topics of discussion; offers disconnected or vague ideas of what to do differently next time.	Identifies and describes acting on a specific student idea during the lesson; offers ideas about what to do differently next time.	Identifies and describes acting on a specific student idea during the lesson *and* offers specific ideas of what to do differently next time in response to evidence; makes logical connections between teaching and learning.

Their findings indicated the intervention of support to help science preservice teachers created more sophistication in the three categories compared to science preservice teachers that were not given the intervention (Barnhart & van Es, 2015). “Most of the candidates who participated in the course scored in the medium to high range for the three skills, while a greater number of the candidates who did not experience the course scored in the low to medium range for all three skills” (Barnhart & van Es, 2015, p. 88). Their findings (Barnhart & van Es, 2015) are consistent with other research in math education (Star, Lynch, & Perova, 2011) that shows preservice teachers can learn to attend to student ideas when instructed to do so. Davis (2006) found similar results studying journal reflections with preservice elementary teachers. In this study (Barnhart & van Es, 2015) researchers find similar results in this idea of teacher noticing, but in science teacher education specifically. Levin, Hammer, & Coffey (2009) also conducted a study of teacher noticing in science preservice teacher education and found similar results, but the scale of sophistication that Barnhart & van Es (2015) help advance the field by providing tools to help with science preservice teacher education.

Aspects of Modeling Instruction

The focus of this study will be on the science and engineering practices, specifically the practice of developing and using models. The *Framework* identify eight science and engineering practices (NRC, 2012).

1. Asking questions and defining problems.
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

In a review of research in peer reviewed journals, Davis et al. (2006) describe how preservice elementary teachers did not have very sophisticated understandings about science inquiry in general or related skills. Inquiry is now better defined with the science and engineering practices in the *NGSS* (NGSS Lead States, 2013). There is literature around preservice teachers and their ideas about the scientific practices prior to 2013 when the *NGSS* (NGSS Lead States, 2013) were published. “The *NGSS* tells us what kinds of ideas should take center stage in classrooms and they feature science practices as the active context for student learning”, but they "provide little insight into how a teacher might design and enact learning experiences for students" (Windschitl, Schwarz, & Passmore, 2014, p. 1-2). We will need to rely on "other literatures that fill in gaps to inform teaching methods, primarily about how to support all students' learning of science" (Windschitl et al., 2014, p. 2). Windschitl et al. (2014) identify seven principles of powerful teaching that have a strong consensus among researchers and knowledgeable practitioners listed below.

- Organizing instruction around intellectually substantive and complex phenomena rather than taking a basics first approach
- Eliciting students' ideas on a regular basis to shape instruction
- Making students' thinking visible so that their ideas, reasoning, and experiences become resources for others in the class
- Providing tools that allow students to revise their thinking over time
- Scaffolding talk, reading, and writing- in particular students' attempts at evidence-based explanations
- Making explicit the "rules of the game" with regard to academic disourse and its relation to everyday language
- Fostering meta-cognition as a habit of mind (Windschitl et al., 2014, p. 2)

Standards "are only one resource for preparing educators about instruction" (Windschitl et al., 2014, p. 2). Smith & Anderson (1999) designed a physics course to help preservice elementary teachers "in the practices and discourses of science through activities they would later use with children" (p. 755). The course (Smith & Anderson, 1999) included components of several science and engineering practices including developing and using models that we find in the *NGSS*. Students who had previously reported positive experiences with science still had difficulty using the practices effectively as the *NGSS* indicate (Smith & Anderson, 1999). Bowen & Roth (2005) conducted a study with preservice science teachers and the practice of analyzing and interpreting data resulted in findings that teachers had difficulty making sense of data from tables even though some had more science course background. Other studies found the same difficulties with preservice teachers' understandings of the practice developing and using models (Ricketts, 2014). In the practice of engaging in argument from evidence, Zembal-Saul et al. (2002) found that even though preservice teachers constructed arguments supported by evidence, their arguments were limited regarding the nature and use of evidence. It was also unclear if preservice teachers knew why they engaged in this practice to learn the science topic that was the focus (Zembal-Saul et al., 2002). These studies show challenges for preservice teachers to understand the practices of science, but interventions in the studies showed improvement in teachers' understandings and uses of the practices to a degree.

In a recent study, Ricketts (2014) sought to find out what preservice elementary teachers understood about the science and engineering practices identified in the *NGSS* after learning more about each practice by collecting data sources of their understandings throughout the duration of the course. "The findings of this study have important implications for teach education, including implications about how teacher educators might use the *Framework* to help develop preservice teachers' ideas about the practices" (Ricketts, 2014, p. 2132). In the findings of this study, the heavy reliance on the *Framework* for preservice elementary science teachers to understand the practices left teachers with difficulty in making personal meanings of the practices to then enact in their teaching (Ricketts, 2014). "These data do not support a claim that simply reading the *Framework* will achieve the goal of making connections between the practices, improving their understandings of the nature of science, developing their scientific literacy, but they do support the claim that using the *Framework* as a reference may help preservice teachers begin to develop these understandings" (Ricketts, 2014, p. 2132). "Preservice teachers will likely need many more opportunities to apply these understandings in their methods class before they are able to make useful meaning of the ideas" (Ricketts, 2014, p. 2132). "When methods instructors make decisions about which investigations to use in class, they may want to consider how this collection of activities provides opportunities for participants to engage in and make sense of each of the practices, especially those known to pose a challenge to preservice teachers" (Ricketts, 2014, p. 2133). These research findings were the same recommendations given in the *Framework* (NRC, 2012) for preservice elementary teachers to experience the practices. Ricketts (2014) believes the need for more experience to understand the practices comes from preservice elementary teachers have little experience in scientific communities, "it is not surprising that their knowledge of scientific practices is limited" (Ricketts, 2014, p. 2120). Ricketts (2014) indicates that preservice teachers "may need extra support in understanding the practices of modeling and data analysis" (p. 2133). This idea of more support in modeling in recent research about the *NGSS* is supported by other researchers (Schwarz, 2009; Windschitl & Thompson, 2006; Justi & Gilbert, 2002; Van Driel, De Jong, & Verloop, 2002) making it the focus of this study along with modeling being mentioned in two of the three dimensions in the *NGSS*. Modeling beyond merely illustrative purposes is often not included in teaching and learning in science, especially in elementary settings (Louca et al., 2012). To focus on this practice in research, but in a more meaningful way as Ricketts (2014) describes by using more than the *Framework* to help educators, it will be important to know what current research indicates is important to apply this practice, developing and using models, in the classroom.

Windschitl et al. (2014) indicated in their recommendations about preservice teachers and the *NGSS*, seen in this section of the literature review, that neither the *Framework* nor the *NGSS* alone would be enough. Ricketts' study (2014) validated this concern. It will also be important to know what preservice teachers' preconceptions are about this practice without any intervention, the focus of this study. This is different from Ricketts' (2014) study, because in that study preservice teachers evaluated the *Framework* for this practice. These preconceptions without any intervention will help us know what teachers already know and knowing what current research indicates is important to apply this practice, developing and using models, in the classroom will help us know the end goal, thus helping us create well informed instruction for the preservice teachers. Learning about the practices in preservice elementary education programs is not a new idea or studying preservice teachers' understandings and application of scientific practices, but with "publication of these new influential documents calls for new research investigating preservice elementary teachers' understandings about the practices" (Ricketts, 2014, p. 2120). "Teacher educators who are informed about their preservice teachers' ideas are in a better position to help them construct more sophisticated understandings about scientific practices and enact those understandings effectively in the classroom" and "in turn these future teachers may be better able to support their students' scientific literacy" (Ricketts, 2014, p. 2121). The next section of this literature review will serve as a foundational understanding about what the *NGSS* (NGSS Lead States, 2013) and the *Framework* (NRC, 2012) indicate what should be the focus of this practice, developing and using models, but will also serve as a foundation of what past research tells us about what works to enact learning experiences for students with this practice.

"Models serve the purpose of being a tool for thinking with, making predictions, and making sense of experience" and "scientists construct mental and conceptual models of phenomena" (NRC, 2012, p. 56). Conceptual models, explicit representations, are the focus of the descriptions of this practice in the *Framework* (NRC, 2012). "The innate drive to figure out and make sense of the world is at the core of the practice of modeling and forms the basis of the scientific enterprise" (Schwarz et al., 2017, p. 112). *A Framework for K-12 Science Education* states, "both scientists and engineers use models—including sketches, diagrams, mathematical relationships, simulations, and physical models—to make predictions about the likely behavior of a system, and they then collect data to evaluate the predictions and possibly revise the models as a result" (NRC, 2012, p. 46). In addition, the *NGSS* (NGSS Lead States, 2013) gives a definition of modeling that will be used for this study that better defines the descriptions of this practice in the *Framework* (NRC, 2012). A scale was created from this definition and will be further clarified in chapter three.

> Models include diagrams, physical replicas, mathematical representations, analogies, and computer simulations. Although models do not correspond exactly to the real world, they bring certain features into focus while obscuring others. All models contain approximations and assumptions that limit the range of validity and predictive power, so it is important for students to recognize their limitations. In science, models are used to represent a system (or parts of a system) under study, to aid in the development of questions and explanations, to generate data that can be used to make predictions, and to communicate ideas to others. Students can be expected to evaluate and refine models through an iterative cycle of comparing their predictions with the real world and then adjusting them to gain insights into the phenomenon being modeled. As such, models are based upon evidence. When new evidence is uncovered that the models can't explain, models are modified. In engineering, models may be used to analyze a system to see where or under what conditions flaws might develop, or to test possible solutions to a

problem. Models can also be used to visualize and refine a design, to communicate a design's features to others, and as prototypes for testing design performance." (NGSS Lead States, 2013, Appendix F pg.6)

This definition does not direct what students and teachers need to do in order to successfully implement this practice in the classroom. The national standards only identify the capabilities students are expected to develop by the end of each grade band (NGSS Lead States, 2013). These are listed in Table 4 below. Previous science education reform efforts included progressions of learning, but state science standards often did not include this aspect (Pruitt, 2014). The *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013) developed learning progressions across K-12 to keep a coherent strengthened approach (Pruitt, 2014).

Table 4

Capabilities Students are Expected to Develop in the NGSS (NGSS Lead States, 2013)

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
Modeling in K–2 builds on prior experiences and progresses to include using and developing models (i.e., diagram, drawing, physical replica, diorama, dramatization, or storyboard) that represent concrete events or design solutions. • Distinguish between a model and the actual object, process, and/or events the model represents. • Compare models to identify common features and differences. • Develop and/or use a model to represent amounts, relationships, relative scales (bigger, smaller), and/or patterns in the natural and designed world(s). • Develop a simple model based on evidence to represent a proposed object or tool.	Modeling in 3–5 builds on K–2 experiences and progresses to building and revising simple models and using models to represent events and design solutions. • Identify limitations of models. • Collaboratively develop and/or revise a model based on evidence that shows the relationships among variables for frequent and regular occurring events. • Develop a model using an analogy, example, or abstract representation to describe a scientific principle or design solution. • Develop and/or use models to describe and/or predict phenomena. • Develop a diagram or simple physical prototype to convey a proposed object, tool, or process. • Use a model to test cause and effect relationships or interactions concerning the functioning of a natural or designed system.	Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. • Evaluate limitations of a model for a proposed object or tool. • Develop or modify a model—based on evidence – to match what happens if a variable or component of a system is changed. • Use and/or develop a model of simple systems with uncertain and less predictable factors. • Develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable phenomena. • Develop and/or use a model to predict and/or describe phenomena. • Develop a model to describe unobservable mechanisms. • Develop and/or use a model to generate data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs, and those at unobservable scales.	Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. • Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism or system in order to select or revise a model that best fits the evidence or design criteria. • Design a test of a model to ascertain its reliability. • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. • Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations. • Develop a complex model that allows for manipulation and testing of a proposed process or system. • Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.

"Curriculum developers and teachers determine strategies that advance students' abilities to use the practices. Practices represent what students are expected to do, and are not teaching methods or curriculum" (NGSS Lead States, 2012, appendix F pg. 2-3). The *Framework* (NRC, 2012) occasionally offers suggestions for instruction and the *NGSS* (NGSS Lead States, 2013) avoids giving instructional suggestions since the goal is to describe what students do. The *NGSS* (NGSS Lead States, 2013) also do not give all of the capabilities within the practices. With these instructional aspects missing, it is important to turn to past research about the practice of developing and using models.

A number of researchers have recently developed definitions of modeling. Louca, Zacharia, and Constantinou state, "[m]odels of physical phenomena are epistemological constructs of the physical sciences and provide operational descriptions of physical systems" (2012, p. 919). Windschitl, Thompson, and Braaten (2008) clarify this basic definition by stating, "models are representations constructed as conventions within a community to support disciplinary activity" (p. 944). Samia Khan defines mental modeling by writing that "[t]hese forms of knowledge organization are not static one-to-one representations of the external world but are changing abstractions that can be used to interpret experience and make meaning. Mental models can be analogical, partial, and fragmentary" (2007, p. 879). These definitions, however, are very broad and written from an academic perspective "[b]ut, because modeling has not been widely enacted as a pedagogy, it is conceptually-ill defined, like ―inquiry and ―standards-based teaching as examples of other broad and perhaps ―elastically defined approaches to science teaching" (Campbell et al., 2014, p. 160). "Consequently, little about the effectiveness of modeling pedagogies is known or few of the specifics of the pedagogical function of modeling that can assist students in learning has been aggregated into a clear framework informed by important modeling research that has occurred" (Campbell et al., 2014, p. 160).

The definition of modeling instruction that will be used for this study is "instruction that is centered around models, so that students explore, create, test, evaluate, and revise models in singular or iterative cycles in sense making processes within science classrooms" (Campbell et al., 2014, p. 160). Although many other terms may be used in research (model-based inquiry and model-based reasoning), the definition of modeling instruction given by Campbell et al. (2014) encompasses the consistency among the forms seen in science education literature. Campbell et al. (2014) developed a comprehensive literature review from four top tier science education journals over the last decade. The journals included in their survey were the *Journal of Research in Science Teaching, Science Education,* the *International Journal of Science Education,* and the *Journal of Science Education and Technology.* Within these four journals they completed a review using the keywords model, modeling, and model-based to search within abstracts and titles from 2001 to 2011. From the list that followed, abstracts were reviewed, and only those articles that had a focus on modeling as an instructional intervention with learner modeling were included, the final set of articles to be used in the core of their review numbered 81. Using a four-step data analysis process the authors coded nine facets for their four over-arching research questions (Campbell et al., 2014). "This literature review begins by intently focusing on the teacher to better understand the pedagogies that have been enacted and investigated, the pedagogical functions of these pedagogies, the critical discursive acts within these functions and pedagogies, and the role technology has played within the pedagogies identified" (Campbell et al., 2014, p. 160).

Their findings in Table 5 listed below revealed more of a focus on modeling in the 9-16 grade band and the lowest percentage of research found in K-5 classrooms (Campbell et al., 2014, p. 166). This study will serve to add to the need of growing research in the K-5 classroom.

Table 5

Demographic Statistics of Review Articles (Campbell et al., 2014, p. 166)

Grade Level	**% of Articles (n)**
K-5	10 (8)
8	15 (12)
9-12	31 (25)
13-16	17 (14)
Content Area (9-16)	
High School Biology	10 (8)
High School Physics	5 (4)
High School Chemistry	11 (9)
Undergraduate Biology	1 (1)
Undergraduate Physics	7 (6)
Undergraduate Chemistry	9 (7)
Research Methodology	
Quantitative	23 (19)
Qualitative	51 (41)
Mixed	26 (21)

Chemistry and biology were the most common in the 9-16 grade band and the most common type of research methodology was qualitative (Campbell et al., 2014). "The most common purpose or pedagogical function of engaging students in modeling was developing conceptual understanding of disciplinary core ideas of science" in 81% of the articles that were reviewed (Campbell et al., 2014, p. 165). Another purpose identified in using modeling was to engage students in science practices (most often referred to as inquiry) making up 10% of the articles and 30% of the articles "focused on developing students understanding of the nature of models specifically or the nature of science more broadly" (Campbell et al., 2014, p. 166). The majority of articles focused on a single purpose (focusing on conceptual understanding) for engaging students in developing and using models (Campbell et al., 2014). 14% had two purposes (conceptual understanding was always one of the two purposes) and only 1% had three purposed concurrently (conceptual understanding, science practices, nature of models/science (Campbell et al., 2014). The *NGSS* (NGSS Lead States, 2013) require students to learn by integrating the three dimensions and the findings of this research (Campbell et al., 2014) to focus on modeling as a means to learn about disciplinary core ideas in the majority of research fits in with this vision.

Campbell and his fellow authors seek to move towards a better-defined understanding of modeling as pedagogy and have suggested five modeling pedagogies (originally developed by Oh and Oh, 2011) to categorize the review of articles. The five pedagogies are "1) Exploratory modeling, 2) Expressive modeling, 3) Experimental modeling, 4) Evaluative modeling, and 5) Cyclic modeling" (Campbell et al., 2014, p. 162). These five pedagogies were previously defined (Campbell, Oh, & Neilson, 2013, p.7-8) to be "translatable at the level of classroom learning, as a framework for teachers to enact as initial instructional heuristics" (Campbell et al., 2014, p. 162). These five pedagogies were a means to develop approaches and strategies for the *NGSS* (Campbell et al., 2014).

- *Exploratory modeling, where students investigate the property of a pre-existing model by engaging with the model (e.g., changing parameters) and observing the effects.*
- *Expressive modeling, where students express their ideas to describe or explain scientific phenomena by creating new models or using existing models.*
- *Experimental modeling (called inquiry modeling originally in van Joolingen, 2004), where students form hypotheses and predictions from models and test them through experimenting with phenomena.*
- *Evaluative modeling, where students compare alternative models addressing the same phenomenon or problem, assess their merits and limitations, and select the most appropriate one(s) to explain the phenomenon or solve the problem.*
- *Cyclic modeling, where students are engaged in ongoing processes of developing, evaluating, and improving models to complete rather long science projects (Campbell et al., 2013, p. 7-8).*

Figure 6. Five pedagogies to develop approaches and strategies for the NGSS

(Campbell et al., 2014, p. 162)

All five pedagogies were identified when coding the literature, but some were used more often as can be seen in Table 6 below.

Table 6

Five Modeling Pedagogies Represented in Articles (Campbell et al., 2014, p. 162)

Modeling Pedagogy	% of Articles (n)
Expressive modeling	54 (44)
Exploratory modeling	43 (35)
Experimental modeling	28 (23)
Evaluative modeling	27 (22)
Cyclic modeling	22 (18)

Note: *In many cases articles employed multiple modeling pedagogies, leading to an overall n-size greater than the number of articles reviewed since some articles included 2-3 modeling pedagogies. The percentage of articles including each modeling pedagogy was calculated by dividing the number of times the modeling pedagogy was found by the total number of articles reviewed (i.e., 81) since no article included the same modeling pedagogy more than once.*

Exploratory and expressive modeling were the most used teaching strategies for modeling (Campbell et al., 2014). Frequently there were two or more modeling pedagogies being used concurrently (Campbell et al., 2014). Expressive and experimental modeling as well as expressive and exploratory modeling were most frequently used together (Campbell et al., 2014). Expressive modeling was the most frequently used pedagogy when targeting student conceptual understanding (Campbell et al., 2014). When developing student understanding with science practices, expressive modeling was used most frequently (Campbell et al., 2014). When focused on developing student understanding of the nature of models, all pedagogies were used with almost equal frequency (Campbell et al., 2014). With learning progressions across K-12, many of these pedagogies will be used concurrently depending on the criteria of developing and using models they will be engaged in. Moving forward it will be important to have this framework of modeling pedagogies identified by Campbell et al. (2013) to help teachers see the overall vision of this practice identified in the *NGSS* (NGSS Lead States, 2013).

"There is little debate about the importance of the connection between modeling and other scientific practices, especially discourse" (Campbell et al., 2014, p. 162). Although there are "other possible factors that are important in modeling instruction, many researchers have identified discursive acts as among some of the most important facets" (Campbell et al., 2014, p. 162). When looking at what discursive acts were identified as important in modeling instruction (See Table 7), peer to peer cooperative/collaborative learning, scientific reasoning, teacher scaffolding, and explanation were used most frequently (Campbell et al., 2014).

Table 7

Quantity and Types of Discursive Acts in Articles (Campbell et al., 2014)

Discursive Acts	**% of Articles (n)**
Peer-Peer Cooperative/Collaborative Learning	40 (32)
Scientific Reasoning	37 (30)
Teacher Scaffolding	35 (28)
Explanation	26 (21)
Peer Evaluation	11 (9)
Negotiation	10 (8)
Writing	9 (7)
Argumentation	6 (5)
Communication	5 (4)
Diologicity	4 (3)

Note: *In many cases, articles included multiple important discursive acts, which led to an overall n-size greater than the number of articles reviewed. The percentage of articles including each discursive act was calculated by dividing the number of times the discursive act was found by the total number of articles reviewed (i.e., 81) since no article included the same discursive act more than once.*

When conceptual understanding was the focus of the research, scientific reasoning, peer to peer cooperative/collaborative learning, teacher scaffolding, and explanation were identified as important discursive acts (Campbell et al., 2014). These discursive acts can be broadly categorized as student-student and student- teacher discourse. When developing student understanding of science practices, scientific reasoning, and peer to peer cooperative/collaborative learning discursive acts were identified (Campbell et al., 2014). When the purpose of modeling instruction focused on developing understanding about the nature of models, peer to peer cooperative/collaborative learning, teacher scaffolding, and explanation were the discursive used (Campbell et al., 2014). Table 8 below gives examples of the most frequently used discursive acts in the research that was reviewed (Campbell et al., 2014, p. 168).

Table 8

Examples of Discursive Acts (Campbell et al., 2014, p. 168)

Discursive Acts	Example
Scientific reasoning	*Students constructed a conceptual connection between the specific chemical definitions and the general formula (Connection 1), a visual connection between structural formulas and mental models (Connection 2), and referential connections between this general formula and their mental models (Connection 3) (Wu, Krajcik, & Soloway 2001).*
Peer-to-peer cooperative/collaborative learning	*Students, working in groups, were asked to describe and interpret annual cycles of temperature, salinity, oxygen, turbidity, and fluorescence data collected from Puget Sound (Winn et al., 2006).*
Teacher scaffolding	*The interplay between the students' and Neil's [teacher] questions and comments provided the opportunity for reflection and activated the formative assessment feedback loop that encourages knowledge growth. Although student mental model feedback was imprecise/incomplete, Neil could diagnose misunderstandings and clarify the target concept with yet another analogy or by expanding the current analogy (Harrison & Jong, 2005, p. 1146).*
Explanation	*Students used submicroscopic and symbolic representations in their explanations of chemical phenomena (Treagust, Chittleborough & Mamiala, 2003)*

The authors emphasize the importance of rooting modeling pedagogy frameworks in student-student and student-teacher discourse. The findings by Campbell et al. (2014) closely mirror the study of Louca et al. (2011), which examined an elementary classroom specifically for student-teacher discursive acts within the process of modeling. Louca et al. (2011) note that "up until now, there is no research describing a framework on what the role of the teacher should be in modeling based learning" (Louca et al., 2011, p. 945). After concluding their study, the authors found that students were only able to overcome obstacles and move between modeling frames when they received the necessary discursive scaffolding from their teacher (Louca et al., 2011). All important discursive acts (Campbell et al., 2014) are encompassed in the four teacher goals and five reflective questions (Michaels & O'Connor, 2012) for academically productive talk described in the section of the literature review about the *NGSS* classroom. These four goals and five reflective questions for academically productive talk come from talk science research "investigating how teachers develop their capacity at leading productive science discussions to foster students' scientific reasoning" (Technical Education Research Centers (TERC), n.d). This addresses Louca et al. (2011) and the role of the teacher in discursive acts for modeling instruction. These two tools serve as a framework in this study to understand preservice teachers' understandings about their role in the use of discourse in the practice of developing and using models.

Summary of Chapter 2

The integration of the science and engineering practices, crosscutting concepts, and disciplinary core ideas directly into the standards is a new approach. As such the integration of the three dimensions in the *NGSS* has not yet been implemented in all science classrooms. As we look to implement the *NGSS*, past research and recent science education reform can inform the process of changing instruction in the classroom to meet this new vision for science education. Instructional changes mean students and teachers will be making alterations to meet the new standards. Preservice elementary teachers will need the most support. Since modeling instruction is new in the *NGSS*, understanding the aspects that make this practice effective in the classroom will need to be developed in teacher preparation programs for preservice teachers.

In chapter three, the methodology that was used to investigate the preconceptions of preservice elementary teachers have about modeling instruction will be discussed. The methodology, including the participants, instruments, procedure, and methods of data analysis, will be defined in this section as well.

Chapter 3: Research Design

Introduction

This descriptive non-experimental study use a mixed methods design. The participants in the study were surveyed and interviewed to investigate their current state of knowledge about the science practice of developing and using models in the *NGSS* (NGSS Lead States, 2013). McMillan (2012) describes non-experimental descriptive studies as those that “simply describe a phenomenon” without the use of “direct or active intervention” (p. 176). It is important to know what preservice teachers’ preconceptions are about this practice without any intervention. These preconceptions will help the field know what preservice teachers already know about modeling. Knowing about preservice teachers’ preconceptions will help us create well informed instruction for the preservice teachers.

A mixed methods design was utilized to collect data. The rationale for using a mixed methods design is that it helps create a better understanding of “a research problem that either quantitative or qualitative data alone” cannot provide (Creswell, 2013, p.48). Qualitatively, the researcher interpreted the preservice teachers’ responses to a survey (See Appendix B) to give them a numerical code. The preservice teachers were given codes for each of their responses in the survey (See Appendix B) based on a scale determined by the researcher. Interviews conducted on a sample of the preservice teachers (See Appendix D) were qualitatively coded using the themes from the scales created for the survey responses to clarify their responses in the survey. Quantitatively, the researcher represented the numerical codes from the qualitative data by finding a single value, the mean, of the entire data set for each response to best describe the preconceptions of the preservice teachers. Both types of data in combination with each other will allow for a more complete investigation. The purpose of this study was to determine the preconceptions teachers have about the *NGSS* practice of developing and using models in the classroom (NGSS Lead States, 2013). The study was also intended to determine what preconceptions the preservice teachers have about the research-based components of modeling instruction that have been determined as necessary for the success of this practice in the classroom. This chapter provides an overview of the research design and methodology used in this study to answer the three main research questions on preservice teachers' previous knowledge of the *NGSS* practice of developing and using models in the classroom and the modeling instruction involved with this practice (NGSS Lead States, 2013). It covers the areas of design and methods, instruments, and procedure.

Purpose of the Study

This study was designed to determine the preconceptions of elementary preservice teachers about the nature of modeling instruction to meet the science practice of developing and using models described in the *NGSS* (NGSS Lead States, 2013). The extent of elementary preservice teachers' ability to identify the components that make up the science practice of developing and using models described in the *NGSS* (NGSS Lead States, 2013) was examined. The preconceptions of the significant modeling instruction component of student-student and student-teacher discourse (Campbell et al., 2014) was also examined in the study. The results of the surveys and interviews conducted in this study helped establish patterns and reasoning that elementary preservice teachers had about modeling instruction to meet the vision of the developing and using models science practice in the *NGSS* (NGSS Lead States, 2013). The implications of the study include a better understanding of where teachers begin in the implementation of this new vision for science education. This can, in turn, help to serve the shift that will be needed in teacher preparatory programs to bridge the gap between current levels of knowledge about modeling instruction and the greater role that modeling will play in the *NGSS* (NGSS Lead States, 2013).

Research Questions

The following research questions guided the study:

1. What are elementary preservice teachers' preconceptions about developing and using models in the classroom?
2. What student-student and student-teacher interactions are identified by elementary preservice teachers as critical to developing and using models in the classroom?
3. What teaching strategies do preservice elementary teachers identify as critical to developing and use models in the classroom?

Participants

The sample for this study consisted of 36 elementary preservice teachers enrolled in two sections of a science methods course for the Fall of 2016 at a mid-western public university. All the preservice teachers were admitted into the School of Education at this university and were either juniors or seniors. The purpose of the science methods course was to help preservice teachers develop an understanding of how children learn science and why science education is important. Students examined effective approaches to teaching, instructional materials, and student assessment. They also learned how to plan and implement a science unit. The course emphasized a guided-inquiry approach to science instruction appropriate for the abilities and interests of children in grades K-6. The science methods course was the first science methods course the preservice teachers had taken. The preservice elementary teachers were given a demographic questionnaire (See Appendix A). The course has a much higher percentage of females than males and consisted of one male and 35 females across the two sections. The ages of the preservice teachers ranged from 19-41, however the vast majority were 20-21 years of age. The preservice elementary teachers were given a consent form (See Appendix C) to sign prior to the study indicating their consent to an in-class survey that was conducted as well as the possibility of a follow-up interview if selected. The consent form explained that their responses to the survey (See Appendix B) would be used in a research study and their names would be kept anonymous and would not affect their course grade. The in-class activities were described in the consent form (See Appendix C) and students had the option of not participating, even though the survey was held in class. The preservice teachers had the option to withdraw from the study at any time without participation affecting their grade for the class (See Appendix C). Table 9 presents a summary of the basic demographics of the participants (See Appendix A).

Table 9

Participant Demographic Information

Student ID	**Gender**	**Age**	**Number of previous collegiate science classes taken**
001	F	20	3
002	F	21	2
003	F	20	6
004	F	20	3
005	M	20	5
006	F	21	7
007	F	20	4
008	F	21	3
009	F	20	4
010	F	20	2
011	F	20	2
012	F	21	3
013	F	20	3
014	F	20	3
015	F	20	4
016	F	41	4
017	F	20	4
018	F	20	3
019	F	20	5
020	F	20	2
021	F	20	4

022	F	20	3
023	F	21	2
024	F	20	3
025	F	23	5
026	F	21	6
027	F	20	5
028	F	20	1
029	F	21	3
030	F	20	2
031	F	19	1
032	F	20	3
033	F	20	4
034	F	20	4
035	F	24	5
036	F	21	2

Instruments

A variety of instruments were used to gather the data. Further descriptions of the instruments in a timeline are clarified in the procedure section of this chapter. NVivo qualitative data analysis software (QSR International, 2014) was used to code the responses. Further descriptions of the qualitative coding method will be described in the data analysis section of this chapter. Prior to this study, a pilot of the instruments was used in the Spring of 2016. The pilot consisted of students from the same science methods course and the participant group had very similar characteristics and total numbers as the participants in this study. The use and development of the instruments throughout the pilot will be described in this section relating to how they influenced the final instruments used in this study. Participating preservice teachers were given a questionnaire asking their basic demographic information, including their age, gender, academic classification, the number of college level science courses, and the names of those courses (See Appendix A) to determine characteristics of the population of study. Participants were assigned an anonymous subject number for the purposes of this study.

To determine their preconceptions of the practice of developing and using models, as expressed in the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013), preservice teachers were asked about their preconceptions of how this practice would be applied in the classroom in the first open ended question in the survey (See Appendix B). The first question was:

1. What are your perceptions of how the practice of developing and using models should be applied in the classroom?

The answers the preservice elementary teachers provided were coded on a discrete scale (See Appendix E) and this scale was used to help answer the first research question.

1. What are elementary preservice teachers' preconceptions about developing and using models in the classroom?

The discrete scale (See Appendix E) was adapted from a previous study that coded preservice teacher responses (Flake, 2014) to describe their level of noticing for a mathematics focused study. The mathematics study (Flake, 2014) used a discrete scale consisting of a score of 0 for novice responses, a score of 1 for emerging responses, a score of 2 for transitional responses, and a score of 3 for skilled responses. The pilot of this study in the Spring of 2017 used a similar discrete scale with three scores instead of four. The pilot study yielded important findings about the vision for this practice described in the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013), but modifications were made to the discrete scale for this study to include a fourth level to describe the elementary preservice teachers' continuum of learning for a more nuanced evaluation as seen in the mathematics study (Flake, 2014). Descriptions of the scores are one aspect of this scale. This discrete scale (See Appendix E) contains categories to code the responses against a set of criteria and was adapted from the definition of the developing and using models practice in the *NGSS* (NGSS Lead States, 2013) that expresses the vision of this practice in the *Framework* (NRC, 2012).

> Models include diagrams, physical replicas, mathematical representations, analogies, and computer simulations. Although models do not correspond exactly to the real world, they bring certain features into focus while obscuring others. All models contain approximations and assumptions that limit the range of validity and predictive power, so it is important for students to recognize their limitations. In science, models are used to represent a system (or parts of a system) under study, to aid in the development of questions and explanations, to generate data that can be used to make predictions, and to communicate ideas to others. Students can be expected to evaluate and refine models through an iterative cycle of comparing their predictions with the real world and then adjusting them to gain insights into the phenomenon being modeled. As such, models are based upon evidence. When new evidence is uncovered that the models can't explain, models are modified. In engineering, models may be used to analyze a system to see where or under what conditions flaws might develop, or to test possible solutions to a problem. Models can also be used to visualize and refine a design, to communicate a design's features to others, and as prototypes for testing design performance." (NGSS Lead States, 2013, Appendix F pg.6)

This definition was broken down into six categories for the discrete scale (See Appendix E) to fully encompass all aspects of the practice developing and using models: types of models, models are not exact, limitations of models, using models as a tool for thinking, revising models, and models in engineering. This discrete scale (See Appendix E) yielded a numerical score for each category and response of the elementary preservice teachers and better helps us know what aspects of the vision of the practice developing and using models (categories in the scale) these elementary preservice teachers may understand and at what level (numerical scores) they understand this aspect of the practice. Although this scale (See Appendix E) will tell us more about the preconceptions preservice teachers have about the practice of developing and using models, this scale does not tell us about the level of sophistication of noticing skills for preservice teachers. The purpose of this study was to understand the preconceptions preservice teachers have about the practice of developing and using models for implications about preservice teacher preparation, so another scale was used to code the responses. The ordinal levels of sophistication used by Barnhart and van Es (2015), described in chapter two, was also used to code the responses to this question and better show the quality of responses to make for a better analysis of the data for implications about preservice teacher preparation. The levels of sophistication include low sophistication, medium sophistication, and high sophistication in three categories (attending, analyzing, responding) (Barnhart & van Es 2015). "Attending refers to what teachers attended to, how they analyze instruction, and how they choose to respond to students" and can be seen in the ordinal scale in Table 3 (Barnhart & van Es, 2015, p. 87).

The ordinal scale by Barnhart and van Es (2015) was adapted and slight modifications were made to clarify criteria from one level to the next (See Appendix F). The ordinal scale (See Appendix F) was added after the pilot in the Spring of 2017 yielded results that gave more information about preconceptions preservice teachers have about the practice of developing and using models, but the quality of their preservice teacher responses was not described. Both instrumentation scales (See Appendix E & F) served to code the responses for criteria about the practice under study and better describe the quality of responses. These combined scales (See Appendix E & F) provided implications about preservice teacher preparation described in chapter five.

The other two research questions in the study were explored by having participants (during class) view a video clip that demonstrated high school students grappling with developing and using models. The remaining two research questions are below.

2. What student-student and student-teacher interactions are identified by elementary preservice teachers as critical to developing and using models in the classroom?
3. What teaching strategies do preservice elementary teachers identify as critical to developing and using models in the classroom?

During the pilot in the Spring of 2016, preservice teachers had limited ideas about their preconceptions of the practice of developing and using models including little understanding that this practice is a social endeavor (NRC, 2012; Campbell et al., 2014; Michaels & O'Connor, 2012; NRC, 2007; Schwarz et al., 2017). In order to explore what preconceptions preservice elementary teachers had of critical student-student and student-teacher communication patterns for the success of the practice of developing and using models, a video was shown to the teachers for exploration of the research questions. The use of this video was not intended to be an intervention, but instead to provide minimal context through video for teachers to be able to respond in the survey (See Appendix B) to the following questions.

2. What communication patterns between students do you think led to groups successfully developing and using their model?
3. What communication patterns between the students and teacher do you think led to the groups successfully developing and using their model?
4. Can you identify three other factors that may have led to groups successfully developing and using their model?

5. What three things would you do if you were the teacher at the end of the video to continue to help students develop and use their model?

Although showing the video might have been a minimal unintended intervention, and was indicated as a limitation to this study, an intervention or intervening variable described by Creswell (2013) indicates a direct influence is intended. In designing research based professional development for *NGSS*, Reiser (2013) recommends structuring “teacher sensemaking around rich images of classroom enactment,” specifically the use of video cases (p. 15). Reiser (2013) states that videos “enable teachers to analyze student thinking, and the work of other teachers to elicit student ideas and help students work with one another’s ideas” (p. 15). This is done with the direct intention of influence and the elementary preservice teachers in this study were not guided or instructed during this study or prior to their responses early on in their science methods course.

Research on teacher expertise shows that expert teachers are better able to distinguish between what is important and unimportant when evaluating a complex situation, they are then able to reason about what they observed, and can use this information to make better informed decisions for instruction (Berliner, 2001). “The preconceptions preservice teachers bring into the profession can interfere with what they choose to reflect on and how they reason about the effectiveness of their teaching; and preservice teachers may lack the observation skills and pedagogical content knowledge required for sophisticated analyses of teaching and learning” (Barnhart & van Es, 2015, p. 84). Barnhart and van Es (2015) conducted a study with two groups and provided an intervention of support to one group to help science preservice teachers create more sophisticated responses to observations of classroom interactions (Barnhart & van Es, 2015). The group that observed classroom interactions without the support of the intervention did not show teacher expertise like those that received the intervention (Barnhart & van Es, 2015). It is with this rationale that the video was used to create context with the elementary preservice teachers in this study without any direct intervention to help understand the teachers' preconceptions. The results of the pilot in the Spring of 2016 validated the use of the video to provide context without great influence that would have been provided if guidance or instruction was given as indicated by Barnhart and van Es (2015).

The video was hosted on the Annenberg Learner website (WGBH Boston, 2000). Annenberg Learner is a joint project of the Annenberg School of Communication and the Corporation for Public Broadcasting. Annenberg Learner is a website dedicated to teacher professional development. It hosts videos on inquiry-based science and math. They show science classrooms around the country, including life, physical, and earth/space science, as well as integrated science. The videos include a range of teaching techniques and student/teacher interactions. *The Physics of Optic*s video in the series entitled "Teaching High School Science," (WGBH Boston, 2000) was chosen for this study due to the student-student and student-teacher interactions present while the class engaged in the science and engineering practice of developing and using models. This class studied the phenomena of light (waves), lenses, and the human eye during their model based scientific inquiry. An effort was made to find a similar video at the elementary level that demonstrated the types of interactions that Campbell and his co-authors (2014) found as being integral to model based inquiry in science. However, the recent *NGSS* standards have only just begun to incorporate developing and using models in elementary classrooms, because of this, a video of a high school classroom is used in this study. The video was used in the pilot conducted in the Spring of 2016 and yielded important information for the research questions. The preservice elementary teachers did not need to have deep conceptual knowledge of the science disciplinary ideas (physics concepts) in the video, but they were provided context so the researcher could identify what the teachers' preconceptions are of important aspects of modeling instruction. In the video, a high school physics teacher, Arthur Eisenkraft (currently a Distinguished Professor of Science Education and the Director of the Center of Science and Math in Context at the University of Massachusetts Boston, and past president of the National Science Teachers Association), asks the students to use the information that they have learned about lenses to develop a model of the human eye and its ability to focus all images all of the time (WGBH Boston, 2000). Fifteen minutes of the video were viewed by preservice teachers that include the interaction between student groups in their development of the eye as well as student-teacher interactions in this successful classroom session of the science and engineering practice, developing and using models.

To determine the preservice elementary teachers' preconceptions about the practice of developing and using models and the critical components it incorporates as a social endeavor (NRC, 2012; Campbell et al., 2014; Michaels & O'Connor, 2012; NRC, 2007; Schwarz et al., 2017), two discrete scales were adapted from the web-based tools created for professional learning to improve academic productive talk in the science classroom (National Science Foundation, DR-K12 Grant, 2009-2013). A discrete scale was adapted to code the responses to the following survey question (See Appendix B) and comes from a reflection tool (See Appendix G) used in the Talk Science Inquiry Project (TERC, 2012b).

2. What communication patterns between students do you think led to groups successfully developing and using their model?

The tool (See Appendix G) from the Talk Science Inquiry Project (TERC, 2012b), further clarified in chapter two, describes reflection questions that an educator can examine to look at the quality of the meaning making discussions. These reflection questions in the tool (See Appendix G) help an educator evaluate the discussions students are having and help analyze if students are progressing toward scientific understanding (TERC, 2012b). These student-centered reflection questions in the tool (TERC, 2012b) were adapted to create a discrete scale for coding and help answer the second research question.

2. What student-student and student-teacher interactions are identified by elementary preservice teachers as critical to developing and using models in the classroom?

The discrete scale (See Appendix H) was also adapted from the previous study by Flake (2014) that consists of the following scores: a score of 0 for novice responses, a score of 1 for emerging responses, a score of 2 for transitional responses, and a score of 3 for skilled responses. The pilot of this study in the Spring of 2017 used a similar discrete scale with three scores instead of four. The pilot study yielded important findings about the vision for this practice described in the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013), but modifications were also made to this discrete scale for this study to include a fourth level to describe the elementary preservice teachers' continuum of learning for a more nuanced evaluation as seen in the mathematics study (Flake, 2014). Descriptions of the scores are one aspect of this scale. This discrete scale (See Appendix H) contains categories to code the responses against a set of criteria and was adapted from the reflection tool (See Appendix G) (TERC, 2012b) that expresses criteria necessary for students to be successful in sense making discussions. These criteria were broken down into four categories for the discrete scale (See Appendix H) to fully encompass all aspects of the student-student discussions for sense making. The categories are as follows: use of evidence to support answers, critiquing their own and others' answers/ideas, merging ideas to develop an explanation, and apply learning to a new of different context. This discrete scale (See Appendix H) yields a numerical score for each category and response of the elementary preservice teachers and will better help us know what aspects of critical student-student communication patters (categories in the scale) these elementary preservice teachers understood and at what level (numerical scores) they understood this aspect of the communication. Although this scale (See Appendix H) tells us more about the preconceptions preservice teachers have about critical student-student communication for successfully using the practice of developing and using a model, this scale does not tell us about the level of sophistication of noticing skills for preservice teachers. The same ordinal scale (See Appendix F) adapted from the sophistication tool by Barnhart and van Es (2015) was used to code the responses for this survey question. Both instrumentation scales (See Appendix F & H) served to code the responses for criteria about the student-student communication patterns for the practice under study and better describe the quality of responses.

To determine the preservice elementary teachers' preconceptions about the critical student –teacher communication patterns in the practice of developing and using models, another discrete scale was also adapted from the web-based tools created for professional learning to improve academic productive talk in the science classroom (National Science Foundation, DR-K12 Grant, 2009-2013). A discrete scale was adapted to code the responses to the following survey question (See Appendix B) and comes from a checklist to address four goals and nine productive discussion talk moves used by the teacher (See Appendix I) and used in the Talk Science Inquiry Project (TERC, 2012a).

3. What communication patterns between the students and teacher do you think led to the groups successfully developing and using their model?

The checklist and nine talk moves (See Appendix I) from the Talk Science Inquiry Project (TERC, 2012a), further clarified in chapter two, describes four goals (nine talk moves encompassed within the four goals) that an educator can use to help students have productive discussions in the science classroom. These four goals and the nine talk moves in the checklist (See Appendix I) equip an educator with talk moves that the teacher can employ when working towards the four goals for productive discussion in sense making (TERC, 2012a). These teacher-centered moves in the checklist (TERC, 2012a) were adapted to create a discrete scale for coding and help answer the second research question.

2. What student-student and student-teacher interactions are identified by elementary preservice teachers as being critical to the success of developing and using models as a science practice in the classroom?

The discrete scale (See Appendix J) was also adapted from the previous study by Flake (2014) that consists of the following scores: a score of 0 for novice responses, a score of 1 for emerging responses, a score of 2 for transitional responses, and a score of 3 for skilled responses. The pilot of this study in the Spring of 2017 used a similar discrete scale with three scores instead of four. The pilot study yielded important findings about the vision for this practice described in the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013), but modifications were also made to this discrete scale for this study to include a fourth level to describe the elementary preservice teachers' continuum of learning for a more nuanced evaluation as seen in the mathematics study (Flake, 2014). Descriptions of the scores are one aspect of this scale. This discrete scale (See Appendix J) contains categories to code the responses against a set of criteria and was adapted from the checklist of goals and talk moves (See Appendix I) (TERC, 2012a) that expresses criteria necessary for student-teacher communication to be successful in sense making discussions in the science classroom. This criterion was broken down into four categories for the discrete scale (See Appendix J) to fully encompass all aspects of the student-teacher discussions for sense making. The categories are as follows: helping individual students share, expand, and clarify their own thinking, helping students listen carefully to one another, helping students deepen their reasoning, and helping students think with others. This discrete scale (See Appendix J) yields a numerical score for each category and response of the elementary preservice teachers and will better help us know what aspects of critical student-teacher communication patters (categories in the scale) these elementary preservice teachers may understand and at what level (numerical scores) they understand this aspect of the communication. The same ordinal scale (See Appendix F) adapted from the sophistication tool by Barnhart and van Es. (2015) will be used to code the responses for this survey question. Both instrumentation scales (See Appendix F & J) served to code the responses for criteria about the student-teacher communication patterns for the practice under study and better describe the quality of responses.

The remaining two questions below that were given in the survey (See Appendix B), were intended to elicit any other preconceptions the preservice teachers have about this practice and the critical communication patterns necessary to successfully use this practice in the classroom.

4. Can you identify three other factors that may have led to groups successfully developing and using their model?
5. What three things would you do if you were the teacher at the end of the video to continue to help students develop and use their model?

A blend of all three discrete scales and one ordinal scale (See Appendix E, F, H, & J) that were adapted to code the previous three questions in the survey (See Appendix B) was used to code for the two remaining responses that were used to elicit any other preconceptions the elementary preservice teachers have. The data from these two questions was used to analyze overall preconceptions the preservice teachers have about this practice and was used to elicit as much elaboration for the participants as possible.

A small sample, six participants of the total thirty-six, of the preservice elementary teachers from the larger group were interviewed using a set of interview questions in a previously developed protocol (See Appendix D) to elaborate on their responses in the survey (See Appendix B). The interview protocol was created using the necessary components described by Creswell (2013). The interview selection process was time sensitive due to the nature of interviewing the participants as close to the initial day the survey was given so participants would have better recollection of their responses in the survey. The interview protocol helped to elicit why they responded the way that they did in the survey. The interview protocol was previously developed in a pilot conducted in the Spring of 2017 and modified to include probes that better elicited further clarification from participants about their initial survey responses. In the pilot conducted in the Spring of 2017, four participants were interviewed with the overall total of participants being very close in number to this study. The sample of interview participants was increased to six participants in this study to allow for a more appropriate representation of patterns in responses to the interview questions than was seen in the pilot. The smaller subject group of preservice teachers that were interviewed were selected based on some important variables. The survey responses were initially reviewed by the researcher and screened for a quick raw data of sophistication in responses that are in fitting with the ordinal sophistication scale used in this study (See Appendix F). Attending to the important variable of varied sophistication in responses from participants, the six participants included two participants that responded with more criteria that fit a low sophistication, two with medium sophistication, and two with high sophistication (See Appendix F). Another important variable to consider was the representation of the population by gender. Most participants for the initial survey responses were female and efforts were made by the researcher to include a male in the selection of interview participants. One male and five female participants were interviewed using the interview protocol developed in the pilot and modified for this study (See Appendix D). The interviews were transcribed, coded, and analyzed by the researcher similarly to the survey responses using the coding scales as a frame of reference to find emerging themes. The responses from the interviews served to elicit as much information about the survey responses as possible from participants. Responses to the interview questions in the pilot study and in this study yielded emerging themes different than the other codes used in this study. These emerging themes were consistent with the research done by McNeill et al. (2015) and the three categories (investigating practices, sensemaking practices, and critiquing practices) used to describe the practices. “The investigating practices focus on asking questions and investigating the natural world” and the products of these investigation are usually data (McNeill et al., 2015, p. 22). “The sensemaking practices focus on analyzing that data by looking for patterns and relationships to develop explanation and models” (McNeill et al., 2015, p. 23). “The critiquing practices emphasize that students need to compare, contrast, and evaluate competing explanations and models as they make sense of the world around them” (McNeill et al., 2015, p. 23).

Table 1

Grouping the Eight Science Practices into Investigating, Sensemaking, and Critiquing (McNeill et al., 2015, p. 23)

	Investigating practices	Sensemaking practices	Critiquing practices
Science practices	1. Asking Questions 3. Planning and Carrying Out Investigations 5. Using Mathematics and Computational Thinking	2. Developing and Using Models 4. Analyzing and Interpreting Data 6. Constructing Explanations	7. Engaging in Argument from Evidence 8. Obtaining, Evaluating, and Communicating Information

The authors note that the practice of developing and using models, depending on how it is used, could be in each of these three categories (McNeill et al., 2015). A nominal coding scale (See Appendix K) adapted from the three categories described by McNeill et al. (2015). The process of finding emerging themes will be further clarified in the data analysis section of this chapter. Qualitative only analysis was conducted on the interview responses. The nominal coding scale was also used to code the survey questions for an overall understanding about the preconceptions preservice teacher have about thinking of the practice of developing and using models in these three categories (See Appendix K).

Procedure

Prior to the semester in which the study was conducted (fall 2016), a pilot study in the spring of 2016 was used with elementary preservice teachers from the same science methods course. Elementary preservice teachers were shown the same video in this study and asked to answer the same demographic questionnaire (See Appendix A), five question survey (See Appendix B), and interviews (See Appendix D) were later conducted on a sample of the teachers (4). After the survey responses were recorded, all the data was coded using the instruments (See Appendix E, F, H, &J) that were further modified for this study (described in instruments section for this chapter). The discrete scales in each instrument were adapted from Flake (2014) and for the pilot were comprised of three scores: 0-beginner, 1-emerging, and 2-transitional. These scores were later modified from three to four scores described in the instrument section of this chapter: 0- beginner, 1-novice, 2- emerging, 3-transitional. The descriptions of the scores for each category were already established and adapted from various resources described in the instrument section of this chapter. During the pilot study, the researcher had the opportunity to strengthen the descriptions of the codes in each instrument to match those emerging themes from participants for each score and category. These modifications described in the instrumentation section of this chapter provided clear definition of the codes for this study.

In the fall semester of 2016, the students in this study were in the science methods course for two weeks (four class periods) before this study took place. The *NGSS* (NGSS Lead States, 2013) and the practice of developing and using models were not used for instruction the first two weeks of class. The first day of the third week at the beginning of class, the students were given the consent form for this study. Students were asked to answer the demographic questionnaire (See Appendix A). The students were given the survey (See Appendix B) and answered the first question prior to watching the video in this study (rationale in instrumentation section of this chapter).

1. What are your perceptions of how the practice of developing and using models should be applied in the classroom?

To answer the remainder of the questions about the practice of developing and using models, a 20-minute video segment described in the instrument section of this chapter was shown to the students. The students viewed the video and answered the remaining questions in the survey (See Appendix B).

2. What communication patterns between students do you think led to groups successfully developing and using their model?
3. What communication patterns between the students and teacher do you think led to the groups successfully developing and using their model?
4. Can you identify three other factors that may have led to groups successfully developing and using their model?
5. What three things would you do if you were the teacher at the end of the video to continue to help students develop and use their model?

After they completed the survey and questionnaire, the researcher conducted an initial coding of their responses using the sophistication scale (See Appendix F) and selected participants for the interviews (See Appendix D). The selected participants represented two participants that had low sophistication, two that had medium sophistication, and two that had high sophistication in their responses. The interview protocol (See Appendix D) was used to conduct the six interviews no later than three weeks after the survey was conducted. The interviews were transcribed for data analysis. The survey responses were coded using the instruments discussed in the previous section (See Appendix E, F H, & J). The interviews were coded using the same scales as frameworks and were further coded using Appendix K.

Data Analysis

The method of qualitative data analysis used in this study comes from research design methods described by Creswell (2013). There are six steps involved in qualitative data analysis (Creswell, 2013) used in this study and is summarized in Figure 7 below (p. 197). The approach builds from the bottom to the top and the stages are interrelated (Creswell, 2013).

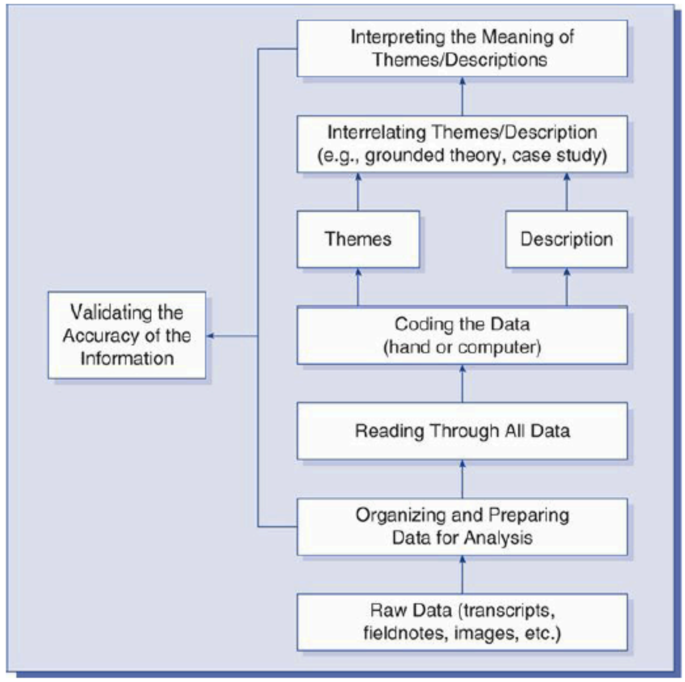

Figure 7. Six steps involved in qualitative data analysis

(Creswell, 2013, p. 197)

The first step involves organizing all the data for analysis by transcribing interviews, scanning materials, typing field notes, and sorting the data into categories by source of information (Creswell, 2013). Next the researcher in this study read all the data, which helped provide overall meaning, while keeping initial notes during this first look at the data. The third step involved coding all the data (Creswell, 2013) using a combination of predetermined scales (See Appendix E, F, H, J, & K) as well as developing emerging themes of both the survey responses and interviews. The development of emerging themes when coding the data in this third step was done using Tesch's (1990) steps in forming codes summarized in the Figure 8 below (Creswell, 2013, p. 198).

1. Get a sense of the whole. Read all the transcriptions carefully. Perhaps jot down some ideas as they come to mind as you read.
2. Pick one document (i.e., one interview)—the most interesting one, the shortest, the one on the top of the pile. Go through it, asking yourself, "What is this about?" Do not think about the substance of the information but its underlying meaning. Write thoughts in the margin.
3. When you have completed this task for several participants, make a list of all topics. Cluster together similar topics. Form these topics into columns, perhaps arrayed as major, unique, and leftover topics.
4. Now take this list and go back to your data. Abbreviate the topics as codes and write the codes next to the appropriate segments of the text. Try this preliminary organizing scheme to see if new categories and codes emerge.
5. Find the most descriptive wording for your topics and turn them into categories. Look for ways of reducing your total list of categories by grouping topics that relate to each other. Perhaps draw lines between your categories to show interrelationships.
6. Make a final decision on the abbreviation for each category and alphabetize these codes.
7. Assemble the data material belonging to each category in one place and perform a preliminary analysis.
8. If necessary, recode your existing data. (pp. 142–149)

Figure 8. Tesch's eight steps in the coding process

(Creswell, 2013, p. 198)

The next step involved organizing the data using the predetermined scale themes or from the segmented noted topics throughout the data in the previous step (iterative cycle) to determine emerging themes. The researcher in the fifth step of this process analyzed the themes and the researcher described them narratively to include in chapter four results. The last step used by the researcher in the qualitative analysis method (Creswell, 2013) was to interpret the data for action or implications that will be included in chapter five.

The data collected consisted of preservice teacher responses to the demographic questionnaire (See Appendix A), the survey (See Appendix B) (five questions) response sheet, and six interviews (See Appendix D). All responses were transcribed for the survey and interview and entered into NVivo qualitative data analysis software (QSR International, 2014), for coding and interpretation. The researcher compiled the demographic questionnaire data to determine ranges of age, gender, and number of previous science courses for a complete description of the participants in the study (See Table 9 in this chapter). The survey responses were coded using the ordinal sophistication scale (See Appendix F) and three discrete scales previously mentioned in the instrument section of this chapter (see Appendix E, H, & J). The coded data from the five survey responses using the discrete scales were given a numerical score of 0 for novice responses, a score of 1 for emerging responses, a score of 2 for transitional responses, and a score of 3 for skilled responses. The coded numerical data (scored) for each discrete scale was collected and used to create a mean score for each category within each discrete scale. The survey responses were also analyzed using the ordinal sophistication scale to describe the quality of the sophistication of noticing for a preservice teacher for each survey question. The interviews were initially transcribed using a transcribing service and further transcription was made by the researcher to ensure accuracy of participant responses. The interview responses were analyzed qualitatively by finding emerging themes and the nominal scale (See Appendix K) was also used to code for data due to emerging themes that were found in the pilot study. The interview responses were used as a data source to develop deeper explanations of the survey responses and helped to develop themes that answered how or why participants responded the way they did to the survey questions. The interviews were also used as a method to clarify common terms used by a significant number of participants and to probe further to see if the interview method would elicit further identification of criteria than the survey did not produce.

Summary of Chapter 3

This chapter includes the design method, instruments, procedures, and analysis methods that will be used to determine the preconceptions preservice elementary teachers have about modeling instruction. Through the use of quantitative methods, participants were numerically identified on three discrete scales to identify their preconceptions of modeling instruction. Qualitative methods were used to further categorize their responses to indicate the levels of sophistication they were able to construct in their responses using an ordinal scale. Qualitative analysis of the interviews also categorized responses based emerging themes and how elementary preservice teachers view this practice of developing and using models in relation to three categories: investigating, sensemaking, and critiquing using a nominal scale. The data analysis will conclude preconceptions by participants so determinations can be made about the progress that will need to be made in their knowledge of modeling instruction.

The fourth chapter will discuss the results of the research study. An explanation of the data found from the analysis will be presented.

Chapter 4: Analysis of Data

Introduction

The purpose of this study was to determine the preconceptions, or current state of knowledge, elementary preservice teachers had about the science and engineering practice of developing and using models as described in the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013). The study also aimed to determine the preconceptions elementary preservice teachers had about the research-based components of modeling instruction, student-student and student-teacher discourse, that have been identified as necessary for the success of this practice in the classroom (Campbell et al., 2014). Preconceptions about teacher strategies for this practice were also part of the study to better understand what preservice teacher education reform would need to help elementary preservice teachers use this practice in the classroom. Qualitative and quantitative analysis were used in this study. Qualitatively, the researcher interpreted the preservice teachers' responses to three of the survey questions and gave the responses a numerical code. The preservice teachers' responses were coded based on a scale determined by the researcher to understand their preconceptions. Further qualitative analysis of the survey responses was conducted with scales that had no numerical analysis (e.g quality of the responses regarding sophistication of response by preservice science teachers). Interviews conducted on a sample of the preservice teachers were qualitatively coded using the themes from the scales created for the survey responses to clarify their responses in the survey and will be used to elaborate on findings in this chapter. Quantitatively, the researcher represented the numerical codes from the qualitative data by finding a single value, the mean, of the entire data set for each response to best describe the preconceptions of the preservice teachers. Frequency and percentage statistics were also used to represent the data from the survey responses.

Research Questions

This study will provide answers to the following research questions, previously introduced in chapter three:

1. What are elementary preservice teachers' preconceptions about developing and using models in the classroom?
2. What student-student and student-teacher interactions are identified by elementary preservice teachers as critical to developing and using models in the classroom?
3. What teaching strategies do preservice elementary teachers identify as critical to developing and use models in the classroom?

Organization of Data Analysis

The data are presented in three sections, which correspond to the research questions. The first section includes an analysis of the elementary preservice teachers' preconceptions of the science and engineering practice of developing and using models as described in the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013). The following research question is analyzed in the first section.

2. What are elementary preservice teachers' preconceptions about developing and using models in the classroom?

One question in the survey (See Appendix B) directly corresponds to the first research question in this study (See Table 10). Table 10 summarizes the question, its purpose in answering this research question as well as instrumentation used and representation of findings. The coding systems that were developed (See Appendix E & F) to score the preservice teachers' responses are described in chapter three.

The first survey question that is directly related to answering this first research study question is as follows:

1. What are your perceptions of how the practice of developing and using models should be applied in the classroom?

Numerical scores were given when coding this survey question using the discrete scale developed and described in chapter three (See Appendix E). The mean, frequency and percentage statistics of those scores are represented to describe the preservice teachers' overall preconceptions about this practice. The discrete scale developed in Appendix E describes preservice teachers' preconceptions about the overall criteria of this practice as described in the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013). This discrete scale does not reveal sophistication in the preservice teachers' responses. An ordinal scale adapted from the work of Barnhart and van Es (2015) was used to analyze the responses to this question and was further discussed in chapter three (See Appendix F) to couple with the discrete scale. The two categories in that ordinal scale that were used to code this first survey question were the attending and analyzing categories. The preservice teachers only attended and analyzed in this survey question. Barnhart and van Es (2015) describe (respectively) attending, analyzing, and responding as follows: "attend to student thinking and learning and the interactions that unfold among students and between teachers and students," "interpret student understanding from these interactions," and "decide next steps based on this analysis" (p. 84). The frequency and percentage statistics are represented for the sophistication of response findings. The coupling of these two scales capture their preconceptions in relation to reform definitions of this practice and the quality of responses regarding the sophistication of attention and analysis of student ideas. Interviews were conducted on a sample of the elementary preservice teachers, six out of thirty-six, and the findings related to this research question are reported in narrative form at the end of this section. The interview protocol developed (See Appendix D) and described in chapter three was used to ask participants to describe their ideas in more detail and to elicit participants' rationale.

Table 10

Section 1 Data Analysis

Research Question: What are elementary preservice teachers' preconceptions about developing and using models in the classroom?			
Corresponding Survey Questions (See Appendix B)	**Instrumentation**	**Purpose**	**Representation**
1.What are your perceptions of how the practice of developing and using models should be applied in the classroom?	Discrete Scale: Developing and Using Models (See Appendix E)	Preconceptions as identified in the *Framework* and *NGSS*	Frequency and percentage statistics
			Mean of numerical scores
	Ordinal Scale (Attending and Analyzing Categories Only): Sophistication of Preservice Teacher Responses (See Appendix F)	Sophistication of Preservice Teacher Response	Frequency and Percentage Statistics
	Interview	Elicit more details and determine rationale for survey responses	Narrative form

The second section presents results of the study which provide analysis of the elementary preservice teachers' preconceptions of the critical discourse (student-student and student-teacher) needed for the success of developing and using models in the science classroom. Campbell et al. (2014) conducted a thorough review of literature on modeling instruction that was discussed in chapters two and three and their findings yielded research that points to this practice being a social endeavor. The pilot described in chapter three clarified preservice teachers' limited views about this practice as a social endeavor and the use of a video to elicit ideas about the critical discourse needed to use this practice in the classroom was used. The use of the video is not intended as an intervention, but the limitations of this study have been identified to include use of the video. This is further described in chapter three. The following research question is analyzed in this second section.

2. What student-student and student-teacher interactions are identified by elementary preservice teachers as critical to developing and using models in the classroom?

There are two questions in the survey (See Appendix B) that directly correspond to this research question in this study (See Table 11). Table 11, below, summarizes the questions, their purpose in answering this research question, as well as instrumentation used and representation of findings.

Table 11

Section 2 Data Analysis

Research Question: What student-student and student-teacher interactions are identified by elementary preservice teachers as critical to developing and using models in the classroom?			
Corresponding Survey Questions (See Appendix B)	**Instrumentation**	**Purpose**	**Representation**
1.What communication patterns between students do you think led to groups successfully developing and using their model?	Discrete Scale: Student-Student Communication (See Appendix H)	Preconceptions of critical student-student communication patterns (TERC, 2012b)	Frequency and percentage statistics
			Mean of numerical scores
	Ordinal Scale (Attending and Analyzing Categories Only): Sophistication	Sophistication of Preservice Teacher Response	Frequency and Percentage Statistics

	of Preservice Teacher Responses (See Appendix F)		
	Interview	Elicit more details and determine rationale for survey responses	Narrative form
2.What communication patterns between the students and teacher do you think led to the groups successfully developing and using their model?	Discrete Scale: Student-Teacher Communication (See Appendix J)	Preconceptions of critical student-teacher communication patterns (TERC, 2012a)	Frequency and percentage statistics
			Mean of numerical scores
	Ordinal Scale (Attending and Analyzing Categories Only): Sophistication of Preservice Teacher Responses (See Appendix F)	Sophistication of Preservice Teacher Response	Frequency and Percentage Statistics
	Interview	Elicit more details and determine rationale for survey responses	Narrative form

The coding systems that were developed (See Appendix H & J) to score the preservice teachers' responses are described in chapter three. The survey questions that directly relate to answering this research study question are as follows:

2. What communication patterns between students do you think led to groups successfully developing and using their model?
3. What communication patterns between the students and teacher do you think led to the groups successfully developing and using their model?

Numerical scores were given when coding the responses to these two survey questions using the discrete scales developed and described in chapter three (See Appendix H & J). The mean, frequency, and percentage statistics of those scores are represented to describe the preservice teachers' overall preconceptions about the critical student-student and student-teacher discourse needed to successfully carry out this practice in the classroom. The discrete scale developed in Appendix H was adapted from the TERC Talk Inquiry reflection tool (TERC, 2012b) that looks at the quality of meaning making discussions students are having. The discrete scale developed in Appendix J was adapted from productive discussion talk moves used by the teacher in the Talk Science Inquiry Project (TERC, 2012a). An ordinal scale adapted from the work of Barnhart and van Es (2015) was also used to analyze the responses to this question and further discussed in chapter three (See Appendix F) to couple with the two discrete scales. The two categories in that ordinal scale that were used to code these survey questions were the attending and analyzing categories. The preservice teachers attended and analyzed only in these two survey questions. The frequency and percentage statistics are represented for the sophistication of response findings. The coupling of these two discrete scales (See Appendix H & J) and the ordinal sophistication scale (See Appendix F) capture the preservice teachers' preconceptions in relation to the student-student and student-teacher discourse needed for this practice and the quality of responses regarding the sophistication of attention and analysis of student ideas. Interview findings related to this research question are reported in narrative form at the end of this section and are used to elaborate on what participants said in the survey as well as summarize participants' rationale.

The third section includes an analysis of the elementary preservice teachers' preconceptions or beginning understandings about critical teacher strategies needed to develop and use models in the classroom. The following research question is analyzed in the third section.

3. What teaching strategies do preservice elementary teachers identify as critical to developing and use models in the classroom?

There is one question in the survey (See Appendix B) that directly corresponds to the third research question in this study (See Table 12). Table 12 summarizes the question, its purpose in answering this research question, as well as instrumentation used and representation of findings.

Table 12

Section 3 Data Analysis

<table>
<tr><td colspan="4">Research Question: What teaching strategies do preservice elementary teachers identify as critical to developing and use models in the classroom?</td></tr>
<tr><th>Corresponding Survey Questions (See Appendix B)</th><th>Instrumentation</th><th>Purpose</th><th>Representation</th></tr>
<tr><td rowspan="3">1.What three things would you do if you were the teacher at the end of the video to continue to help students develop and use their model?</td><td>Nominal Scale: Teacher Strategy Responses (See Appendix K)</td><td>Preconceptions of thinking about the practice of developing and using models in three distinct ways</td><td>Frequency and percentage statistics</td></tr>
<tr><td>Ordinal Scale (Responding Category Only): Sophistication of Preservice Teacher Responses (See Appendix F)</td><td>Sophistication of Preservice Teacher Response</td><td>Frequency and Percentage Statistics</td></tr>
<tr><td>Interview</td><td>Elicit more details and determine rationale for survey responses</td><td>Narrative form</td></tr>
</table>

The coding systems that were developed (See Appendix K & F) to score the preservice teachers' responses are described in chapter three.

The survey question that directly relates to answering this first research study question is as follows:

5. What three things would you do if you were the teacher at the end of the video to continue to help students develop and use their model?

One teacher strategy was already identified in section two, and the findings centered around discourse (See Appendix J). This section includes an analysis of elementary preservice teachers thinking about this practice as an investigating, sense making, and critiquing tool as described by McNeill et al. (2015) that was further clarified in chapter two and three. The authors note that the practice of developing and using models depending on how it is used could be in each of these three categories (McNeill et al., 2015). McNeill et al. (2015) indicate that in their professional development work with teachers, they found most existing curricular resources to focus on the investigating practices that lead to collecting data about the natural world, and that the critiquing practices are the rarest. A necessary critical teacher strategy for this practice will include expanding on thinking about this practice as only an investigating tool. Responses were coded for this survey question using the nominal scale developed and described in chapter three (See Appendix K). The frequency and percentage statistics of those nominal scale codes are represented to describe the preservice teachers' preconceptions about this practice in three distinct ways. This nominal scale does not reveal preservice teacher sophistication in their responses. An ordinal scale adapted from the work of Barnhart and van Es (2015) was also used to analyze the responses to this question and further discussed in chapter three (See Appendix F) to couple with the nominal scale in this section. One category in that ordinal scale was used to code this last survey question; the responding category (See Appendix F). The preservice teachers responded only in this survey question. The frequency and percentage statistics are represented for the sophistication of response findings. The coupling of these two scales capture their preconceptions in relation to thinking about this practice in three distinct ways and the quality of responses regarding the sophistication of responding to student ideas. Interview findings related to this research question are also reported in narrative form at the end of this section to elaborate on what participants said in the survey and to include participants' rationale.

The Practice of Developing and Using Models Results

This study analyzed elementary preservice teachers' preconceptions about the science and engineering practice of developing and using models as described in the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013). To do this, teachers responded to the survey question below (See Appendix B) prior to watching a video of a successful session of the practice being used in a classroom to elicit preconceptions about the practice.

1. What are your perceptions of how the practice of developing and using models should be applied in the classroom?

In a pilot study a discrete scale (See Appendix E) was adapted from the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013) to code responses to the survey question. The responses to the survey received a score of zero (0) beginner, one (1) novice, two (2) transitional, or three (3) skilled (See Appendix E) by the researcher to interpret their preconceptions for each of the categories that represent the practice in the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013). The responses to the survey question were also coded using an ordinal scale (See Appendix F) to capture the sophistication of response so further implications could be made about preservice teacher education in chapter five (attending and analyzing categories only). This ordinal scale was used in a previous study on preservice science teachers (Barnhart & van Es,

2015) to score the quality of responses regarding sophistication. Responses for sophistication received a score of low sophistication, medium sophistication, or high sophistication in three categories (attending, analyzing, and responding). Responses were coded using the attending and analyzing categories only for this survey question because teachers were not responding. The coupling of these two scales reveals the preconceptions preservice teachers have about the practice of developing and using models as described in recent reform documents and their sophistication of response tells the researcher what could be done next to further their learning about this practice. Tables 13 and 14 below give example of a sample of responses (one category from each scale) that relate to the scores given for each of the scales to further clarify how these instruments were used.

Table 13

Discrete Scale Developing and Using Models: Example Survey Responses

Example Survey Responses **Discrete Scale: Developing and Using Models (See Appendix E)**		
Category 1: Types of Models (represents a sample of one category only)		
Score	Example Response	Coding Rationale
A Score of 0 (Novice)	"For developing and using models, I would guide students on what to do and set up guidelines. The students will put the model together with the available supplies. I would only have them do models for things where a model would be most beneficial" (Participant #17)	Describes models using no specific descriptions of the different types of models and only describes models generally as a tool used to better visualize or understand the phenomena under investigation
A Score of 1 (Emerging)	"My idea of using models in the classroom would be having the students build or draw out whatever the	Describes some specific descriptions of the types of models using general terms to indicate there are different types

	concept being taught is" (Participants #15)	
A Score of 2 (Transitional)	"I think it is very important to include visual models in the classroom. Whether its posters around the room or demonstrations" (Participant #14)	Describes models to include one or two of the following types of models: diagrams, physical replicas, mathematical representations, analogies, or computer simulations
A Score of 3 (Skilled)	No responses at this level	Describes models to include two or more of the following types of models: diagrams, physical replicas, mathematical representations, analogies, or computer simulations

Table 14

Ordinal Scale Sophistication of Preservice Teacher Responses: Example Survey Responses

Example Survey Responses **Ordinal Scale: Sophistication of Preservice Teacher Responses (See Appendix F)**		
Category 1: Attending (represents a sample of one category only)		
Score	Example Response	Coding Rationale
Low Sophistication	"Developing and using models might include incorporating different philosophies and ways of teaching a specific content area in a specific study in which some students learn better through different models" (Participant #11)	Highlights classroom events, teacher behavior, student behavior, and or classroom climate. Little to no attention to student or teacher thinking.
Medium Sophistication	"These models should be supplemental to the instruction so that students can further expand their learning. Models should be relevant and not too distracting. Get to know your	Highlights student or teacher thinking with more of a procedural focus (teacher use of pedagogy strategies)

	class beforehand so that you can determine which models should be developed or applied throughout the lesson" (Participants #23)	
High Sophistication	"My interpretation of a model is a physical (usually 3D) representation of something. For example, a model of our solar system using Styrofoam spheres. This can be helpful to students because they have a more tangible way to learn a concept, especially those they cannot see" (Participant #26)	Highlights student or teacher thinking with more of a conceptual focus (teacher analyzing and understanding of appropriate use of pedagogy strategies)

The frequency and percentage statistics when coding preservice teacher survey responses to the first question, regarding the six categories of the discrete scale (See Appendix E), are in the Table 15 below.

Table 15

Discrete Scale Developing and Using Models: Frequency and Percentage Statistics

Frequency and Percentage Statistics Discrete Scale: Developing and Using Models (See Appendix E)						
Category	**Statistics**	**Score**				
		0-Novice	**1-Emerging**	**2-Transitional**	**3-Skilled**	**No Use**
1	Frequency	25	6	1	0	4
	Percentage (n=36)	69.4 %	16.7 %	2.8 %	0 %	11.1 %
2	Frequency	8	1	0	0	27
	Percentage	22.2 %	2.8 %	0 %	0 %	75.0 %

	(n=36)					
3	Frequency	14	0	0	0	22
	Percentage (n=36)	38.9 %	0 %	0 %	0 %	61.1 %
4	Frequency	23	6	0	0	7
	Percentage (n=36)	63.9 %	16.7 %	0 %	0 %	19.4 %
5	Frequency	1	0	0	0	35
	Percentage (n=36)	2.8 %	0 %	0 %	0 %	97.2 %
6	Frequency	0	0	0	0	36
	Percentage (n=36)	0 %	0 %	0 %	0 %	100 %

Criteria from categories two (models are not exact), three (limitations of models), five (revising models), and six (models in engineering) were not identified by more than 50% of the participants when elementary preservice teachers described how this practice might look in the classroom. No elementary preservice teacher used criteria from category six, models in engineering, in their description of the practice developing and using models. Category one (types of models) and four (using models as a tool for thinking) were by more than 80% of the elementary preservice teachers when describing the practice of developing and using models. Although category one and category four were identified by more participants, this was done at a novice (score of 0) level by over 60% of participants. This novice level does not meet the expectations of how this practice is used in the classroom defined by the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013). The frequency and percentage statistics when coding preservice teacher survey responses to the first question, regarding two categories (attending and analyzing) of the ordinal scale (See Appendix F), are in Table 16 below.

Table 16

Ordinal Scale Sophistication of Preservice Teacher Responses: Frequency and Percentage Statistics

Frequency and Percentage Statistics Ordinal Scale: Sophistication of Preservice Teacher Responses (See Appendix F)				
Statistics	**Category**	**Score**		
		Low	**Medium**	**High**
Frequency	Attending	20	14	2
Percentage (n=36)		55.6 %	38.9 %	5.6 %
Frequency	Analyzing	20	7	0
Percentage (n=36)		55.6 %	19.4 %	0 %

Although the criteria described by the elementary preservice teachers for the practice of developing and using models for this section was low, the capacity to attend to or analyze student thinking (sophistication) was better evenly distributed between the first two scores (low and medium) in the attend category. This even distribution dropped when moving to the analyzing category. Elementary preservice teachers had higher sophistication of responses in the attending category than the analyzing category. The mean of the scores for each of the six categories in the discrete scale used for developing and using models (See Appendix E) are listed in Table 17 below. The mean only represents those answers that could be coded for each category, because the responses to the survey for each preservice teacher did not identify criteria in each category.

Table 17

Discrete Scale Developing and Using Models: Statistical Mean of Scores

Statistical Mean of Scores Discrete Scale: Developing and Using Models (See Appendix E)		
Category	**Mean Min.=0, Max.=3**	**Percentage of Participants Who Identified Criteria in this Category**
Category 1	0.3	32 of 36 = 88.9 %
Category 2	0.1	9 of 36 = 25 %
Category 3	0	14 of 36 = 38.9 %
Category 4	0.2	29 of 36 = 80.6 %
Category 5	1	1 of 36 = 2.8 %
Category 6	0	0 of 36 = 0 %

There were two mean scores for category one and four (lower than 0.5) that show the current knowledge of this practice in relation to achieving the vision (score of 3) in the Framework (NRC, 2012) and *NGSS* (NGSS Lead States, 2013).

There were two questions at the end of the survey to help elicit anymore preconceptions from the elementary preservice teachers about their beginning understanding of the practice developing and using models and the critical communication patterns needed to use this practice in the classroom. The following statistical mean scores are represented from the data collected about anymore the preservice teacher could identify from the six categories in the discrete scale identifying criteria from the *Framework* (2012) and *NGSS* (NGSS Lead States, 2013). Although the video was not intended to be an intervention, it has been identified as a limitation to this study. The further identification of criteria from the two categories in Table 18 below are after watching the video for the survey.

Table 18

Discrete Scale Developing and Using Models: Statistical Mean of Scores from Additional Survey Questions

Statistical Mean of Scores from Additional Questions Discrete Scale: Developing and Using Models (See Appendix E)		
Category	**Mean Min.=0, Max.=3**	**Percentage of Participants Who Identified Criteria in this Category**
Category 1	1.9	7 of 36 = 19.7 %
Category 5	0.5	33 of 36 = 91.7 %

More participants in this study could identify category five (revising models), but the mean score only increased slightly. The video showed students revising models, but the preservice teachers were still not able to identify this category at levels (score of 3) described by the *Framework* and *NGSS*. Not many participants elaborated on the types of models (category 1), but those that did (19.7 %) increased the comparison mean score by more than 1.5 points. The video gave them context that helped them identify different types of models, but interviews conducted on a sample of the preservice teachers revealed their ideas to fall back in line with those in the data from before the video was watched.

Six participants were interviewed using a protocol (See Appendix D) to have preservice teachers elaborate on their survey responses and to probe for possible influences on their responses. The six participants were asked to describe their current comfort level in teaching science on a scale of zero to ten. The mean current comfort level of teaching science was a score of 6.4. Although their comfort level is above a score of five (middle score), the data from analyzing this research question is low in their understanding of what the practice of developing and using models is. Even though participants saw the classroom video (not intended as an intervention), the participants were not able to describe anything different than their original survey responses that would move them out of a novice level. This finding is in keeping with the idea that because the video was not used as an intervention, students were not impacted in changing their ideas of this practice. Two emerging themes developed when analyzing the data from the interviews related to this first research question, use of teacher centered models and little previous experience with developing models. Five of the six interview participants originally described the practice of developing and using models as a teacher-centered practice. The models were made and used by the teacher to display some content knowledge to students. One participants described this by saying, “I think I haven't developed that many models in my classes and I feel like I'm learning how to teach way different than I was taught” (Participant #3, October 19, 2016). This does not fit the new vision for this practice and describes developing and using models as a student practice. When asked for why they may have responded to the survey question in this manner, participants described their previous experience with the practice of developing and using models. Their collective previous experiences were limited to using models as described above (teacher made, for use by students) or participants describe little experience creating models at all. All six participants described little experience creating or developing models and all participants described doing so after knowledge about the content was already acquired. This also does not fit the new vision for this practice. One participant described creating a representation of what they learned about in their third-grade rain forest unit: “we turned our class into a rain forest displaying the plant and animal life" (Participant #5, October 9, 2016). Another participant described creating a model of a cell, saying, "I was piecing together information from what I had already learned" (Participant #4, October 9, 2016). This experience was mimicked by another student who described making a representation of the solar system with his mother at home in middle school after learning about the content in class. Their previous experiences with models are very limited compared to the description in the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013). The researcher attributes the low scores for research question one because of the previous experiences of models the elementary preservice teachers have had. Their experiences developing models were a rare occurrence in their previous learning as students and they only developed models to display a topic after content learning had occurred. Most of the experiences described with models centered around the teacher creating or showing a model to students to demonstrate a topic and one participant said, "I would say most of the models were given to me to look at" (Participant #5, October 9, 2016) to describe his experiences with this practice.

Developing and Using Models as a Social Endeavor Results

This study analyzed elementary preservice teachers' preconceptions about the critical student-student and student-teacher communication needed for successful use of the science and engineering practice of developing and using models. To do this, teachers responded to the two survey questions below after watching a video described in chapter three (See Appendix B) to elicit preconceptions about critical communication patterns needed for this practice.

2. What communication patterns between students do you think led to groups successfully developing and using their model?

3. What communication patterns between the students and teacher do you think led to the groups successfully developing and using their model?

In a pilot study, two discrete scales (See Appendix H & J) were adapted from a TERC reflection tool that describes desirable student-student interactions (TERC, 2012b) and teacher talk moves that the teacher uses to help student have meaning making discussions (TERC, 2012a) to code responses to the two survey questions. The responses to the survey questions received a score of zero (0) beginner, one (1) novice, two (2) transitional, or three (3) skilled (See Appendix H & J) by the researcher to interpret their preconceptions for each of the categories represented in each discrete scale. The responses to the survey question were also coded using an ordinal scale (See Appendix F) to capture the sophistication of response so further implications could be made about preservice teacher education in chapter 5 (attending and analyzing categories only). This ordinal scale was used in a previous study on preservice science teachers (Barnhart & van Es, 2015) to score the quality of responses regarding sophistication. Responses for sophistication received a score of low sophistication, medium sophistication, or high sophistication in three categories (attending, analyzing, and responding). Responses were coded using the attending and analyzing categories only for this survey question because teachers were not responding. The coupling of a discrete scale, found in Appendix H for the student-student responses and Appendix J for the student-teacher responses, with the ordinal sophistication scale (See Appendix F) reveals the preconceptions preservice teachers have about the practice of developing and using models as a social endeavor and their sophistication of response tells the researcher what could be done next to further their learning about this practice. Tables 19, 20, and 21 below give example of a sample of responses (one category from each scale) that relate to the scores given for each of the two discrete scales and ordinal scale to further clarify how these instruments were used.

Table 19

Discrete Scale Student-Student Communication: Example Survey Responses

Example Survey Responses **Discrete Scale: Student-Student Communication (See Appendix H)**		
Category 2: Critiquing Their Own and Others' Answers/Ideas (represents a sample of one category only)		
Score	Example Response	Coding Rationale
A Score of 0 (Novice)	"They were talking between each other, throwing out ideas and information and would write down the one they felt was most suitable" (Participant #10)	Describes students generally having discussions in a group, but no distinctions made to show there were differences in answers/ideas of the students
A Score of 1 (Emerging)	"Some students in the group asked other group members questions. The students shared their own ideas and collaborated to come up with a master idea. " (Participants #8)	Describes students generally discussing answers/ideas of their own and others, but does not include specific descriptions of students critiquing those answers/ideas (agree/disagree, build on each other's answers, distinguish evidence from opinion, identify questions, ask if we have enough evidence)
A Score of 2 (Transitional)	"Asking one another questions and making short statements to see if beliefs were supported. The students would restate the student's ideas/belief to make sure they understood. They would confirm support for stated belief or they would build onto it. This became a pattern of communication as the student built their model. " (Participant #16)	Describes students generally discussing answers/ideas of their own and others, but includes little description of students critiquing those answers/ideas (agree/disagree, build on each other's answers, distinguish evidence from opinion, identify questions, ask if we have enough evidence)

A Score of 3 (Skilled)	No responses at this level	Describes students critiquing their own and others' answers/ideas (students agree/disagree, build on each other's answers, distinguish evidence from opinion, identify questions, ask if we have enough evidence)

Table 20

Discrete Scale Student-Teacher Communication: Example Survey Responses

Example Survey Responses **Discrete Scale: Student-Teacher Communication (See Appendix J)**		
Category 1: Helping Individual Students Share, Expand, and Clarify Their Own Thinking (represents a sample of one category only)		
Score	Example Response	Coding Rationale
A Score of 0 (Novice)	"Walk around and ask guiding questions that got students thinking about whether their model would function correctly. Give feedback to each individual group so they can develop their models even more. " (Participant #23)	Describes the teacher asking students general questions or providing support with no specific descriptions of the types of questions or support
A Score of 1 (Emerging)	"The teacher used open ended questions to make the students think about their ideas. The teacher avoided telling them the facts and instead led them to the answers. He connected it to other subjects. He encouraged students when if they didn't come to the right conclusion. " (Participants #5)	Describes the teacher asking students questions that fall under one of the following categories: share, expand, or clarify using general descriptions
A Score of 2 (Transitional)	"Teacher came around and individually clarified questions and probed for questions. Challenged	Describes the teacher helping students to share, expand, and clarify their own thinking using

	students to come up with alternate ways. "If you think that’s what happens, I want you to write it down". ” (Participant #30)	some descriptions of strategies like the following: -Giving time to think (partner talk, writing as think time, wait time) -Asking students to say more (elaborate, clarify, and ask for examples) -Asking students to validate teacher summary of their thinking (giving space for the original student to agree/disagree or say more)
A Score of 3 (Skilled)	No responses at this level	Describes the teacher helping students to share, expand, and clarify their own thinking using descriptions of strategies like the following: -Giving time to think (partner talk, writing as think time, wait time) -Asking students to say more (elaborate, clarify, and ask for examples) -Asking students to validate teacher summary of their thinking (giving space for the original student to agree/disagree or say more)

Table 21

Ordinal Scale Sophistication of Preservice Teacher Responses: Example Survey Responses

Example Survey Responses **Ordinal Scale: Sophistication of Preservice Teacher Responses (See Appendix F)**		
Category 1: Analyzing (represents a sample of one category only)		
Score	Example Response	Coding Rationale
Low Sophistication	“The teacher used open ended questions to make the students think about their ideas. The teacher avoided	Little or no sense-making of highlighted events; mostly descriptions. No elaboration of analysis of interactions and

	telling them the facts and instead led them to the answers. He connected it to other subjects. He encouraged students when if they didn't come to the right conclusion. ” (Participant #5)	classroom events; little or no use of evidence to support claims
Medium Sophistication	“The teacher checked up on the groups and asked them questions to get them to think about what they're drawing. The teacher also asks if they may have learned relative things from different subjects. He was supportive and accepted exploration and uncertainty. ” (Participants #8)	Begins to make sense of highlighted events. Some use of evidence to support claims.
High Sophistication	“Tell me what’s going on here?" "Why would bending of lens cause you to focus?" "Is there another way to get it to focus?" "I want students to try many different ways and find best way it works" "What classes have you learned this in?" He asked questions and lets them fumble for the answer in their existing schemas. ” (Participant #25)	Consistently makes sense of highlighted events. Consistent use of evidence to support claims.

The frequency and percentage statistics when coding preservice teacher survey responses about critical student-student communication patterns, regarding the four categories of the discrete scale (See Appendix H), are in Table 22 below.

Table 22

Discrete Scale Student-Student Communication: Frequency and Percentage Statistics

Frequency and Percentage Statistics

Discrete Scale: Student-Student Communication (See Appendix H)						
Category	Statistics	Score				
		0-Novice	1-Emerging	2-Transitional	3-Skilled	No Use
1	Frequency	16	16	1	0	3
	Percentage (n=36)	44.4 %	44.4 %	2.8 %	0 %	8.3 %
2	Frequency	10	23	3	0	0
	Percentage (n=36)	27.8 %	63.9 %	8.3 %	0 %	0 %
3	Frequency	14	21	1	0	0
	Percentage (n=36)	38.9 %	58.3 %	2.8 %	0 %	0 %
4	Frequency	0	2	0	0	34
	Percentage (n=36)	0 %	5.6 %	0 %	0 %	94.4 %

Criteria from categories one (use of evidence to support answers), two (critiquing their own or others' answers or ideas), and three (merging ideas to develop and explanation) were used by more than 90% of participants when describing what student-student communication patterns led to the students successfully developing and using their models. Category two (critiquing their own or others' answers or ideas), and three (merging ideas to develop and explanation) had more participants score at an emerging (score of 1) level than at a novice (score of 0) level. All three categories where more than 90% of participants identified criteria from were still at the novice (score of 0) or the emerging (score of 1) level. There were few that could describe the criteria in this category at higher levels. Criteria from category four (apply learning to a new or different context) was not used by more than 90% of participants. The frequency and percentage statistics when coding preservice teacher survey responses about critical student-teacher communication patterns, regarding the four categories of the discrete scale (See Appendix J), are in Table 23 below.

Table 23

Discrete Scale Student-Teacher Communication: Frequency and Percentage Statistics

Frequency and Percentage Statistics Discrete Scale: Student-Teacher Communication (See Appendix J)						
Category	**Statistics**	**Score**				
		0-Novice	**1-Emerging**	**2-Transitional**	**3-Skilled**	**No Use**
1	Frequency	11	20	4	0	1
	Percentage (n=36)	30.6 %	55.6 %	11.1 %	0 %	2.8 %
2	Frequency	7	28	1	0	0
	Percentage (n=36)	19.4 %	77.8 %	2.8 %	0 %	0 %
3	Frequency	8	19	7	0	2
	Percentage (n=36)	22.2 %	52.8 %	19.4 %	0 %	5.6 %
4	Frequency	25	10	0	0	1
	Percentage	69.4 %	27.8 %	0 %	0 %	2.8 %

	(n=36)					

The student-teacher scale was used by the researcher to see what preconceptions elementary preservice teachers have about important communication patterns and all four categories were used by almost all participants. Category one (helping individual students share, expand, and clarify their own thinking), two (helping students listen carefully to one another), and three (helping students deepen their reasoning) found more participant descriptions scoring at an emerging (score of 1) than at a novice (score of 0) level. Category four (helping student think with others) had more participant responses score at a novice (score of 0) level than at an emerging (score of 1) level. All four categories were used in preservice teacher descriptions for this response in the survey, but they majority were still at the novice (score of 0) or emerging (score of 1) level. The frequency and percentage statistics when coding preservice teacher survey responses to the first question, regarding two categories (attending and analyzing) of the ordinal scale (See Appendix F), are in Table 24 below.

Table 24

Ordinal Scale Sophistication of Preservice Teacher Responses: Frequency and Percentage Statistics

Frequency and Percentage Statistics Ordinal Scale: Sophistication of Preservice Teacher Responses (See Appendix F)				
Statistics	**Category**	**Score**		
		Low	**Medium**	**High**
Frequency	Attending	12	21	3
Percentage (n=36)		33.3 %	58.3 %	8.3 %

Frequency	Analyzing	17	17	2
Percentage (n=36)		47.2 %	47.2 %	5.6 %

The capacity to attend to and analyze (sophistication) in the preservice teacher responses were at higher levels when comparing the scores of the same two categories (attending and analyzing) in the previous section about their preconceptions for the practice of developing and using models. Preservice teachers attended at a higher level in the medium score compared to the low score. Very few participants scored at a high level for these two categories. The mean of the scores for each of the four categories in the two discrete scales used to elicit the preservice teachers' preconceptions about communication patterns in this practice (See Appendix H &J) are listed in Table 25 and 26 below. The mean only represents those answers that could be coded for each category, because the responses to each survey questions for each preservice teacher did not identify criteria for every category.

Table 25

Discrete Scale Student-Student Communication: Statistical Mean of Scores

Statistical Mean of Scores **Discrete Scale: Student-Student Communication (See Appendix H)**		
Category	**Mean** **Min.=0, Max.=3**	**Percentage of Participants Who Identified Criteria in this Category**
Category 1	0.5	33 of 36 = 91.7 %
Category 2	0.8	36 of 36 = 100 %
Category 3	0.6	36 of 36 = 100 %
Category 4	1	2 of 36 = 5.6 %

Although more than 90 % of participants identified criteria for three first three categories (one, two, and three) of the student-student communication pattern discrete scale, their mean scores are still below a score of one (emerging). The mean score for category four (apply learning to a new or different context) is high, but only two participants identified criteria in this category skewing the mean.

Table 26

Discrete Scale Student-Teacher Communication: Statistical Mean of Scores

Statistical Mean of Scores **Discrete Scale: Student-Teacher Communication (See Appendix J)**		
Category	**Mean** **Min.=0, Max.=3**	**Percentage of Participants Who Identified Criteria in this Category**
Category 1	0.8	35 of 36 = 97.2 %
Category 2	0.8	36 of 36 = 100 %
Category 3	1.0	34 of 36 = 94.4 %
Category 4	0.3	35 of 36 = 97.2 %

More than 90 % of participants identified criteria for all four categories in the student-teacher communication discrete scale. The mean scores are the highest of all mean scores for this study. There were two questions at the end of the survey to help elicit anymore preconceptions from the elementary preservice teachers about their beginning understanding of the practice developing and using models and the critical communication patterns needed to use this practice in the classroom. The following statistical mean scores are represented from the data collected on anymore the preservice teacher could identify from the four categories in the two discrete scales identifying student-student and student-teacher communication patterns critical to the practice of developing and using models.

Table 27

Discrete Scale Student-Student Communication: Statistical Mean of Scores Additional Questions

Statistical Mean of Scores from Additional Questions Discrete Scale: Student-Student Communication (See Appendix H)		
Category	**Mean Min.=0, Max.=3**	**Percentage of Participants Who Identified Criteria in this Category**
Category 1	1.0	17 of 36 = 47.2 %
Category 2	0.7	20 of 36 = 55.6 %
Category 3	0.4	11 of 36 = 30.6 %
Category 4	0.5	13 of 36 = 36.1 %

The mean increased for the student-student communication discrete scale by 0.2 points for the first category (use of evidence to support answers) and 0.4 points for category three (merging ideas to develop an explanation). Of all participants, 36.1% were able to identify category four (apply learning to a new of different context) compared to the initial responses by teachers in this section of analysis that totaled 5.6%.

Table 28

Discrete Scale Student-Teacher Communication: Statistical Mean of Scores Additional Questions

Statistical Mean of Scores from Extra Questions Discrete Scale: Student-Teacher Communication (See Appendix J)		
Category	**Mean Min.=0, Max.=3**	**Percentage of Participants Who Identified Criteria in this Category**
Category 1	0.6	10 of 36 = 27.8 %

Category 2	1.0	1 of 36 = 2.8 %
Category 3	0.6	26 of 36 = 72.2 %
Category 4	0.4	18 of 36 = 50.0 %

The two questions at the end of the survey to help elicit anymore preconceptions from the elementary preservice teachers about their beginning understanding of the practice developing and using models and the critical student-teacher communication patterns needed to use this practice in the classroom did not yield any new findings. The statistical mean scores were similar to those from the initial responses in this section.

The mean scores for responses to survey questions about the practice of developing and using models as a social endeavor (second research question) were higher than the scores that displayed elementary preservice teacher's preconceptions about how the practice of developing and using models is used in the classroom (first research question). The six elementary preservice teachers that were interviewed (See Appendix D) were asked to elaborate on their survey responses about this practice as a social endeavor (student-student and student-teacher communication). The researcher asked the participants questions to probe deeper about why they may have responded the way they did that resulted in higher mean scores to this research question than the first research question. The researcher established emerging themes when coding the interview data about the social aspect of the practice of developing and using models. Three emerging themes appeared in the data that explain the higher scores; accumulated classroom management knowledge, previous practicum experience, and previous course work attending to student thinking. All participants described classroom management experiences in their descriptions. These descriptions included participants describing previous knowledge about how to facilitate group work and the intervention as the teacher during this group work as one of the primary emerging themes. One participant used the term “classroom management” to mean “good interactions and bad interactions” students were having (Participant #5, October 9, 2016). Another participant described needing “training on classroom management and also intervention” (Participant #6, October 16, 2016) when describing what would help them strengthen their ability to facilitate student-student and student-teacher communication while using the science and engineering practice of developing and using models in the classroom. Another emerging theme was previous experience observing students in the classroom (as a teacher or student) and most participants referred to this experience as practicum experience. All participants described experiences under this emerging theme. Experiences ranged from those as a student in the classroom and noticing how students interact or how the teacher helped facilitate conversations. Other experiences included practicum college experience; “I think our practicum classes in math and social studies have really helped with providing a lesson or providing an overall unit talking about how you might interject with questions for students” (Participant #4, October 9, 2016). Another participant described their previous practicum experience as “the opportunity we have had the most to observe and understand student interactions” (Participant #9, October 18, 2016). The last emerging theme is previous course work attending to student thinking. Participants described a wide range of teacher strategies attending to student thinking and described these strategies as those learned in previous course work. One participant described student-teacher communication patterns as those you would see in an informal assessment check with students during class; “I think of it in terms of assessment that you as the teacher kind of know for sure that the students are learning the material and if they are struggling they have to recognize that they are struggling” (Participant #6, October 16, 2016). Another participant described student-student interaction as that where students can express communication using their preferred learning style. The participant described learning about learning styles in a previous teacher pedagogy course and said, “it is okay for them to choose the learning style that would appeal to them when communicating, but you just have to make sure that everyone had their own individual ideas before coming up with the same group idea in creating their model” (Participant #4, October 9, 2016). The elementary preservice teachers were probably better able to score higher mean scores when noticing the social aspects (student-student and student-teacher communication) of this practice because of previous practicum experience observing students in the classroom or observing this behavior as a student in the classroom, previous accumulated classroom management knowledge, and the attention to student thinking in other college courses. When participants described these emerging themes, almost all events were not linked to any science related experiences. Only one participant described a previous science related experience that led him to respond the way he did in the survey; “I was in anatomy lab and we were working with cadavers and there were a lot of times where all three of us just had a different idea of what was happening and so that was a time she would come and mediate to help us get to the final answer” (Participant #6, October 16, 2016). The descriptions of these emerging themes were also not described as being isolated from one experience, but instead were accumulated experiences throughout many of mostly non-science related events they learned from. The varied and numerous experiences about student-student and student-teacher communication outside of their science pedagogy work could have also led to higher mean scored on this topic. One participant described how they came to the conclusions they did on the survey about this practice as a social endeavor over many accumulated experiences and said, “I mean not one specific course I think it is kind of a variety” (Participant #4, October 9, 2016).

Teacher Strategies for the Practice of Developing and Using Models Results

The study analyzed elementary preservice teachers’ preconceptions about the critical teacher strategies needed for successful use of the science and engineering practice of developing and using models in the classroom. To do this, teachers responded to the one (directly related) survey question below after watching a video described in chapter three (See Appendix B) to elicit preconceptions about critical teacher strategies needed for this practice.

5. What three things would you do if you were the teacher at the end of the video to continue to help students develop and use their model?

A nominal scale (See Appendix K) was adapted from a study conducted by McNeill et al. (2015) identifying the practice of developing and using models in three distinct ways (investigating, sensemaking, and critiquing tools) to code responses to two survey questions. The direct survey question identified above was coded using this scale and the following indirect survey question was also coded using the same scale.

1. What are your perceptions of how the practice of developing and using models should be applied in the classroom?

Analyzing all survey questions (the two identified) where preservice teachers talked about the practice with elaboration will help identify what preconceptions they have about using this practice in the three ways McNeill et al. (2015) describe. The responses to the survey questions received a code of investigating, sensemaking, or critiquing (See Appendix K) by the researcher to interpret their preconceptions for each of the categories represented in the nominal scale. The responses to the direct survey question for this section was also coded using an ordinal scale (See Appendix F) to capture the sophistication of response (responding category only) so further implications could be made about preservice teacher education in chapter 5. This ordinal scale was used in a previous study on preservice science teachers (Barnhart & van Es, 2015) to score the quality of responses regarding sophistication. Responses for sophistication received a score of low sophistication, medium sophistication, or high sophistication in three categories (attending, analyzing, and responding). Responses were coded using the responding category only for this survey question because teachers were responding to student thinking. The coupling of a nominal scale, Appendix K for the three distinct ways to think about this practice, with the ordinal sophistication scale (See Appendix F) reveals the preconceptions preservice teachers have about the practice of developing and using models as a tool used in three categories and their sophistication of response tells the researcher what could be done next to further their learning about this practice (critical teacher strategies). Tables 29, 30, and 31 below give examples of sample responses (one category from each scale) that relate to the scores given for the nominal and ordinal scales to further clarify how these instruments were used.

Table 29

Nominal Scale Teacher Strategy Responses: Example Survey Responses

Example Survey Responses **Nominal Scale: Teacher Strategy Responses (See Appendix K)**		
Coding Category	**Example Response**	**Coding Rationale**
Investigating	"I would inquire as to what my students' perceptions were about a science topic. I would have them write up a hypothesis. I would then pair my students up for a lab. I would model the use of materials first. Then I would have student perform the lab	Described the developing and using models practice by describing students asking questions or implementing methods of data collection to investigate the natural world

	with a partner. Lastly, the partnered pair would write down their findings together" (Participant #16)	
Sensemaking	"Students would be building something to visually represent a concept. Students will be using the models to understand how things work. Building models is a hands-on learning approach that involved inquiry-based learning by students. Models should be used frequently in the classroom for elementary science" (Participants #32)	Described the developing and using models practice by describing students analyzing data, looking for patterns or relationships to develop explanations and design representations based (constructing models) on data to explain how and why phenomena occur
Critiquing	"I would have the students write about what they liked about the other classmates models and what they would change if they could do it again. As a later project I would have the students go back to their original models and use that information to help them construct a 3 dimensional model of the eye. I would have the students group up with someone different from their group and compare/contrast each others models, discuss what you liked and what you were confused on" (Participant #33)	Described the developing and using models practice by describing students evaluating, comparing, and contrasting different claims, explanations, or models as they make sense of the world around them

Table 30

Ordinal Scale Sophistication of Preservice Teacher Responses: Example Survey Responses

Example Survey Responses **Ordinal Scale: Sophistication of Preservice Teacher Responses (See Appendix F)**

Category 3: Responding (represents a sample of one category only)		
Score	**Example Response**	**Coding Rationale**
Low Sophistication	"Develop a model together as an entire class that is the correct model. Use the model in subsequent lessons and incorporate it into new concepts the students will learn. Post each group's model around the room so students could analyze and critique the different models and what is right and work about each to give feedback rather than the teacher doing all of the work" (Participant #32)	Does not identify or describe acting on specific student ideas as topics of discussion; offers disconnected or vague ideas of wat to do differently next time.
Medium Sophistication	"Directly after group presentations; hold a class discussion about what they concluded about how the eye works. Talk about what wen well or what needed more work on each groups model. Allow each group to correct their models. Hang models in classroom and continue further research on topic over the next few days" (Participants #31)	Identifies and describes acting on a specific student idea during the lesson; offers ideas about what to do differently next time.
High Sophistication	"If I were the teacher, after having the students present their models, I would have them go back to their models and research how an eye actually works, and then either correct their model to make sure that it was accurate, or draw a new model. Then when they were done, the could go up again and tell the class either why	Identifies and describes acting on a specific student idea during the lesson and offers specific ideas of what to do differently next time in response to evidence; makes logical connections between teaching and learning.

	their model was incorrect or correct" (Participant #1)	

The frequency and percentage statistics when coding preservice teacher survey responses (in both survey questions) about their preconceptions of how the practice of developing and using models is used as a tool (a critical teacher strategy), regarding the three categories of the nominal scale (See Appendix K), are in Tables 31, 32, and 33 below. The frequency represents how many times in each question the practice of developing and using models was referred to as an investigating, sensemaking, or critiquing practice. The percentage statistic represents the percentage of use for that category in responses out of the total combined use of all three categories. Frequency and percentage statistics are reported for each question individually and then combined for an overall analysis of elementary preservice teachers' use of the three categories during the survey (both questions combined).

Table 31

Nominal Scale Survey Question One Teacher Strategy Responses: Frequency and Percentage Statistics

Survey Question One: Frequency and Percentage Statistics Nominal Scale: Teacher Strategy Responses (See Appendix K)		
Category	**Frequency Statistic**	**Percentage Statistic (n=46)**
Investigating Practice	32	69.7 %
Sensemaking Practice	12	26.1 %

Critiquing Practice	2	4.3 %

Table 32

Nominal Scale Survey Question Five Teacher Strategy Responses: Frequency and Percentage Statistics

Survey Question Five: Frequency and Percentage Statistics **Nominal Scale: Teacher Strategy Responses (See Appendix K)**		
Category	**Frequency Statistic**	**Percentage Statistic (n=53)**
Investigating Practice	11	20.8 %
Sensemaking Practice	18	33.4 %
Critiquing Practice	24	45.3 %

Table 33

Nominal Scale Combined Teacher Strategy Responses: Frequency and Percentage Statistics

Total Frequency and Percentage Statistics **Nominal Scale: Teacher Strategy Responses (See Appendix K)**		
Category	**Frequency Statistic (used in both questions)**	**Percentage Statistic (n=99)**
Investigating Practice	43	43.4 %
Sensemaking Practice	30	30.3 %
Critiquing Practice	26	26.3 %

The practice of developing and using models was referred to more as an investigating practice than any other type of practice overall. Developing and using models was described as a critiquing practice the least when coding for all three categories (investigating, sensemaking, and critiquing) overall. Survey question one was administered before the video and participants could describe the practice of developing and using models primarily as an investigating practice and a quarter of the time as a sensemaking practice. The researcher has established in research question one findings that although sensemaking was used to describe the practice, this was done to make sense of learning after the learning had already taken place. This is not in keeping with the new vision for this practice in the classroom. Describing the practice as a critiquing practice was used less than 5% by participants. The use of these categories (investigating, sensemaking, critiquing) during the survey shifts when the video has been introduced and participants are asked what they would do as the teacher at the end of the video to continue to help students develop and use their model. The frequency and percentage statistics show sensemaking and critiquing being used primarily (critiquing the highest) to describe the practice of developing and using models. The video provided a successful session of developing and using models increasing the scores in these the two categories that participants were not originally able to describe in higher numbers. The video helped provide context to answer research questions that the researcher investigated and without this context important aspects of this practice would not have been possible (see methodology in chapter three), but an identified limitation of this study has been the use of the video. Although showing the video might have been a minimal unintended intervention, and was indicated as a limitation to this study, an intervention or intervening variable described by Creswell (2013) indicates a direct influence is intended. In designing research based professional development for *NGSS*, Reiser (2013) recommends structuring “teacher sensemaking around rich images of classroom enactment,” specifically the use of video cases (p. 15). Reiser (2013) states that videos “enable teachers to analyze student thinking, and the work of other teachers to elicit student ideas and help students work with one another’s ideas” (p. 15). This is done with the direct intention of influence and the elementary preservice teachers in this study were not guided or instructed, only observing, during this study. Further evidence described in the findings for research question one indicate when participants elaborated on their responses, they did not move out of novice levels for understanding the practice of developing and using models. This indicated the use of this video as a tool to provide context to investigate the research question and did not have the impact that an intervention would have.

Interviews conducted by the researcher on a sample of the participants also validated the same pattern seen in table 31 (frequency and percentage statistics for the first survey question). When coding the interviews using the three ways (investigating, sensemaking, critiquing) to think about this practice (See Appendix K), all participants described this practice primarily as an investigating practice when elaborating about their responses and searching for further knowledge to display about this practice. One participant described the practice of developing and using models as investigating practice by saying, “we were supposed to draw out what we think the model of the foil boats would be and then predict the number of pennies it could hold” (Participant #9, October 18, 2016). When seldom describing the practice as a sensemaking practice, participants used descriptions that implied the model was made by the teacher or student by making sense of content already previously learned. These findings are also discussed in the data analysis section for research question one in this chapter. This is not the sensemaking described in the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013). The sensemaking described there refers to students working to develop or use a model to better make sense of a phenomena during their learning and not as a representation after learning the content has occurred. One participant described this type of sensemaking by saying, “I keep thinking of the ocean and kind of like how different parts of the ocean work together and so maybe if you're studying one part at one time you would kind of design your own model of the ocean revolving around the sea floor or whatever that could be" (Participant #6, October 16, 2016). The only time participants referred to the practice of developing and using models as a critiquing practice was in response to questions using the video as context. This mimicked the evidence in the frequency and percentage statistics tables for these findings. Any other time participants reached into their funds of knowledge to display their preconceptions about this practice, they reverted to thinking about this practice as primarily an investigatory practice.

The frequency and percentage statistics when coding preservice teacher survey responses to the directly related question in this section, regarding one category (responding) of the ordinal scale (See Appendix F), are in Table 34 below.

Table 34

Ordinal Scale Sophistication of Preservice Teacher Responses: Frequency and Percentage Statistics

Frequency and Percentage Statistics Ordinal Scale: Sophistication of Preservice Teacher Responses (See Appendix F)				
Statistics	**Category**	**Score**		
		Low	**Medium**	**High**
Frequency	Responding	22	13	1
Percentage (n=36)		61.1 %	36.1 %	2.8 %

When using the ordinal scale (See Appendix F) to code preservice teacher responses for sophistication in attending to, analyzing, or responding to student ideas the responding category represented in this section had the most number of participants scoring a low score compared to the other two categories. The researcher explains these findings with previous analysis of interviews discussed in this chapter. Elementary preservice teachers described having previous experience in observing students and taking courses that attend to student thinking. They have not had a lot of experience responding to students in the classroom and this study was conducted at the beginning of this science methods course.

The combined findings in this third section reveal the need for elementary preservice teachers to increase their understandings about the practice of developing and using models as more than just an investigatory practice. This will need to be done using intervention, because these findings show that observing a video with a successful session using this practice did not create lasting impact in their understanding about this practice to include more sensemaking and critiquing use. The preservice teachers were weakest in the sophistication of response in the responding category compared to attending and analyzing. More work in the classroom responding to students will help increase their sophistication in this category. At the end of the interview, participants described what instruction in their preservice teacher program would be needed to successfully help students develop and use models in the classroom. Three themes emerged; actual practice developing and using models in a science methods course as a student would experience this practice, facilitating the social aspect of this practice, and increased science content knowledge. Five of the six participants described only one or two of these categories and could not use their experience in this study to provide reasoning for why they needed support in the manner they described (use the video to describe what they lacked). Only one participant described all three emerging themes and used the video to say she was not able to replicate this successful episode without more support or instruction as a preservice teacher. This participant described the instruction needed and said “I think just practice and facilitating creating a model, because I think it's definitely a different type of lesson than what we have been taught” (Participant #4, October 9, 2016). She described previous experiences to elaborate on her claim by saying “I think I was looking at analyzing models as a class, there wasn't really much group work, a lot of times when there was group work there were group labs it was following a set of directions it wasn't really creating your lab or it wasn't creating a model, it was much more like using and doing rather than creating, and so it was like a much lower level on like Bloom's taxonomy for example” (Participant #4, October 9, 2016). She further described the help she would need in facilitating the social aspect of this practice by saying, “I think this kind of this interactive discussion based lesson isn't necessarily the traditional lesson” and “maybe just practice in creating those things effectively in facilitating those lessons because I mean I’d be facilitating a lesson based around this model creation and you have to have that classroom management to facilitate that model” (Participant #4, October 9, 2016). She finished her description by saying, “you also have to have practice in a way interacting with groups of students to help them focus on a certain area but also like knowing how to respond with the correct questions and how to guide them and push them further” (Participant #4, October 9, 2016).

Summary of Chapter 4

In summary, the elementary preservice teachers’ responses to the survey were coded and analyzed to answer the research questions. The analysis of the data showed the lack of understanding about the practice of developing and using models as described in the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013). The analysis showed more promising results when preconceptions about this practice as a social endeavor were elicited from the elementary preservice teachers. Finally, the analysis of data showed that when thinking about this practice in a variety of ways (investigating, sensemaking, and critiquing) as described by Barnhart and van Es (2015) as a teacher strategy, elementary preservice teachers identified this practice as an investigating practice more than any other category. The sophistication of preservice teacher responses was coupled with each of the three sections of data analysis to show quality of the responses for further implications. The results presented in this chapter provide information for future modeling instruction studies, as well as working with elementary preservice teachers in the future to develop this practice. These implications will be discussed thoroughly in the final chapter.

Chapter 5: Findings and Conclusions

Introduction

This study examined elementary preservice teachers' preconceptions about the practice of developing and using models as described in the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013). Preservice teachers were also surveyed about their preconceptions of the practice of developing and using models as a social endeavor and critical teacher strategies necessary to carry out the practice in the classroom.

This chapter begins with a brief summary of the study, followed by an overview of the findings about the preconceptions of the elementary preservice teachers for the practice of developing and using models including this practice as a social endeavor and critical teacher strategies needed for successful implementation. The results are then discussed. Finally, suggestions and implications for future research and teacher education based on the findings are provided.

Summary of the Study

A Science Framework for K-12 Science Education (NRC, 2012) and the *Next Generation Science Standards* (NGSS Lead States, 2013) created a vision for three-dimensional learning in science education and expressed "a vision in science education that requires students to operate at the nexus of three dimensions of learning: Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas" (NGSS Lead States, 2013, Appendix F p.1). As mentioned in the literature review, "[t]eachers must meld all three of the dimensions together to build effective science lessons, but before they can do that, they need to understand each dimension and the shifts in emphasis around each that are central to the definition and structure of the *NGSS*" (Duncan et al., 2017, p. vii). Modeling appears in two of these three dimensions. Developing and using models is one of the eight identified practices in the dimension of science and engineering practices. Likewise, systems and system models is one of the seven identified concepts in the dimension of crosscutting concepts. The practice of developing and using models will have a great impact on teacher preparation because it utilizes several of the other seven practices and modeling is a part of two of the three dimensions in this new vision for science education (NRC, 2012). As mentioned above, “[i]ncreasingly, more science education researchers and U. S. national standards documents have noted the importance of models in science and engineering and have subsequently called for an increased role for models in K-12 science teaching and learning” (Campbell et al., 2014, p. 159-160). With the implementation of the science and engineering practices in the *NGSS*, shifts in science preservice professional learning will be needed. To quote Bybee, again, “[b]ecause science and engineering practices are basic to science education and the change from inquiry to practices is central, this innovation for the new standards will likely be one of the most significant challenges for the successful implementation of science education standards” (2012, p. 34). And as Ricketts has stated, “[c]onsidering that preservice elementary teachers have little to no experience participating in a scientific community, it is not surprising that their knowledge of scientific practices is often limited” (Ricketts, 2014, p. 2110). “The emphasis on modeling is also new and will need to be an explicit element of teacher preparation” (NRC, 2012, p. 258). Preservice teacher’s combining their previous knowledge of the science and engineering practice of developing and using models with an awareness of their collective renewed meaning will help them reach the new vision for science education.

The following questions were answered in this study:

1. What are elementary preservice teachers’ preconceptions about developing and using models in the classroom?

2. What student-student and student-teacher interactions are identified by elementary preservice teachers as critical to developing and using models in the classroom?
3. What teaching strategies do preservice elementary teachers identify as critical to developing and use models in the classroom?

Thirty-six preservice elementary teachers, enrolled in one of the two sections of a science methods course for the Fall of 2016 at a Midwestern public university were the participants in this study. The purpose of the course was to educate the preservice teachers on how to develop an understanding of how children learn science and why science education is important. Students were shown and critiqued effective approaches to teaching, instructional materials, and student assessment. This course was the first science methods course the preservice teachers had taken. A variety of instruments were used to gather the information required to answer the three research questions. These consisted of a survey comprised of five open-ended questions (See Appendix B) in which preservice teachers answered one question before the video to get their preconceptions of the practice of developing and using models. They then answered another four questions after viewing a video demonstrating students using the practice of developing and using models in the classroom to understand their preconceptions of this practice as a social endeavor. The responses to this survey were interpreted using several scales to code for preconceptions to answer the three research questions. Furthermore, a sample of six participants of the total thirty-six were interviewed using a set of questions from a previously developed protocol (See Appendix D) to elaborate on their responses to the survey. These instruments (survey, video, scales, and interviews) were all used to determine elementary preservice teachers' preconceptions about the components that make up the science and engineering practice of developing and using models.

Due to the reform in science education it is critical for elementary preservice teachers to have strong knowledge of the science and engineering practices. These science and engineering practices build on prior reforms of inquiry in science classrooms and better articulate “what successful inquiry looks like when it results in building scientific knowledge” as a “kind of Inquiry 2.0-not a replacement for inquiry” (Schwarz, Passmore, & Reiser, 2017, p.5). The science and engineering practice of developing and using models will be utilized in a reform-based science classroom. As a part of the *NGSS,* students are expected to use modeling instruction in two of the three dimensions (NGSS Lead States, 2013). The practice of developing and using models is described by the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013). The components of this practice will need to be understood by elementary preservice teachers as they described in the recent reform documents (NGSS Lead States, 2013). When Campbell et al. (2014) conducted a thorough literature review of modeling instruction over the last decade, they described the practice of developing and using models as a social endeavor. Additionally, elementary preservice teachers will need to know the critical student-student and student-teacher discourse patterns to implement this practice. McNeill et al. (2015) described a critical teacher strategy as important first steps in assessing the science practices. McNeill et al. (2015) described the practice of developing and using models as an investigating, sensemaking, and critiquing practice. In order for the practice of developing and using models to have the impact on the reformed science classroom as described in the *NGSS* (NGSS Lead States, 2013) it will be important for elementary preservice teachers to move away from a focus on the investigating practice and to include all three categories that McNeill et al. (2015) describe. “The preconceptions preservice teachers bring into the profession can interfere with what they choose to reflect on and how they reason about the effectiveness of their teaching; and preservice teachers may lack the observation skills and pedagogical content knowledge required for sophisticated analyses of teaching and learning" (Barnhart & van Es, 2015, p. 84). Finally, not only will the elementary preservice teachers need to improve their content knowledge of the practice of developing and using models, but they will also need to improve the observation skills required for sophisticated analyses of teaching and learning as described by Barnhart and van Es (2015). "The range of what we think and do is limited by what we fail to notice. And because we fail to notice *that* we fail to notice, there is little we can do to change until we notice how failing to notice shapes our thoughts and deeds" (Goleman, 1985, p. 24). The improvement in the areas of knowledge of the practice and in observation skills will help meet the new vision for science education. This study examined elementary preservice teachers' preconceptions around the components of the science and engineering practice of developing and using models as a starting point in the improvement process, to think about creating preservice teacher education for this new vision.

Findings

Research Question 1. A survey (See Appendix B) and interview (See Appendix D) were administered to determine the first research question about what preconceptions the elementary preservice teachers have about developing and using models as a science practice in the classroom. The study analyzed elementary preservice teachers' preconceptions about the science and engineering practice of developing and using models as described in the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013). The practice of developing and using models as described in the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013) were used to create a discrete scale (See Appendix E) to categorize and score preservice teachers' preconceptions about this practice. The researcher conducted this study at the beginning of a science methods course and the scores when analyzing data for this research question were mostly at the novice level, which can be explained by the timing of the study and the circumstance that this is the first science methods course for these participants. Novice scores when describing the practice of developing and using models (See Appendix E) were expected, but the absence of use for some categories of the discrete scale (See Appendix E) for preservice teachers' descriptions show some areas will need more work than others when helping the preservice teachers understand what the science and engineering practice of developing and using models is intended to help students with in the classroom. This is especially important if teachers are to use this practice in the classroom. Criteria from categories two (models are not exact), three (limitations of models), five (revising models), and six (models in engineering) were not used in the survey responses by more than 50% of the participants when elementary preservice teachers described how this practice might look in the classroom.

Elementary preservice teachers' preconceptions of this practice showed two (types of models and using models as a tool for thinking) of the six categories were used most often when describing what they knew about using this practice in the classroom. When describing models in the first survey question prior to watching the video, preservice teachers used the first category labeled "types of models" with high frequency, but were not able to identify the many types of models in this category (See Appendix E). Most participants scored at the novice (score of 0) level and described that models are a tool used in science to better visualize a topic (usually described as "hands-on") without understanding that there are many types of models. Most participants could describe this practice by identifying that students use models, but with little description of the different types of models described in the *NGSS* (diagrams, physical replicas, mathematical representations, analogies, and computer simulations) (NGSS Lead States, 2013).

Some emerging themes that the researcher noticed when coding responses for this first category was the use of the term "model." Most participants described pre-made teacher models rather than students developing and using models. This was further validated during the interviews when most participants elaborated on their responses to indicate they know this practice to mean pre-made teacher models that students use. Category four (using models as a tool for thinking) was also used with high frequency alongside category one (types of models), but most participants scored at the novice (score of 0) level as well. Elementary preservice teachers could describe the idea that models represent a disciplinary core idea that is being taught to students, but could not further describe that models represent a system (or parts of a system) that can aid in the development of questions and explanations, are used to generate data that can be used to make predictions, and to communicate ideas to others. The emerging themes described above where the term "model" was used to mean a tool the teacher pre-made for the students to use for thinking was found in this category as well. Although category one and four were identified by many participants, they were still at a novice level (score of 0) because of their limited view on what makes a model and that this practice encompasses more than using a pre-made teacher model as a tool for thinking. Furthermore, the criteria from categories two (models are not exact), three (limitations of models), five (revising models), and six (models in engineering) were not identified by more than 50% of the participants when elementary preservice teachers described how this practice might look in the classroom. If preservice teachers thought of this practice as pre-made teacher models that the students use, then these findings for these categories validate those preconceptions. Because preservice teachers have a limited view on what a model is, and can be, with the new vision for science education, the nuances of this practice in categories two, three, five, and six could not be identified. These results show the categories that will need more work with the elementary preservice teachers when understanding what this practice entails for implementation into the science classroom.

An ordinal scale (See Appendix F) to measure the sophistication of preservice teacher responses was created using the previous research conducted by Barnhart and van Es (2015) to measure the quality of response separate from the criteria of developing and using models. Their research analyzed the preservice teacher's ability to "attend to student thinking and learning and the interactions that unfold among students and between teachers and students," (attending category) "interpret student understanding from these interactions," (analyzing category) and "decide next steps based on this analysis" (responding category) (Barnhart & van Es, 2015, p. 84). The same survey responses that were evaluated using the discrete scale (See Appendix E) were analyzed and given a score for sophistication of response (low, medium, high). As expected, their level of observation skills required for sophisticated analyses of teaching will need to improve as well. The responses for this first research question were coded for sophistication of response in two categories (attending and analyzing categories). The scale used (See Appendix F) identified more than 50% of participants at a low score. Most participants were highlighting classroom events with little attention to student or teacher thinking and when highlighting classroom events, the participants made little sense of the events. The highest level for the attending category describes teachers highlighting student or teacher thinking with more of a conceptual focus and the highest score for the category analyzing describes preservice teachers consistently using evidence to support their sense-making of highlighted events.

Overall the results show that there are areas that show a greater lack of knowledge in understanding what the science and engineering practice of developing and using models is intended to help students with in the classroom. Elementary preservice teachers described the practice of developing and using models with little understanding that this practice includes the following ideas: models are not exact, models have limitations, models involve revising, and models are included in engineering. Preservice teachers had limited ideas about the practice of developing and using models, but are lacking in some areas more than others. Preservice teachers will need help improving their ideas about the practice of developing and using models and this will need to be improved alongside their observation skills (analyzing and attending) for sophisticated analysis for teaching and learning related to this practice. Coupling their understanding of the practice of developing and using models alongside their sophistication of observation will lead to the vision outlined in the recent reform. Not only do we need to focus on the newer ideas of the science reform, we must also attend to the preservice teacher and moving them on the continuum of analyzing teaching and learning.

Research Question 2. The survey (See Appendix B) and interview (See Appendix D) were also used to answer the second research question about what preconceptions the elementary preservice teachers have about critical student-student and student-teacher interactions for the success of developing and using models as a science practice in the classroom. A discrete scale (See Appendix H & J) were developed using research about what student-student (TERC, 2012b) and student-teacher communication (TERC, 2012a) patterns are involved in productive science talk. Novice scores can expected for this population of participants as indicated in the findings for the first research question, but elementary preservice teachers had higher scores (still on the lower end) when analyzing data for this second research question (this practice as a social endeavor) compared to the first research question. This indicated that they had more previous understandings about the social aspect of this practice than they did for the components of the practice as defined in the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013). An ordinal scale (See Appendix F) to measure the sophistication of preservice teacher responses was created using the previous research conducted by Barnhart and van Es (2015) to measure the quality of response separate from the criteria of developing and using models. Their research analyzed the preservice teacher's ability to "attend to student thinking and learning and the interactions that unfold among students and between teachers and students," (attending category) "interpret student understanding from these interactions," (analyzing category) and "decide next steps based on this analysis" (responding category) (Barnhart & van Es, 2015, p. 84). The responses for this second research question were coded for sophistication of response (attending and analyzing categories). The scale used (See Appendix F) identified nearly 50% of participants at a medium score for each category showing they had more previous knowledge about this practice as a social endeavor. About half of the participants were highlighting classroom events with a procedural focus and were beginning to make sense of highlighted events by using some evidence to support their claims. The highest level for the attending category describes teachers highlighting student or teacher thinking with more of a conceptual focus and the highest score for category analyzing describes preservice teachers consistently using evidence to support their sense-making of highlighted events. These findings can be explained by the interview data and show where the funds of knowledge may come from when understanding why elementary preservice teachers know more about this practice as a social endeavor than what components make up this practice as described in the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013). Three emerging themes appeared in the interview data that explain the higher scores; accumulated classroom management knowledge, previous practicum experience, and previous course work attending to student thinking.

For their preconceptions about critical student-student communication, more than 90% of preservice teachers identified criteria from categories one (use of evidence to support answers), two (critiquing their own or others' answers or ideas), and three (merging ideas to develop and explanation) (See Appendix H). The preservice teachers that identified criteria in these categories scored primarily at the novice (score of 0) and emerging (score of 1) levels. More of the participants scored at the emerging level (score of 1) than the novice level (score of 0) for these three categories. Criteria from category four (apply learning to a new or different context) was not used by much of the participants and those few that did scored in the novice level. This category will need more improvement than the others when thinking about possible goals for meaning making discussions students have when implementing this practice.

For their preconceptions about critical student-teacher communication, the student-teacher scale (See Appendix J) was used by the researcher to see what preconceptions elementary preservice teachers have about important communication patterns. All four categories were used by almost all of the participants. Category one (helping individual students share, expand, and clarify their own thinking), two (helping students listen carefully to one another), three (helping students deepen their reasoning), and four (helping students think with others) had most scores at the novice (score of 0) or emerging (score of 1) levels. The mean scores for the student-teacher discrete scale were the highest of all three mean scores calculated for this study. This indicated more understanding about teacher social practices than student social practices for the preservice teachers.

These results indicate that preservice teachers had higher levels of preconceptions about the practice of developing and using models as a social endeavor including sophistication of noticing skills than they did for the description itself as described in the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013) from the results of the first research question. Preservice teachers had a better beginning knowledge base (preconceptions) about this practice as a social endeavor than thinking about the reformed vision for this practice identified with the results from the first research question. The elementary preservice teachers were able to score higher mean scores when noticing the social aspects (student-student and student-teacher communication) of this practice because of three emerging themes that were found in the interview data; previous practicum experience observing students in the classroom or observing this behavior as a student in the classroom, previous accumulated classroom management knowledge, and the attention to student thinking in other college courses. When participants described these emerging themes in the interview data, almost all events were not linked to any science related experiences. The descriptions of these emerging themes were also not described as being isolated from one experience, but instead were accumulated experiences throughout mostly non-science related events they learned from. The varied and numerous experiences about student-student and student-teacher communication outside of their limited science pedagogy work led to higher mean scores on this topic.

Although the scores for this research question were higher than the first, the mean scores were still at a low score (ranging from mostly a score of 0.5 to one out of a total of three). Often, the practices in the *NGSS* call for interaction with other students for productive classroom discourse (NRC, 2012). Preservice teachers still need help improving their ideas about the practice of developing and using models as a social endeavor to reach higher levels of student-student and student-teacher critical communication patterns. “There is little debate about the importance of the connection between modeling and other scientific practices, especially discourse” (Campbell et al., 2014, p. 162). Improving these skills will be crucial in helping them to better develop their understanding of this practice as a social endeavor. This work will help "teachers develop their capacity at leading productive science discussions to foster students' scientific reasoning" (TERC, n.d).

Research Question 3. Research question three was answered using the survey (See Appendix B) and interview (See Appendix D) to understand preservice elementary teachers' preconceptions about critical teacher strategies to develop and use models in the classroom. The previous research question addressed teacher questioning strategies in the classroom discourse for this practice. Further teacher strategies were analyzed for this research question. An ordinal scale (See Appendix F) to measure the sophistication of preservice teacher responses was created using the previous research conducted by Barnhart and van Es (2015) to measure the quality of response separate from the criteria of developing and using models. Their research analyzed the preservice teacher's ability to "attend to student thinking and learning and the interactions that unfold among students and between teachers and students," (attending category) "interpret student understanding from these interactions," (analyzing category) and "decide next steps based on this analysis" (responding category) (Barnhart & van Es, 2015, p. 84). Responses to the survey (See Appendix B) were coded using this ordinal scale (See Appendix F) for the responding category only. As expected for beginning teachers, the preservice teachers in this study scored low on their ability to respond to student ideas when using the ordinal scale (See Appendix F) to code survey responses. This category (responding to student ideas) was lower than the attending and analyzing categories used to score responses for the previous research question analysis. When conducting interviews, participants noted little experience working in classrooms responding to students and the researcher attributes the lower scores in the category or responding to this lack of experience. A nominal scale (See Appendix K) was adapted from a study conducted by McNeill et al. (2015) identifying the practice of developing and using models in three distinct ways (investigating, sensemaking, and critiquing tools). This nominal scale (See Appendix K) was used to code responses for this research question. When the researcher reviewed survey and interview data to understand what teacher strategies elementary preservice teachers understand to be critical to this practice, the findings show these preservice teachers primarily think of this practice overall as an investigatory practice (used to investigate the natural world) rather than a practice to explain how and why phenomena occur or a practice to evaluate claims to make sense of the world around them as McNeill et al. (2015) describe in their research. McNeill et al. (2015) describe teachers using these three categories as a critical first step strategy in assessing the science and engineering practices. Using three categories (investigating, sensemaking, and critiquing) to categorize the eight science and engineering practices described in the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013) will be needed to have a framework of thinking when assessing the practices in the classroom (McNeill at al., 2015). These three categories give a broader implication of use for the eight science and engineering practices and can help educators understand their uses and in turn help them know when to use them in the classroom. McNeill et al. (2015) categorize each of the eight science and engineering practices under one of the three categories (investigating, sensemaking, critiquing), but describe the practice of developing and using models can be under all three categories. The *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013) also discuss the practice of developing and using models as an investigating, sensemaking, and critiquing practice in their definition that can be seen in the categories in Appendix E, used to evaluate the first research question. It is important for elementary preservice teachers to move away from a focus on the investigating practice focus if the practice of developing and using models is going to have the impact on the reformed science classroom as described in the *NGSS* (NGSS Lead States, 2013) to include all three categories that McNeill et al. (2015) describe.

The practice of developing and using models was referred to overall as an investigating practice more than any other type of practice described by McNeill et al. (2015) (See Appendix K). The practice of developing and using models was referred to overall as a critiquing practice the least. These results describe overall findings, but when analyzing these categories for individual survey questions, there are some important differences that present important findings. When analyzing the survey data for these three categories, responses before watching the video primarily (over two thirds of the teachers) describe the practice of developing and using models as an investigating practice. When analyzing data for these three categories in the survey response for this research question after the video was viewed, responses described this practice as mostly a sensemaking practice (about 33%) and a critiquing practice (about 45%). Because there was little use of the sensemaking and critiquing categories in the survey question before the video was viewed, the overall results show that survey responses for both questions in the survey administered together, the elementary preservice teachers described this practice as an investigating practice primarily. The use of the video, not intended as an intervention in this study, to display a successful session of the practice in the classroom helped participants reach categories (sensemaking and critiquing) they could not initially use prior to the video. Since the use of the video was not intended as an intervention, the interviews of six participants validate that without an intervention, intentional or unintentional, the participants reverted to talking about the practice as primarily an investigating practice. These findings relate to research question one. The findings for the first research question showed that elementary preservice teachers could not identify the nuances for the practice of developing and using models that take it from being an investigating practice to more of a sensemaking and critiquing practice that McNeill et al. (2015) describe. The preservice teachers need to begin thinking about this practice as a sensemaking and critiquing practice to help them identify those nuances from the discrete scale (See Appenix E) for the practice of developing and using models used for research question one. Even though they were not able to identify this practice primarily as more than an investigating practice before watching the video, they were able to identify this practice as a sensemaking and critiquing practice more with the help of the context in the video. Because the video was not intended as an intervention, the context from the video did not have a lasting impact on their overall understanding (seen in results from the interview) of this practice as an investigating, sensemaking, and critiquing practice. As preservice teachers expand their ideas of the practice of developing and using models to be more than an investigating practice as a teacher strategy, implementation of this practice will improve. Similarly, their sophistication of responding to student ideas will also be improved concurrently for elementary preservice teachers to be able to analyze teaching and learning at a high sophistication level (needed for the new vision of science education).

Concluding Remarks

This study focused on the science and engineering practice of developing and using models described in the *Framework* (NRC, 2012) and the *NGSS* (NGSS Lead States, 2013). “Because science and engineering practices are basic to science education and the change from inquiry to practices is central, this innovation for the new standards will likely be one of the most significant challenges for the successful implementation of science education standards (Bybee, 2012, p. 34). The practices are one of the three dimensions (disciplinary core ideas, science and engineering practices, and crosscutting concepts) described in the new vision for science education (NGSS Lead States, 2013). Elementary teachers will need to integrate all three dimensions to form “deeper experiences with, and understanding of, science concepts and practices” (Bybee, 2014, p. 215). To achieve this vision, elementary preservice teachers will need to understand each of the dimensions so they are able to design instruction that integrates them for student learning. Table four in chapter two describes the specific elements for elementary science learning related to the practice of developing and using models. In order to implement these in the classroom, teachers will need basic understandings about the practices themselves. This study focused on the beginning understandings for a portion (developing and using models) of one of those dimensions (science and engineering practices). The preservice teachers’ scores using the different scales for the administered survey showed overall novice knowledge of the practice of developing and using models described in the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013), but some categories were lacking more than others. Numerous studies demonstrate that elementary teachers do not have enough content knowledge to teach science (NRC, 2001). These previous studies already show deficits for the disciplinary core ideas (one of the three dimensions) with elementary teachers and this study showed their beginning understandings about the newer dimension science and engineering practices. “Teachers at all levels must understand the scientific and engineering practices, crosscutting concepts, and disciplinary core ideas; how students learn them; and the range of instructional strategies that can support their learning” (NRC, 2012, p. 256). A continuum of learning, beginning in teacher preservice education, for elementary preservice teachers will need to be constructed to achieve the vision of integrated three-dimensional learning in the classroom. Currently elementary teachers only “take a limited number of science courses and a single science methods course” (NRC, 2012, p. 259). These courses will need to include learning for each of these three dimensions, but will need to be based upon previous research to guide what to focus on due to the limited number of science courses and single science methods course taken by preservice elementary teachers.

McNeill, Katsh-Singer, and Pelletier (2015) describe a shift that educators will need to make towards prioritizing the science practices and this involves needing to move away from "science as a body of memorized facts to science as a way of thinking, talking, and acting that students need to engage in to make sense of the natural world" (p. 22). As educators make those shifts McNeill et al., (2015) have noted in their experiences the challenges educators have in thinking about the eight distinct practices and instead have grouped the practices as a way of introduction to help educators make appropriate shifts in using them in classroom instruction. The *Framework* (NRC, 2012) describes the following eight science and engineering practices: asking questions and defining problems, 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, obtaining evaluating and communicating information. McNeill et al. (2015) group the practices into three categories (investigating practices, sensemaking practices, and critiquing practices) based on how they were presented in the *Framework* (McNeill et al., 2015, p. 23). The practice of developing and using models is one of the few practices that fits into all three categories. This categorization can help preservice teacher improve their understanding about how to implement this practice. McNeill et al. (2015) indicate that in their professional development work with teachers, they found most existing curricular resources to focus on the investigating practices that lead to collecting data about the natural world and the critiquing practices are the rarest. The findings in this study mimic those same curricular resource findings by McNeill et al. (2015). In this study the findings indicate preservice teachers think of the practice of developing and using models primarily as an investigating practice. The findings show the preservice teachers are beginning to think about the practice of developing and using models as more than just an investigating practice, but will need more teacher preparation to reach all the nuances described in the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013) that make this practice a sensemaking and critiquing practice (McNeill et al., 2015) as well. The practices make up one of the dimensions of the new vision for science education and strategies like the one described by McNeill et al. (2015) will be needed to help preservice teachers in their continuum of learning about integrated three dimensional instruction. Preservice elementary teachers need to have more opportunities categorizing and thinking about the eight science and engineering practices as described by McNeill et al. (2015) to help teachers think about how and when to use them to make sense of phenomena in the classroom.

Current elementary preservice teachers are a product of the type of science education found prior to the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013) vision. While the previous efforts in science education reform did not intend science to be discrete pieces of knowledge, state standards often reduced it to just that (Pruitt, 2014). “Making sense of the world, or sense-making for short, is the fundamental goal of science and should be at the core of what happens in science classrooms” (Schwarz et al., 2017, p. 6). Research in science teaching and learning has shown that teaching content separate from how to use it used has resulted in disconnected ideas that students find difficult to use and apply (NRC, 2007). In a national survey (*Report of the 2012 National Survey of Science and Mathematics Education*) given to science teachers, explaining an idea to the whole class was a frequent activity in science classrooms (88-96 percent use this practice every week) (Banilower et al., 2013). The report (Banilower et al.,

2013) indicated that only half of teachers reported using hands-on learning once a week and that this will need to increase due to the number of science and engineering practices (NRC, 2012) that require inquiry learning from students. Banilower et al. (2013) reported that in the most recent lessons, 59 percent of high school teachers said students were completing textbook/worksheet problems with middle school (51 percent) and elementary (43 percent) following closely in those numbers. This report (Banilower et al., 2013) was conducted one year prior to the release of the *NGSS*. When interviewing participants in this study and analyzing responses in the survey used, the researcher found data corresponding to these disconnected ideas from practices in their K-12 learning experiences. Participants described learning experiences as those that come from the case presented in chapter two of Ms. Sheridan's class (Schwarz et al., 2017) where the primary focus was on learning content in isolation from the practices. The other classroom case described in chapter two (Ms. Lee's class) is focused more on "learning about" instead of "figuring out" that the shifts in the *NGSS* are moving away from (Schwarz et al., 2017). The video used in the study displayed a classroom that focused on "figuring out" and integrated the content with practices as Schwarz et al. (2017) describe. Although the video was not intended to be an intervention, the use of the video produced higher scores in some categories throughout the study. When interviewing the participants on a later date from when the survey was conducted (when they viewed the video), participants were not able to continue using these new ideas from viewing the video that yielded some higher scores in study. Prior experiences these elementary preservice teachers had that were not aligned to the shifts described in the *Framework* (NRC, 2012) (integrates the three dimensions better creating connected learning ideas for students) are deeply engrained in how these preservice teachers perceive science education to be implemented in the science classroom. Davis et al. (2006) in their review of literature about *Challenges New Science Teachers Face* reported "preservice elementary teachers found that past experience (e.g., in science classes) was the most important factor in deciding whether they would concentrate in science" (p. 614). When asking why participants responded the way they did, they referred to these experiences as their funds of knowledge to describe their preconceptions. "Ultimately, the interactions between teachers and students in individual classrooms are the determining factor in whether students learn science successfully" (NRC, 2012, p. 255). These elementary preservice teachers will need repeated intentional instruction to help them "understand the scientific and engineering practices, crosscutting concepts, and disciplinary core ideas; how students learn them; and the range of instructional strategies that can support their learning" (NRC, 2012, p. 256). Although the use of a video increased some scores, there was no lasting impact in viewing this video. Intervention will need to be repeated and intentional during learning experiences for elementary preservice teachers.

Science learning "is an inherently social and cultural process that requires mastery of specialized forms of discourse and comfort with norms of participation in the scientific community of the classroom (NRC, 2007, p. 203). Preservice teachers had relatively better beginning understandings (preconceptions) about the science and engineering practice of developing and using models as a social endeavor, than the criteria for this practice in the *Framework* (NRC, 2012), because of their previous experiences analyzing social interaction in non-science related activities. Elementary preservice teachers will be integrating science and engineering practices, disciplinary core ideas, and crosscutting concepts to achieve the new vision for science education (NRC, 2012). "Each of the eight practices, as it is introduced and elaborated and experienced in the classroom, requires that students externalize their reasoning"

(Schwarz et al., 2017, p. 311). Although the elementary preservice teachers in this study have had previous experience in analyzing non-science social interaction, authors In *Taking Science to School: Learning and Teaching Science in Grades K-8* (NRC, 2007) describe scientific discourse as different from that of everyday life and support is needed to engage in this type of discourse. The elementary preservice teachers scored higher when describing this practice as a social endeavor, but they still had novice or emerging scores (score of 0 or 1 out of a total of 3). To achieve higher levels of student-student and student-teacher communication that leads to productive science talk in the classroom, preservice teachers will need experience with scientific discourse that is different than other types of everyday communication. Talk and discursive practices are fundamental to all the science practices in the classroom and mimic that of experienced scientists and engineers (Schwarz et al., 2017). Preservice elementary teachers need to have more enhanced opportunities to expand their knowledge about scientific discourse specifically. Identifying what science specific student-student and student-teacher communication patterns are critical to the success of implementing the science and engineering practices are important to reach the science education vision described in the *Framework* (NRC, 2012). The preservice teachers in this study had stronger preconceptions about student-teacher interactions than student-student interactions to successfully implement this practice. Enhanced opportunities within both areas will be needed, but the preservice teachers in this study will need more intentional instruction about what critical student-student interactions are necessary for the implementation of this practice.

The new vision for science education includes a complex integration of three dimensions (NRC, 2012). Preservice teachers will not only need to know more about each of the three dimensions, but will need to couple this with sophisticated levels of teacher observation and analysis of student learning to reach this new vision. Research on teacher expertise shows that expert teachers are better able to distinguish between what is important and unimportant when evaluating a complex situation, they are then able to reason about what they observed, and can use this information to make better informed decisions for instruction (Berliner, 2001). Recent research in math education call these skills "teacher noticing" (Jacobs, Lamb, & Philipp, 2010). These skills will be needed as science education moves into more complex types of learning with this new vision. Preservice elementary teachers will not only need to know more about each of the three dimensions, but they will need to develop their sophistication of analysis for teaching and learning. Due to the complexity of the science and engineering practices, preservice teachers' ability to analyze and reflect on teaching and learning will need to be strengthened concurrently with reformed ideas of the practices. "The preconceptions preservice teachers bring into the profession can interfere with what they choose to reflect on and how they reason about the effectiveness of their teaching; and preservice teachers may lack the observation skills and pedagogical content knowledge required for sophisticated analyses of teaching and learning" (Barnhart & van Es, 2015, p. 84). This study used the research by Barnhart and van Es (2015) that investigated how a support influenced science preservice teachers' ability to analyze and reflect on teaching and learning. The analysis required the science preservice teacher to "attend to student thinking and learning and the interactions that unfold among students and between teachers and students," "interpret student understanding from these interactions," and "decide next steps based on this analysis" (Barnhart & van Es, 2015, p. 84). Barnhart & van Es (2015) categorized these descriptions as attending, analyzing, and responding. This study used the three categories developed by Barnhart & van Es (2015) to score preservice teacher responses in each of these three categories and the category of responding was the lowest.

This study was conducted at the beginning of a science methods course and the preservice teachers indicated little experience in a practicum setting analyzing science teaching and learning at the time of the study. When conducting interviews the researcher found higher scores on the social aspect of the practice of developing and using models because of previous work the preservice teachers had analyzing student communication that was non-science specific. Practicum experience in other content areas besides science were used frequently in the interviews and to increase analysis of teaching and learning that expands beyond student communication, more exposure to analysis of teaching and learning in a science setting will be needed. Barnhart & van Es (2015) found that an intervention of support to help science preservice teachers created more sophistication in the three categories compared to science preservice teachers that were not given the intervention. The intervention included intently helping preservice teachers understand the continuum of sophistication of analysis in teaching and learning and helping them increase in that sophistication (Barnhart & van Es, 2015). "Teachers who have opportunities to rigorously reflect on their work and connect it to research and theory during their professional preparation are better able to identify and respond to dilemmas of practice, more likely to take an analytic stance toward their work, and demonstrate a willingness to take risk and explore alternative pedagogical approaches" (Barnhart & van Es, 2015, p. 83). Increased knowledge about the practice of developing and using models will be needed, and coupling this with improvements to their attending, analyzing, and responding sophistication skills will help them use that knowledge to better analyze the teaching and learning that will be needed to implement this practice.

Implications for Teacher Education

"Instead of presenting science as "inquiry" or as "the scientific method" the focus on eight science and engineering practices will "raise the bar for elementary science teaching by directly challenging the assumption that younger students should engage primarily in the practice of making observations and describing things" (Roth, 2014, p. 364). The vision set forth by the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013) includes use of these practices by students to help them understand the disciplinary core ideas while adding another dimension of the crosscutting concepts to help students think conceptually about these ideas. Research shows it is possible to teach science in better ways than most current practices in the elementary science classroom (Duschl et al., 2007; Donovan & Bransford, 2005; Campbell et al., 2014). "But transforming elementary science teaching from its current status to the more ambitious forms of teaching needed to achieve the goals laid out in the *NGSS* (and other reform documents) will require drastic change" (Roth, 2014, p. 365).

As mentioned above, currently elementary teachers only "take a limited number of science courses and a single science methods course" (NRC, 2012, p. 259). Elementary preservice teachers focus on other content areas in their preservice teacher programs creating a dilemma of time to focus on science teaching and learning. The new vision for science education is complex. The *Framework* "expresses a vision in science education that requires students to operate at the nexus of three dimensions of learning: Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas" (NGSS Lead States, 2013, Appendix F p.1). With the current status of elementary preservice teachers taking one science methods course, the time with teachers to focus on science teaching and learning will need to be carefully designed. Roth (2014) examined research spanning a decade (2000-2012) on elementary science teaching. Roth (2014) acknowledges the new vision for science education and says, "this chapter takes the stance that the identification of a small set of research-supported, high-leverage science teaching practices could play an important role in closing the gap between what exists and what is needed" (p. 365). Roth (2014) defines high-leverage teaching practices as "teaching practices in which the proficient enactment by a teacher is likely to lead to comparatively large advances in student learning. Ball states "High leverage practices are those that, when done well, give teachers a lot of capability in their work" (as cited in Ball et al., 2009, pp.460-461---p.365). The researcher makes a case for elementary science preservice education to focus on the science and engineering practice of developing and using models when introducing preservice teachers to all eight science and engineering practices as a part of the three-dimensional education teachers will need. This study used the science and engineering practice of developing and using models as a focus, because of its' ability to "give teachers a lot of capability in their work" as Roth (2014) describes in the definition of high-leverage teaching practices (p. 365). Developing and using models is one of the eight identified practices in the science and engineering practices dimension. Similarly, in the dimension of crosscutting concepts, systems and system models is one of seven identified concepts (NGSS Lead States, 2013). The practice of developing and using models has the potential to have a significant impact on teacher preparation because this practice also utilizes several of the other seven practices and modeling has been identified in two of the three dimensions in this new vision for science education (i.e. science and engineering practices, and cross-cutting concepts) (NRC, 2012).

Science learning "is an inherently social and cultural process that requires mastery of specialized forms of discourse and comfort with norms of participation in the scientific community of the classroom (NRC, 2007, p. 203). "Each of the eight practices, as it is introduced and elaborated and experienced in the classroom, requires that students externalize their reasoning" (Schwarz et al., 2017, p. 311). Talk and discursive practices are fundamental to all the science practices in the classroom and mimic that of experienced scientists and engineers (Schwarz et al., 2017). The social aspect of the practices make this important idea a needed inclusion in elementary science preservice education. The practice of developing and using models has also been identified as a practice where discourse is needed to implement this practice. "There is little debate about the importance of the connection between modeling and other scientific practices, especially discourse" (Campbell et al., 2014, p. 162). The combination of the overlapping of other practices within the practice of developing and using models, models identified as a focus in two of the three dimensions for the new science education vision, and the use of discourse in the practice of developing and using models makes this practice a perfect candidate to use as a high-leverage teaching practice. Roth (2014) described using high-leverage teaching practices to close the "gap between what exists and what is needed" (p. 365) and the limitation of time also validates this strategy as one that will be needed as elementary science preservice education is carefully crafted. Roth (2014) describes exploring the idea in the field of "helping teachers be well-started beginners" and that as a field we would benefit "from more studies in thinking about science teaching in terms of a specific framework that is supported by limited number of related teaching strategies that are explored in depth and then implemented in student teaching, internship experiences, and the beginning years of teaching" (p. 387). It is not possible for elementary science preservice teacher to explore in depth all disciplinary core ideas, science and engineering practices, and crosscutting concepts (three dimensions) for their grade band in one science methods course. "This kind of work would represent an important first step in thinking about a continuum of science teacher learning across a career" (Roth, 2014, p. 385).

Although the practice of developing and using models would be a perfect candidate as a high-leverage teaching practice, Roth (2014) also recommends in the review of literature a specific framework needed for this high-leverage teaching practice (with a limited number of related teaching strategies). The researcher in this study identified a framework for discourse that has been identified by other researchers in works that encompass a holistic view about how to achieve the new science vision (Roth, 2014; Schwarz et al., 2017) and was used to create a scale that elicited preservice teachers' preconceptions about the practice as a social endeavor. The use of this discourse framework does not represent the only way to achieve this vision and the framework was only used because the video used this type of discourse strategies to achieve a successful session of developing and using models. As described in chapter two, the *NGSS* (NGSS Lead States, 2013) do not give the pedagogy needed by teachers to achieve what needs to be learned by students. If the discourse framework used in this study will be used as a tool to implement the practice of developing and using models, more research will need to be done to use this framework in conjunction with meeting the reformed vision of modeling instruction described in the reform documents. When studying the practice of developing and using models, a video was used by the researcher in this study (see chapter three). This video encompassed the components of this practice as described by the *Framework* (NRC, 2012) and the *NGSS* (NGSS Lead States, 2013). The video did not describe a specific framework to work from when achieving this practice and the video was published prior to the release of the new vision for science education. When Campbell et al. (2014) did a thorough review of research using the components described in the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013) to guide them, they did not reach a consensus to nominate a framework for educators to use that met this vision and their future work included investigation into this type of tool. Roth (2014) examined research in elementary science education (spanning a decade) and identified frameworks for components of the new vision for science education, but says “we do not yet have a research base that is focused enough on the effectiveness of specific teaching frameworks and strategies to nominate a set of high-leverage elementary science teaching strategies” (p. 365). Roth (2014) instead described representative studies that were part of interventions that were promising. This research study mimics those same sentiments. The purpose of this study was to use representative works that best fit the vision of this practice in reform documents, but these works have not been researched enough (with this new vision) to nominate them for implementation use. Roth (2014) describes different representative modeling frameworks, but the researcher in this study adds the idea that a framework for elementary preservice science teachers will look different than those at the secondary level. This study focused on what overall preconceptions elementary science preservice teachers have about components of the practice of developing and using models. A scale in this study used the definition below to research elementary science preservice teachers preconceptions about this practice as a whole.

> Models include diagrams, physical replicas, mathematical representations, analogies, and computer simulations. Although models do not correspond exactly to the real world, they bring certain features into focus while obscuring others. All models contain approximations and assumptions that limit the range of validity and predictive power, so it is important for students to recognize their limitations. In science, models are used to represent a system (or parts of a system) under study, to aid in the development of questions and explanations, to generate data that can be used to make predictions, and to communicate ideas to others. Students can be expected to evaluate and refine models through an iterative cycle of comparing their predictions with the real world and then adjusting them to gain insights into the phenomenon being modeled. As such, models are

based upon evidence. When new evidence is uncovered that the models can't explain, models are modified. In engineering, models may be used to analyze a system to see where or under what conditions flaws might develop, or to test possible solutions to a problem. Models can also be used to visualize and refine a design, to communicate a design's features to others, and as prototypes for testing design performance." (NGSS Lead States, 2013, Appendix F pg.6)

This definition does not direct what students and teachers need to do in order to successfully implement this practice in the classroom. This study did not focus on a specific framework that could be implemented. The purpose of this study was to identify areas of deficit in the overall idea about the practice of developing models and not the implementation of this practice in the classroom. All teachers including elementary preservice teachers will need to know the overall vision of this practice as defined in the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013) (that was given above) so that they know the end goal of this practice. In order to implement this practice in the classroom, a framework as described by Roth (2014) will need more specificity to the progression grade band for this practice for elementary science teachers. Frameworks for middle school science teachers might have some similarities to the frameworks that elementary teachers use, but should increase in sophistication (see Table 4 for progressions of the practice of developing and using models). The five pedagogies described in Figure 6 were a means to develop approaches and strategies for the *NGSS* (Campbell et al., 2014) and should be used to also promote a framework that includes differences in the purpose of modeling instruction as well. If the practice of developing and using models will be used as a high-leverage teaching practice in an elementary science pre-service teaching program, frameworks that match the new vision for science education will be needed.

Loughran (2014) conducted a literature review on science teacher learning. “It has long been recognized that student teachers’ experiences of school science have a major impact on their expectations for and approaches to learning to teach” (Loughran, 2014, p. 812). The interviews in this study mimic the same sentiments and were included in the findings in this chapter. These findings show that elementary science preservice teachers in this study used their previous experiences to describe the practice of developing and using models. Even after watching a video of a successful session of the practice used in a classroom, when asked about their preconceptions about the practice in interviews the participants reverted to using their previous experiences without the new knowledge they may have gained in the video. Richardson states “student teachers find it difficult to move beyond that which they have experiences, are comfortable with, and have been successful at as students” (as cited in Loughran, 2014, p. 812).

This study did not involve a study of implementation of the practice of developing and using models by the elementary preservice teachers, but the preconceptions teachers had of this practice were grounded in their previous experiences as students themselves. “Therefore, a great challenge for teacher education programs is to help student teachers see beyond their own experiences of teaching and find new ways to engage them in conceptualizing practice as something more than how they themselves were taught” (Loughran, 2014, p. 812). For preservice science teachers, the *Framework* (NRC, 2012) says these teachers will need experiences that integrate the three dimensions that will require them to understand in depth what the three dimensions are. Preservice teachers will need help with the following: science pedagogical content knowledge for the disciplinary core ideas in the *NGSS*, help understanding how students think in order to build experiences, experiencing the science and engineering practices for themselves in investigations in order to help students develop those practices, facilitating productive classroom discourse, and how to make the crosscutting concepts a focus when teaching the content (NRC, 2012). Russell and Martin (2014) are teacher educators reviewing literature about learning to teach science. In their review of literature, they make note that although experience will play a role in developing professional knowledge this experience alone will not be enough (Russell & Martin, 2014). The experiences will need to be integrated with the preservice teachers reflectively thinking about their actions (Russell & Martin, 2014). "Just as children in elementary, middle, and secondary schools tend to be unaware of their initial beliefs about phenomena and unaware of how personal experience shape and constrain those beliefs, so those who are learning to teach science tend to be unaware of their initial beliefs about what and how they will learn in a program of science teacher education" (p. 871). Russell and Martin (2014) in their review of literature describe studies that showed gains in teaching shifts and were linked to teachers thinking reflectively about their actions. In this study a scale (See Appendix F) was used and developed by Barnhart and van Es (2015). The scale was used to capture the quality of response that the other *NGSS* (NGSS Lead States, 2013) related scales could not capture. Barnhart and van Es (2015) conducted a study to investigate instructional shifts in science teaching by using reflection of practice as Russell and Martin (2014) describe. Barnhart and van Es (2015) found gains when helping teachers reflect on their practice by using the scale used in this study. As Roth (2014) recommended, high-leverage teaching practices that include framework with a limited number of teaching strategies for this practice will be needed to achieve the new vision for science education. The researcher in this study concludes a teacher reflection tool (similar to the one used in this study) will also be needed as one of the high-leverage teaching practices needed in achieving the new vision of science education when creating an elementary science preservice education program. This study used the scale (See

Appendix F) developed by Barnhart and van Es (2015) not in the manner of implementation. Careful considerations (aligned to meet new vision goal and appropriate for elementary science preservice teachers) will need to be made by the teacher educator when choosing the appropriate tool that Russell and Martin (2014) describe will be needed to make instructional shifts when integrated with the experiences in the program.

In summary, elementary preservice education programs will need to address and introduce teachers to the shifts represented in the *NGSS* (NGSS Lead States, 2013). An understanding of each of the dimensions will be needed and the *Framework* (NRC, 2012) can be used to help teachers in these programs. In chapter two, a study was introduced that used the *Framework* (NRC, 2012) to help elementary preservice teachers make shifts in their teaching, Ricketts (2014) found that simply reading the *Framework* (NRC, 2012) did not achieve the goal of making significant instructional shifts. Ricketts (2014) did conclude that the *Framework* (NRC, 2012) may help preservice teachers begin to develop these understandings. This study conducted by the researcher exposed the preconceptions of the science and engineering practice of developing and using models for a population of elementary science preservice teachers. This knowledge can be used to strengthen greater areas of deficiencies for this practice. Experiences will be needed to help elementary preservice teachers make the instructional shifts (Russell & Martin, 2014). The *Framework* (NRC, 2012) states preservice teachers will need experiences that integrate the three dimensions that will require them to understand in depth what the three dimensions are. Roth (2014) in her review of literature about elementary science teaching regarding the new vision for science education makes some recommendations about the experiences developed for preservice education programs. Roth (2014) states using high-leverage teaching practices will be necessary due to the time constraints with current elementary preservice education programs. These high-leverage teaching practices should give teachers more beginning capability for their work. Roth (2014) also recommends these high-leverage teaching practices should have frameworks with limited teaching strategies. The researcher in this study recommends using the practice of developing and using models to include in the experiences the *Framework* (NRC, 2012) describes (three dimensional) that preservice teachers should have in their preservice programs. This study conducted be the researcher has exposed which parts of the practice will need more development with a population of elementary science preservice teachers. The practice of developing and using models is a high-leverage practice because of the use of discourse to implement it, the overlapping of other practices in the development and use of models, and models represented in two of the overall three dimensions of the new vision for science education. This study did not examine the implementation of the practice of developing and using models and frameworks (including discourse) that are specific to the goals for the elementary grade band using the specification in the *NGSS* (NGSS Lead States, 2013) will be needed when using this practice as a high-leverage teaching practice in an elementary science preservice education program as Roth (2014) describes.

Loughran (2014) in his review of literature about science teacher learning describes research that exposes how preservice teachers hold tight to the previous experiences they have used and have also been successful with as students themselves, and the challenge for teacher education programs will be to help these teachers move beyond how and what they were taught. Building on the idea that it is difficult for preservice teachers to move beyond how and what they were taught, Russell and Martin (2014) in their review of literature about learning to teach science state that experiences will not be enough to create instructional shifts. They (Russell & Martin, 2014) add that these experiences will need to be integrated with support by the teacher educator to help the preservice teachers reflect thoughtfully about their actions. The researcher in this study has concluded that another high-leverage teaching practice will be a reflection tool as Russell and Martin (2014) have described. This tool will need to be chosen carefully so that it aids in achieving the new vision for science education and is appropriate for elementary science preservice teachers. The current state of science teacher preparation will need reform to meet the challenges that come with the *NGSS* (NGSS Lead States, 2013) and the researcher in this study has summarized what elementary service teacher preparation programs will need to meet these challenges based on the findings of this study.

Future Research

The future research found in this section center around three areas; modeling instruction in teacher education programs, modeling instruction with in-service teachers, and modeling instruction in relation to student learning. As noted in the previous section regarding implications for teacher education, frameworks that elementary preservice teachers can use in their setting for implementation of the practice of developing and using models will be needed. In this study interviews were conducted with a sample of the elementary science preservice teachers. When asked about what support the teachers would need to implement this practice in the classroom, one teacher noted the need to have a framework to implement the practice with students. This participant described this framework that would be needed and referenced the Biological Sciences Curriculum Study 5E model (engage, explore, explain, elaborate, evaluate) (Bybee et al., 2006) and how this framework provides a flow of steps that helped her implement lessons in the classroom. Roth (2014) describes the need for frameworks as well in her review of literature to achieve the new science education vision and makes note that the frameworks she promotes do not meet the new vision and that these should be used to show components that showed gains.

A seminal piece of literature used in this study has been the review of literature of modeling instruction conducted by Campbell et al. (2014). “Collectively, in this research, we sought to more generally understand the pedagogical functions that modeling has played in science instruction and research” (Campbell et al., 2014, p. 173). As noted previously, this study did not investigate implementation of modeling instruction and only sought to investigate the preconceptions teachers hold about the practice of developing and using models as described in the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013). “Our aim was also to support the development of our modeling framework in coordination with discursive acts and technology” (Campbell et al., 2014, p. 173). The review of literature conducted by Campbell et al. (2014) will be important when creating frameworks for modeling instruction to achieve this new vision for science education.

> We believe that this emerging framework can provide teachers with a well-defined understanding of modeling pedagogy to help students developing and using authentic scientific practices. As a result of this review, we are better positioned to base our framework on the rich body of literature to support what we think are essential components of meaningful modeling instruction (i.e. pedagogical functions of modeling, modeling pedagogies, discursive acts, and technology). This work can also inform other researchers of insight into how their research sits among others’ work, particularly within the focus of modeling pedagogies we shared in this review. (Cambell et al., 2014, p. 173)

Campbell et al. (2014) do not mention a framework that is specific to the goals in the progression of this practice described in the *NGSS* (NGSS Lead States, 2013). Table four describes these progressions. The framework that Campbell et al. (2014) describe needs to include the need for this practice of developing and using models to increase in sophistication as table four indicates.

More research will need to be done regarding a discourse framework that could be used in conjunction with meeting the reformed vision of modeling instruction described in the reform documents (NRC, 2012; NGSS Lead States, 2013). The researcher in this study described in the section about preservice education programs the need for a high-leverage teaching practice to include a discourse framework. The description of their (Campbell et al., 2014) future work on a framework also includes discursive acts, but because discursive acts are central to the eight science and engineering practices (Schwarz et al., 2017) a framework that is more inclusive of other practices other than developing and using models will be needed for elementary science preservice teachers in their education programs. This type of inclusive framework for discourse is needed because the purpose of a high-leverage teaching practice as Roth (2014) describes it is to help give teachers more capability in their work. If their future work will include all eight science and engineering practices, a discourse framework that helps teachers use the framework to meet each of the practices will be needed.

More research will also need to be done on a reflection tool that could be used in teacher preparation programs that integrate experiences with the preservice teachers reflectively thinking about their actions as Russell & Martin (2014) describe. This was another high-leverage teaching practice that the researcher recommended in the previous section about elementary science preservice teacher programs. The scale (See Appendix F) used in this study was developed by Barnhart and Es (2015) to be used in a reflection study. More research would need to be done about the framework that Barnhart and van Es (2015) used when thinking about the new vision for science education and research about elementary science preservice educators specifically as they have different challenges as noted in the review of literature in this study.

Finally, future research about teacher education and modeling instruction will be needed to investigate how to change modeling instruction that creates lasting transformation with the elementary science preservice education students will be needed. This can be done by creating a pre- and post-study that investigates changing views of modeling instruction that meets the vision in the *NGSS* (NGSS Lead States, 2013).

The researcher in this study investigated elementary science preservice educators' preconceptions of the practice of developing and using models. The following future research studies will be needed to explore more about achieving the new vision for science education and, in particular, modeling instruction with in-service teachers. The current status of how often modeling instruction is used in classrooms will be important in measuring implementation efforts of the new vision for science education that includes the practice of developing and using models in every grade band in differing degrees of sophistication (see Table 4). This current status will need to include the types of modeling instruction that are specific to the vision of the practice of developing and using models described in recent reform documents (NRC, 2012; NGSS Lead States, 2013). The researcher in this study included the specificity from these reform documents and this showed findings that will need more development than others. The participants in this study described the practice of developing and using models in relation to their previous experiences as a student and comparison of these experiences to the current status in classrooms of this practice would elicit any differences to help progress the field on what progress has been made over the years. This current status will help as a beginning point for in-service teachers and the professional learning needed to implement the practice of developing and using models in the classroom. In conjunction with this current status of how often modeling instruction is used in science classrooms, a study about practicing teachers and their preconceptions about this practice will be needed to create that beginning point for professional learning needed.

The same frameworks described for preservice teachers will be needed for in-service teachers, keeping in mind that sophistication of the practice increases when moving across grade bands (See Table 4) will need to be included in the frameworks so that we are meeting the vision. Different methods or frameworks to achieve the vision of the science and engineering practice of developing and using models in the *NGSS* (NGSS Lead States, 2013) can also be an area of future research. These different methods that are investigated could allow for more choice by teachers implementing the practice to meet the demands of their teaching environments.

Finally, more research about how to make shifts that are lasting with modeling instruction and in-service teachers will be needed as well. Pre- and post studies to investigate how to include professional learning that creates lasting change with in-service teachers is needed. In-service teachers have different challenges than those described for preservice teachers in the literature review provided for this study.

The last category for future research includes modeling instruction in relation to student learning. As the field begins creating frameworks and professional learning that meet the vision of the science and engineering practice of developing and using models, the impact of modeling instruction on student learning will need to be conducted. As Roth (2014) mentioned in her review of literature, "we do not yet have a research base that is focused enough on the effectiveness of specific teaching frameworks and strategies to nominate a set of high-leverage elementary science teaching strategies" (p. 365). When the field does have a set of framework and strategies to nominate for use by educators to use for modeling instruction that aligns with the new vision for science education, an investigation on the impact of those strategies or frameworks on student learning can be conducted. This research in turn will help the field refine the modeling instruction framework or strategies used by educators. It is not enough to use frameworks that align with the new vision, but these frameworks need to show they have positive impact on student learning. These studies will need to include methods of measurement that are in line with the vision of what is desired for scientific literacy in students that is laid out in the *Framework* (NRC, 2012). One need the *Framework* (NRC, 2012) describes to reach this vision for scientific literacy by students if for the science and engineering practices to help students make sense of phenomena and work in tandem with the crosscutting concepts to help students understand disciplinary core ideas.

This study provides some useful insight into the professional learning development of elementary science preservice teachers to meet the vision for science education described in the recent reform document the *Framework* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013). The results emphasize the components of the overall idea of the science and engineering practice of developing and using models described in the reform documents (NRC, 2012; NGSS Lead States, 2013) that will need more development. The focus this study on the science and engineering practice of developing and using models is situated in the overall goal of the *NGSS* (NGSS Lead States, 2013) to focus on three dimensions: disciplinary core ideas (science content), science and engineering practices (application of science), and cross cutting concepts (ideas that connect the disciplines in science) that are intended to be integrated for student learning. This future research will provide more information for future studies so that the education field can continue to learn more about how to provide professional learning development for the practice of developing and using models.

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Appendices

Appendix A: Demographic Questionnaire

Name:_________________________________

Age :__________________________________

Gender :_______________________________

Academic Classification :

How many college level science courses have you taken?

Please list the names of the courses you have taken (I.E. Biology, Anatomy and Physiology, etc.)

Appendix B: Participant Survey

Prior to watching the video, please answer the following question:

What are your perceptions of how the practice of developing and using models should be applied in the classroom?

In the video the students were asked to:

1. Develop a model of the eye and its ability to focus images all the time
2. Use knowledge from previous lessons about lenses and wave phenomena
3. Work in groups to develop and use their model

Following the video, please write your answers to the questions in the space provided.

1. What communication patterns between students do you think led to groups successfully developing and using their model?

2. What communication patterns between the students and teacher do you think led to the groups successfully developing and using their model?

3. Can you identify three other factors that may have led to groups successfully developing and using their model?

4. What three things would you do if you were the teacher at the end of the video to continue to help students develop and use their model?

Appendix C: Preservice Teacher Consent Form

INTRODUCTION
The Department of Curriculum and Teaching at the University of Kansas supports the practice of protection for human subjects participating in research. The following information is provided for you to decide whether you wish to participate in the present study. You may refuse to sign this form and not participate in this study. You should be aware that even if you agree to participate, you are free to withdraw at any time. If you do withdraw from this study, it will not affect your relationship with this unit, the services it may provide to you, or the University of Kansas.

PURPOSE OF THE STUDY
The aim of this study is to determine how preservice teachers' recognize discourse patterns in the science practice of developing and using models in the elementary science classroom setting. The preservice teachers' ability to recognize successful student-student and student-teacher discourse patterns will be examined. The other purpose is to determine if there are any patterns of previous science background information that may have led to successful recognition of integral patterns in the science practice of developing and using models in the elementary science classroom setting.

PROCEDURES
If I agree to participate in this study, I allow the researchers:
To analyze my written reflections about a video of students developing and using a model and responding to the video by answering 5 questions regarding successful discourse patterns between the students in groups and the teacher's interaction with the groups of students. **The video will take approximately 10 minutes to watch, while the written responses will also take about 5 to 10 minutes to respond.**

If selected, to interview **and record** me **on a video recorder (the iPad)**, in an individual setting, about what I have noticed about the patterns of discourse in the video and my previous science experiences that could have contributed to my pattern recognition. The recorded interviews will occur (if notified and selected by the researcher) once and will take 10 to 15 minutes. **I am aware that if I do not want to be recorded, I can ask for the recording to be stopped at any time during the individual interview.**

RISKS and BENEFITS
I understand that this method of data collection is not expected to interfere with my teaching or learning. No risks are anticipated for participating in this study.
Participating in this study may help me to think about instructional practices, specifically my own science pedagogy thinking, as well as children's thinking in relation to inquiry based scientific modeling. **I understand that it is not mandatory for me to participate in this study. Although, the activities (analyzing discourse by watching the videos) are conducted in C&T 349, my reflections will not affect my grade. I understand that these activities for the study are part of the course requirements, but if I chose not to participate, my reflections will not be used in the research study. As part of C&T 349, I will be required to participate in video analysis, but I have the option of not being tape recorded if selected for an interview by the researcher. If I chose not to be recorded, it will not affect my grade for the course.** If I am chosen and consent to participate in the interview portion of the study I will receive a twenty dollar ($20) restaurant gift card in compensation for my time and efforts in relation to this study. Investigators may ask for my social security number in order to comply with federal and state tax and accounting regulations.

PARTICIPANT CONFIDENTIALITY
My name will not be associated with any publication or presentation with the information collected about me or with the research findings from this study. Instead, the researcher will use a pseudonym. Any identifiable information about me (e.g., demographic questionnaire, response sheet answers) will not be shared unless (a) it is required by law or university policy, or (b) I give written permission. Data will be stored in a locked filing cabinet and a password-protected computer. **Only the researcher and Dr. Douglas Huffman, the researcher's advisor,** will have access to the data. Data will be kept for **three years** to ensure thorough analysis and then destroyed**. Lizette Burks will be responsible for transcribing all of the interviews.**

REFUSAL TO SIGN CONSENT AND AUTHORIZATION
You are not required to sign this Consent and Authorization form and you may refuse to do so without affecting your right to any services you are receiving or may receive from the University of Kansas or to participate in any programs or events of the University of Kansas. However, if you refuse to sign, you cannot participate in this study.

CANCELLING THIS CONSENT AND AUTHORIZATION

You may withdraw your consent to participate in this study at any time. You also have the right to cancel your permission to use and disclose further information collected about you, in writing, at any time, by sending your written request to: Lizette Burks, 1122 W. Campus Rd. Joseph R. Pearson Hall, University of Kansas, Lawrence, Kansas 66045.

QUESTIONS ABOUT PARTICIPATION

Questions about procedures should be directed to the researcher listed at the end of this consent form.

PARTICIPANT CERTIFICATION:

I have read this Consent and Authorization form. I have had the opportunity to ask and **to** receive answers to any questions that I had regarding the study. I understand that if I have any additional questions about my rights as a research participant, I may call (785) 864-7429, write to the Human Subjects Committee Lawrence Campus (HSCL), University of Kansas, 2385 Irving Hill Road, Lawrence, Kansas 66045-7568, or email irb@ku.edu.

I agree to take part in this study as a research participant. By my signature I affirm that I am at least 18 years old and that I have received a copy of this Consent and Authorization form

____

Print Name

____ ______________________

Signature Date

Researcher Contact Information:	Faculty Advisor Information:
Lizette Burks	Dr. Douglas Huffman
Principle Investigator	Professor
Joseph R. Pearson Hall, Room 321	Joseph R. Pearson Hall, Room 347
1122 W. Campus Road	1122 W. Campus Road
University of Kansas	University of Kansas
Lawrence, KS 66045	Lawrence, KS 66045
785-840-7372	785-864-9675
l232b885@ku.edu	huffman@ku.edu

Audio-Visual Permission
If I give permission, I may be video-recorded for research and educational purposes. "Research and educational purposes" includes sharing the audio tapes during research presentations, in undergraduate and graduate classes, and professional workshops to demonstrate exemplary instructional practices.

Please initial below each purpose for which you give permission:

_______ I give permission to be video recorded during an individual interview if notified and selected by the researcher at KU to discuss what I have recognized for patterns of discourse in the video and what science background may have contributed to my responses
_______ I give permission for my video-recordings, which demonstrate recognition of discourse patterns in model based scientific inquiry and my science background that could contribute to my responses, to be used for research and educational purposes.

_______ At any time, I can ask not to be recorded or to have the tape recorder turned off during individual interview if notified and selected for the interview by the researcher.
_______ Permission denied **to be recorded**.

My signature below indicates that I have read and understand the uses of audio-visual recordings information pertaining to my participation in this study. My questions have been answered to my satisfaction. I have been given a copy of this form.

____

Print Name

____

Signature

Appendix D: Participant Interview Protocol

I. Background Information

1. What is your assigned identification number for this study?

2. How would you describe your comfort level teaching science at the elementary level?

   Probe: Is there a scale system that you could use to describe your comfort level? Describe in detail your level and why you are choosing this level.

II. Familiarity with the *NGSS*

1. Can you describe the three dimensions that make up the new science education standards?

   Probe: How do you perceive the three dimensions working together?
   Probe: What else do you know about the newer standards?
   Probe: Where have you learned or heard about the newer standards?

III. Modeling Perspectives

One of the dimensions of the new science standards, developing and using models, is a newly defined practice. **Note:** In the larger group you observed a video depicting successful use of the practice of developing and using models. The next few questions will ask you to expand on your responses to the initial survey you completed immediately after watching the video.

1. What are your perceptions of how the practice of developing and using models should be applied or used in the classroom?

   Probe: This was the first question in the survey, you can refer to your answer.
   Probe: Can you give an example of a time where you developed and used a model in a previous science classroom experience (as a student or an educator)?
   Probe: What do you perceive as key components to the dimension of developing and using models (stages or steps)?

2. Can you expand on your response to the question, "what communication patterns between students do you think led to groups successfully developing and using their model?"

   Probe: What were students communicating amongst themselves that helped them be successful?
   Probe: What communication patterns would you want to see amongst your own students if they were developing and using a model in your classroom (ex. Developing a model of the water cycle and then use it to communicate to others to make sense of the phenomena)?

3. Can you expand on your response to the question, "what communication patterns between the students and teacher do you think led to the groups successfully developing and using their model?"

   Probe: What was the teacher doing that helped the students be

successful?
Probe: If the teacher was not present during the video, what missing essential communication from the teacher would have stopped the students from being successful?

4. Can you expand on your response to the question, “can you identify three other factors that may have led to groups successfully developing and using their model?”
   Probe: We talked about student-student, and teacher-student communication during the video. Are there any other areas you think were critical in the students developing and using their model?
   Probe: You gave an example of when you’ve developed/used a model previously in this interview. What else would be critical to you developing and using your model?

5. Can you expand on your response to the question, “what three things would you do if you were the teacher at the end of the video to continue to help students develop and use their model?”
   Probe: At the end of the video students presented their models. Do you think their models were complete?
   Probe: What other activities could help them continue developing and using their models?

6. In order to apply the practice of developing and using models in the classroom, what training do you feel you need as a preservice teacher?
   Probe: If you were going to have students develop and use a model like the example of the standard (5-ESS2-1) given here, what help do you need as a teacher to have your students do this? (copy of performance expectation 5-ESS2-1 given to participant)

Appendix E: Discrete Scale Developing and Using Models

Discrete Scale Developing and Using Models	
Survey Question:	What are your perceptions of how the practice of developing and using models should be applied in the classroom?
Category 1: Types of Models	
A Score of 0 (Novice)	Describes models using no specific descriptions of the different types of models and only describes models generally as a tool used in science to better visualize and understand a phenomenon under investigation or develop a possible solution to a design problem
A Score of 1 (Emerging)	Describes some specific descriptions of the types of models using general terms to indicate there are different types (different forms, different tools, etc.) used to better visualize and understand a phenomenon under investigation or develop a possible solution to a design problem
A Score of 2 (Transitional)	Describes models to include one or two of the following types of models used to better visualize and understand a phenomenon under investigation or develop a possible solution to a design problem: diagrams, physical replicas (hands on), mathematical representations, analogies, and computer simulations
A Score of 3 (Skilled)	Describes models to include two or more of the following used to better visualize and understand a phenomenon under investigation or develop a possible solution to a design problem: diagrams, physical replicas, mathematical representations, analogies, and computer simulations
Category 2: Models Are Not Exact	
A Score of 0 (Novice)	Describes models that use real world connections without any language that shows understanding that models are analogous to the real world
A Score of 1 (Emerging)	Describes models using language that shows understanding that models are analogous to the real world, but does not include language that shows understanding that models are not corresponding exactly to the real world
A Score of 2 (Transitional)	Describes models as not corresponding exactly to the real world, but does not include that they can bring in certain features into focus while obscuring others

A Score of 3 (Skilled)	Describes models as not corresponding exactly to the real world, but they bring in certain features into focus while obscuring others
Category 3: Limitations of Models	
A Score of 0 (Novice)	Describes models in terms of its' features with no understanding that it contains some approximations of assumptions that limit the range of validity and predictive power
A Score of 1 (Emerging)	Describes models as containing approximations of assumptions, but does not conclude that this limits the range of validity and predictive power of the model
A Score of 2 (Transitional)	Describes models as containing approximations of assumptions that limit the range of validity, but does not describe the limit in predictive power
A Score of 3 (Skilled)	Describes models as containing approximations of assumptions that limit the range of validity and predictive power
Category 4: Using Models as a Tool for Thinking	
A Score of 0 (Novice)	Describes models as representing a disciplinary core idea that is being taught to students with no language to indicate its' use to aid in the development of questions and explanations, to generate data that can be used to make predictions, or to communicate ideas to others
A Score of 1 (Emerging)	Describes models as representing a system (or parts of a system) with no language to indicate its' use to aid in the development of questions and explanations, to generate data that can be used to make predictions, or to communicate ideas to others
A Score of 2 (Transitional)	Describes models as representing a system (or parts of a system) with some general language to indicate its' use to aid in the development of questions and explanations, to generate data that can be used to make predictions, or to communicate ideas to others
A Score of 3 (Skilled)	Describes models as representing a system (or parts of a system) under study to aid in the development of questions and explanations, to generate data that can be used to make predictions, and to communicate ideas to others
Category 5: Revising Models	
A Score of 0 (Novice)	Describes the evaluation of relationships in models with prior or new knowledge, but no use of language to indicate the idea that models can be revised with new evidence

A Score of 1 (Emerging)	Describes some evaluating and refining of models through an iterative cycle, but not comparing their predictions to the real world and then adjusting them to gain insights into the phenomenon being modeled
A Score of 2 (Transitional)	Describes evaluating and refining models through an iterative cycle of comparing their predictions to the real world and then adjusting them to gain insights into the phenomenon being modeled (does not include modifications are based on new evidence)
A Score of 3 (Skilled)	Describes evaluating and refining models through an iterative cycle of comparing their predictions to the real world and then adjusting them to gain insights into the phenomenon being modeled (modifications based on new evidence)
Category 6: Models in Engineering	
A Score of 0 (Novice)	Identifies models are used in engineering, but does not use any specific language to describe how this can be done
A Score of 1 (Emerging)	Partially identifies one of the following: models may be used to analyze a system to see where or under what conditions flaws might develop, or to test possible solutions to a problem; models can also be used to visualize and refine a design, to communicate a design's features to others, and as prototypes for testing design performance.
A Score of 2 (Transitional)	Identifies one of the following: models may be used to analyze a system to see where or under what conditions flaws might develop, or to test possible solutions to a problem; models can also be used to visualize and refine a design, to communicate a design's features to others, and as prototypes for testing design performance.
A Score of 3 (Skilled)	Identifies two or more of the following: models may be used to analyze a system to see where or under what conditions flaws might develop, or to test possible solutions to a problem; models can also be used to visualize and refine a design, to communicate a design's features to others, and as prototypes for testing design performance.

Appendix F: Ordinal Scale Sophistication of Preservice Teacher Responses

Ordinal Scale Sophistication of Preservice Teacher Responses			
Skill	**Low**	**Medium**	**High**
Attending	Highlights classroom events, teacher behavior, student behavior, and or classroom climate. Little to no attention to student or teacher thinking.	Highlights student or teacher thinking with more of a procedural focus (student collection of data from a scientific inquiry or teacher use of pedagogy strategies).	Highlights student or teacher thinking with more of a conceptual focus (student collection, analysis, and interpretation of data from a scientific inquiry/teacher analyzing and understanding of appropriate use of pedagogy strategies.
Analyzing	Little or no sense-making of highlighted events; mostly descriptions. No elaboration of analysis of interactions and classroom events; little or no use of evidence to support claims.	Begins to make sense of highlighted events. Some use of evidence to support claims.	Consistently makes sense of highlighted events. Consistent use of evidence to support claims.
Responding	Does not identify or describe acting on specific student ideas as topics of discussion; offers disconnected or vague ideas of wat to do differently next time.	Identifies and describes acting on a specific student idea during the lesson; offers ideas about what to do differently next time.	Identifies and describes acting on a specific student idea during the lesson and offers specific ideas of what to do differently next time in response to evidence; makes logical connections between teaching and learning.

Appendix G: TERC Inquiry Project Reflection Tool

Talk Science in the Inquiry Project

Reflection Tool
Are Students Progressing Toward Scientific Understanding?

Step back and look at the quality of the "Make Meaning" discussions. As your students work together to construct an answer to the investigation question, what meanings are they constructing? Are they reasoning scientifically?

Reflection Questions	Notes, Examples and Next Steps
Did students propose answers? Did their answers address the main discussion question? (Typically the discussion question is the investigation question.)	
Did students use evidence to support their answers? Observations and/or measurements from their investigations? Prior experience?	
Did they critique their own and others' answers? Agree, disagree, build on each other's answers? Distinguish evidence from opinion? Identify questions? Ask if we have enough evidence?	
Did students merge their own and other's ideas to develop an explanation? Use relevant scientific ideas from this or prior lessons? Sort through ideas to see which are consistent with their observations? Refer to drawings or diagrams to explain their ideas?	

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Appendix H: Discrete Scale Student-Student Communication

DISCRETE SCALE Student- Student Communication	
Survey Question:	What communication patterns between students do you think led to groups successfully developing and using their model?
Category 1: Use of Evidence to Support Answers	
A Score of 0 (Novice)	Describes students proposing answers/model to the main discussion question or discussing general evidence
A Score of 1 (Emerging)	Describes students using general evidence in their discussions to support their proposed answers/model to the main discussion question
A Score of 2 (Transitional)	Describes students using some evidence (observations, measurements, prior experience), to support their proposed answers/model to the main discussion question
A Score of 3 (Skilled)	Describes students using evidence (observations, measurements, prior experience) to support their proposed answers/model to the main discussion question
Category 2: Critiquing Their Own and Others' Answers/Ideas	
A Score of 0 (Novice)	Describes students generally having discussions in a group, but no distinctions made to show there were differences in answers/ideas of the students
A Score of 1 (Emerging)	Describes students generally discussing answers/ideas of their own and others, but does not include specific descriptions of students critiquing those answers/ideas (agree/disagree, build on each other's answers, distinguish evidence from opinion, identify questions, ask if we have enough evidence)
A Score of 2 (Transitional)	Describes students generally discussing answers/ideas of their own and others, but includes little description of students critiquing those answers/ideas (agree/disagree, build on each other's answers, distinguish evidence from opinion, identify questions, ask if we have enough evidence)

A Score of 3 (Skilled)	Describes students critiquing their own and others' answers/ideas (students agree/disagree, build on each other's answers, distinguish evidence from opinion, identify questions, ask if we have enough evidence)
Category 3: Merging Ideas to Develop an Explanation	
A Score of 0 (Novice)	Describes students developing an explanation or generally sharing their understandings, but does not include any specific language to describe how students merged their ideas to develop an explanation
A Score of 1 (Emerging)	Describes students discussing their own understandings with each other to develop an explanation, but does not use specific language to describe students merging their ideas to develop an explanation (students use relevant scientific ideas from this or prior lessons, sort through ideas to see which are consistent with their observations, refer to drawings or diagrams to explain their ideas)
A Score of 2 (Transitional)	Describes students merging their own and other's ideas to develop an explanation, but provides little evidence to show how students were able to do this (students use relevant scientific ideas from this or prior lessons, sort through ideas to see which are consistent with their observations, refer to drawings or diagrams to explain their ideas)
A Score of 3 (Skilled)	Describes students merging their own and other's ideas to develop an explanation (students use relevant scientific ideas from this or prior lessons, sort through ideas to see which are consistent with their observations, refer to drawings or diagrams to explain their ideas)
Category 4: Apply Learning to a New or Different Context	
A Score of 0 (Novice)	Describes students generally discussing their learning that may include new or different contexts (procedural description), but does not provide more description of its significance that shows students are applying their learning to a new or different context
A Score of 1 (Emerging)	Describes students applied their learning to a new or different context with no description of the application (explain similar situations from the classroom or everyday life)
A Score of 2 (Transitional)	Describes students applying their learning to a new or different context with little description of the application (explain similar situations from the classroom or everyday life)
A Score of 3 (Skilled)	Describes students applying their learning to a new or different context (explain similar situations from the classroom or everyday life)

Appendix I: TERC Inquiry Project Checklist

Checklist

Talk Science in the Inquiry Project

Goals for Productive Discussions and Nine Talk Moves

Goal One Help Individual Students Share, Expand and Clarify Their Own Thinking	Notes/Frequency of Use
☐ 1. **Time to Think** - Partner Talk - Writing as Think Time - Wait Time	
☐ 2. **Say More:** "Can you say more about that?" "What do you mean by that?" "Can you give an example?"	
☐ 3. **So, Are You Saying…?:** "So, let me see if I've got what you're saying. Are you saying…?" (always leaving space for the original student to agree or disagree and say more)	
Goal Two Help Students Listen Carefully to One Another	
☐ 4. **Who Can Rephrase or Repeat?** "Who can repeat what Javon just said or put it into their own words?" (After a partner talk) "What did your partner say?"	
Goal Three Help Students Deepen Their Reasoning	
☐ 5. **Asking for Evidence or Reasoning** "Why do you think that?" "What's your evidence?" "How did you arrive at that conclusion?"	
☐ 6. **Challenge or Counterexample** "Does it always work that way?" "How does that idea square with Sonia's example?" "What if it had been a copper cube instead?	
Goal Four Help Students Think With Others	
☐ 7. **Agree/Disagree and Why?** "Do you agree/disagree? (And why?)" "What do people think about what Ian said?" "Does anyone want to respond to that idea?"	
☐ 8. **Add On:** "Who can add onto the idea that Jamal is building?" "Can anyone take that suggestion and push it a little further?"	
☐ 9. **Explaining What Someone Else Means** "Who can explain what Aisha means when she says that?" "Who thinks they could explain why Simon came up with that answer?" "Why do you think he said that?"	

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The Inquiry Project: Bridging Research& Practice Supported by the National Science Foundation Adapted from: Chapin, S. O'Connor, C., & Anderson, N., (2009). *Classroom Discussions: Using Math Talk to Help Students Learn, Grades 1-6. Sausalito, CA: Math Solutions Publication*

Appendix J: Discrete Scale: Student-Teacher Communication

DISCRETE SCALE **Student-Teacher Communication**	
Survey Question:	What communication patterns between the students and teacher do you think led to the groups successfully developing and using their model?
Category 1: Helping Individual Students Share, Expand, and Clarify Their Own Thinking	
A Score of 0 (Novice)	Describes the teacher asking students general questions or providing support with no specific descriptions of the types of questions or support
A Score of 1 (Emerging)	Describes the teacher asking students questions that fall under one of the following categories: share, expand, or clarify using general descriptions
A Score of 2 (Transitional)	Describes the teacher helping students to share, expand, and clarify their own thinking using some descriptions of strategies like the following: o Giving time to think (partner talk, writing as think time, wait time) o Asking students to say more (elaborate, clarify, and ask for examples) o Asking students to validate teacher summary of their thinking (giving space for the original student to agree/disagree or say more)
A Score of 3 (Skilled)	Describes the teacher helping students to share, expand, and clarify their own thinking using descriptions of strategies like the following: o Giving time to think (partner talk, writing as think time, wait time) o Asking students to say more (elaborate, clarify, and ask for examples) o Asking students to validate teacher summary of their thinking (giving space for the original student to agree/disagree or say more)
Category 2: Helping Students Listen Carefully to One Another	

A Score of 0 (Novice)	Describes the teacher generally monitoring students, but not listening or helping students to listen carefully to each other
A Score of 1 (Emerging)	Describes the teacher generally listening to students, but not specifically helping students to listen carefully to each other
A Score of 2 (Transitional)	Describes the teacher helping students to listen carefully to one another using some descriptions of strategies like the following: o Asking students to rephrase or repeat (after partner talk, placing it into their own words)
A Score of 3 (Skilled)	Describes the teacher helping students to listen carefully to one another using descriptions of strategies like the following: o Asking students to rephrase or repeat (after partner talk, placing it into their own words)
Category 3: Helping Students Deepen Their Reasoning	
A Score of 0 (Novice)	Describes the teacher asking or wanting students to explore or deepen their reasoning and no description of the teacher helping students do this
A Score of 1 (Emerging)	Describes the teacher asking or wanting students to explore or deepen their reasoning with some general description of the teacher helping students do this
A Score of 2 (Transitional)	Describes the teacher helping students deepen their reasoning using some descriptions of strategies like the following: o Asking for evidence or reasoning (what is their thinking or evidence, how did they arrive at conclusions) o Challenging or asking for counterexamples (posing questions to open other paths of thinking)
A Score of 3 (Skilled)	Describes the teacher helping students deepen their reasoning using descriptions of strategies like the following: o Asking for evidence or reasoning (what is their thinking or evidence, how did they arrive at conclusions) o Challenging or asking for counterexamples (posing questions to open other paths of thinking)
Category 4: Helping Students Think With Others	

A Score of 0 (Novice)	Describes the teacher generally having students work with others and providing some general support (providing positive climate, accepting failures, teacher asking general questions to the whole group, etc.)
A Score of 1 (Emerging)	Describes the teacher helping students work with others with some description of the types of support that helped create interaction amongst students
A Score of 2 (Transitional)	Describes the teacher helping students think with others using some descriptions of strategies like the following: o Asking for agree/disagree and why o Asking for students to add on (having students add onto original student idea, can they push it a little further) o Explaining what someone else means (explaining why that student came up with that answer, why do students think the original student said that, what students think the original student means when they give their explanation)
A Score of 3 (Skilled)	Describes the teacher helping students think with others using descriptions of strategies like the following: o Asking for agree/disagree and why o Asking for students to add on (having students add onto original student idea, can they push it a little further) o Explaining what someone else means (explaining why that student came up with that answer, why do students think the original student said that, what students think the original student means when they give their explanation)

Appendix K: Nominal Scale Interview Responses

Nominal Scale: Interview Responses			
Type of Practice Language	**Investigating Practices**	**Sensemaking Practices**	**Critiquing Practices**
Description	Described the developing and using models practice by describing students asking questions and implementing methods of data collection to investigate the natural world	Described the developing and using models practice by describing students analyzing data, looking for patterns or relationships to develop explanations and design representations based (constructing models) on data to explain how and why phenomena occur	Described the developing and using models practice by describing students evaluating, comparing, and contrasting different claims, explanations, or models as they make sense of the world around them