PREPARING PERSERVICE TEACHERS TO TEACH ELEMENTARY SCHOOL SCIENCE

BY

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Abstract

The development of scientifically literate citizens begins in the elementary school. Yet elementary school teachers are ill prepared to teach science (Trygstad, Smith, Banilower, Nelson, & Horizon Research, Inc., 2013). The research base on teacher preparation finds that programs designed to prepare elementary teachers are inadequate in providing both the content knowledge and pedagogical content knowledge necessary to teach science effectively (Baumgartner, 2010; Bodzin & Beerer, 2003; Bulunuz & Jarrett 2009). This mixed methods study examined what happened when a science methods course was interactively co-taught by an expert in elementary teaching methods and a physics expert. This study also aimed to discover what aspects of the curriculum pre-service teachers (PSTs) said helped them in developing their understanding of science content and scientific reasoning, and how to implement inquiry practices to teach science. A nested case study of three PSTs provided descriptive portraits of student experiences in the class.

A whole class case analysis was used to examine what PSTs learned in terms of science, scientific reasoning skills, and pedagogical content knowledge (PCK) from their experiences in the course. It was found that students often conflated science content with the experiences they had in learning the content. Although PSTs felt the interactive co-teaching model effectively created a balance between theory and practice, it was their experiences doing science – conducting physical experiments, developing and discussing scientific models, and the use of inquiry-based instruction -- that they credited for their learning. Even with careful curriculum planning, and a course purposely designed to bridge the theory to practice gap, this study found one semester-long methods course to be insufficient in providing the vast content knowledge and PCK elementary school science teachers need.

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CHAPTER 1: INTRODUCTION

At least 70% of current jobs in the United States require specialized knowledge and skills that include "the capacity to frame, investigate, and solve problems using a wide variety of tools and resources…to find, analyze, and use information for multiple purposes…and to develop new products and ideas" (Darling-Hammond, 2010, p.2). According to the *Next Generation Science Standards* (NGSS) and the National Research Council, the knowledge and skills required for science proficiency in grades K-12 parallel those required for today's skilled workforce (NGSS, 2013; NRC, 2007). In order to compete in a global economy, in which success is measured by innovative thinking, students' scientific literacy and the development of investigative, 21st century thinking has never been more important (Longview Foundation, 2008; NRC, 2007).

Scientifically literate citizens are those who have acquired an understanding of the nature of science, or the cross-disciplinary concepts such as using a variety of methods for scientific inquiry, understanding that scientific knowledge is based in empirical evidence and open to revision in light of new evidence, and viewing science as a way of knowing (NGSS, 2013; Capps & Crawford, 2012), as well as habits of mind that enable students to make some sense of how the natural and designed worlds of science work. They have the ability to think critically and independently about the phenomena they experience and to weigh alternative solutions to problems they face (Bodzin & Beerer, 2003). Learning experiences that facilitate these critical thinking skills and innate interest and investment in the worlds of science begin in the elementary grades.

The NGSS recommend that in the elementary grades teachers teach science by facilitating students' deep conceptual understanding using scientific practices. This requires teachers to be proficient in modeling the practices employed by scientists. These practices are meant to aid students in developing the critical thinking skills necessary to investigate both the natural and designed worlds of science (NGSS, 2013). Specifically, the NGSS recommend teachers in K-12 science classrooms facilitate activities that require students to ask questions and define problems, develop and use models, plan and carry out investigations, analyze and interpret data, use mathematics and computational thinking, construct explanations and design solutions, engage in scientific arguments from evidence, and obtain, evaluate, and communicate information (NGSS, 2013). In order for these practices to become habits, or natural ways of thinking about science and the nature of science, they must be experienced and taught at an early age.

Additionally, in order for students to appreciate how much science impacts their daily lives they need to study multiple science disciplines. The foundation for understanding physical, earth, and life science concepts begins in these early years. How students feel and think about science is dependent upon the way in which each of these disciplines is approached by their elementary school teachers. Teachers who are knowledgeable and passionate about science instruction in all disciplines provide the foundational knowledge and skills needed for students to become engaged and invested in the subject overall.

However, because elementary teachers are prepared to be generalists, who can teach all subject matters, their professional preparation may not be of the quality necessary to teach science in this new way. Since the *No Child Left Behind Act* (NCLB) was voted into law and the era of high-stakes testing was established, content area preparation in untested subjects, such as science, has been steadily declining in teacher education programs (Crippen, Archambault, Ford, & Levitt, 2004; Dee, Jacob, & Schwartz, 2013; Guziec & Lawson, 2004). Though the state of New Jersey requires students to take two science courses as general education requirements, the content is taught in isolation without any focus on how to teach it to young children. Preservice teachers are required to take only one science methods course and the curriculum and instructional methods taught vary greatly from one preparation program to the next and within a program depending upon the knowledge and expertise of the instructor tasked with teaching it (Knaggs & Sondergeld, 2015; Smith & Gess-Newsome, 2004).

Moreover, to be effective teachers of science, elementary school teachers must be confident in *both* their science content knowledge and pedagogical content knowledge (Avery & Meyer, 2012), or the "knowledge of instructional strategies useful for teaching particular content, together with common student conceptions and difficulties with particular content" (Shulman, 1987, as cited in Anderson & Clark, 2012, p. 317). The research base suggests, however, that teacher preparation programs are inadequate in providing both the content knowledge and PCK necessary to teach science effectively (Baumgartner, 2010; Bodzin & Beerer, 2003; Bulunuz & Jarrett 2009; Swars & Dooley, 2010; Trundle & Bell 2010; Ucar & Trundle, 2011). Some programs focus too heavily on science content without discourse about practice while others focus on methods for teaching science without providing students with opportunities to learn science content in depth.

Though elementary school teachers are expected to teach across disciplines, their learning is limited by the instructor's area of expertise and/or preference for one science discipline (Knaggs & Sondergeld, 2015; Lewis, Harshbarger, & Dema, 2014; Smith & Gess-Newsome, 2004). For example, a methods course taught by a biology professor may focus instruction narrowly on life sciences and little, or not at all, on physical and earth sciences. Studies conducted by teacher educators designed to assess the effectiveness of methods for improving PSTs' science content are, therefore, often narrowly focused on one science concept within one discipline (Atwood & Atwood, 1995; Bulunuz & Jarrett 2009; Sangor, 2007; Trundle & Bell, 2010; Ucar & Trundle, 2011). Ucar and Trundle (2011), for example, studied the effects of different approaches to teaching PSTs about tides using three treatment groups, and Bulunuz and Jarrett (2009) examined the effects hands-on learning stations and concept mapping had in improving PSTs' conceptual understanding of earth and space science content. Studies like these explore the instructional methods that increase PSTs' scientific content knowledge, yet their narrow focus on one topic does not conclusively assess the effects of pedagogies across the vast array of content knowledge required of teachers in the elementary school, or test PSTs' ability, or understanding of how, to teach this content in their own future classes (Anderson & Clark, 2012).

Yet strong PCK for teaching science is required. As opposed to emphasizing the memorization of facts or key terms, the NGSS were conceptually designed to increase students' depth of understanding of the nature of science within and across disciplines, each year. The PCK specific to elementary science teachers includes knowing how to build on foundational knowledge to develop more sophisticated conceptual understandings of science through inquiry-based instruction. For example, without fully understanding the concept of day and night, teachers often simply require students to memorize the phases of the moon and define terms like *waxing* and *waning*. However, in order for students to understand how the Earth experiences day and night, they first need to understand the concept of reflected light. Students cannot fully understand that we see the moon because it reflects light from the sun until they understand that we see light only when it is reflected off of something. To fully develop this understanding teachers use 3-dimensional models of the Earth, moon, and sun to help students understand how the configuration of the three allow the moon to appear as though it shines. Opportunities to experiment with the models to develop possible explanations for this scientific phenomenon allow students to think like scientists and to practice habits and skills that set the foundation for scientific literacy.

The use of authentic curriculum materials or prepackaged kits, hands-on experiments, technology-based simulations, concept mapping, modeling, and inquiry-based methods are often the focus of the curriculum in methods courses aimed at teaching PSTs how to teach through inquiry. Research conducted by teacher educators is often either focused narrowly on PSTs' experiences using one of these methods (Baumgartner, 2010; Bulunuz & Jarrett 2009; Forbes, 2011) or broadly using PSTs' general experiences as students of inquiry-based instruction (Davis, Petish, & Smithey, 2006; Mijung, 2011; Swars & Dooley, 2010). For example, Forbes (2010) qualitatively studied how PSTs critique and adapt existing science lessons and curriculum materials to produce more inquiry-based lesson plans. Results from this study showed that through practiced curriculum adaptations, PSTs were able to improve the inquiry-orientation of the lessons in ways that would be useful to their future instruction. Though studies like this one support the importance of teacher preparation coursework based on inquiry-based teaching practices, they do not address the significance of PSTs' knowledge and understanding of science content across disciplines, nor do they formally challenge or test PSTs' scientific content knowledge and conceptual understanding. Potentially, PSTs exit these courses lacking both the content knowledge across disciplines and the methods to teach the NGSS effectively.

If students in the elementary years are to become skilled in understanding science content and the nature of science as it is valued and practiced in the field, their teachers need both a command of science content and an understanding of how to transform it in ways that effectively enable students to experience and practice the doing of science (Anderson & Clark, 2012). Yet assessments of preservice elementary school teachers' science content knowledge and PCK for teaching science finds they often lack both (Baumgartner, 2010; Davis, Petish, & Smithey, 2006; Mijung, 2011; Parker, 2004; Swars & Dooley, 2010). Few choose science as a subject matter specialty in teacher preparation programs (Bodzin & Beerer, 2003) and therefore know little more about science and science instruction than they did upon high school graduation. Those who do seek additional training in college often specialize in *one* discipline, or in one topic within a discipline (i.e. environmental science, astronomy, etc.), though elementary school science instruction requires knowledge in *multiple* disciplines (i.e. life sciences, earth and space sciences, physical sciences, and engineering).

A national survey, conducted in 2013 to determine the status of science education in our nation, included questions specific to the preparedness of elementary school teachers. This large-scale study found that of the 881 elementary school teachers surveyed, only 29% felt they were well prepared to teach life science, 25.5% felt well prepared to teach earth science, and 16.5% felt they were well prepared to teach physical science (Trygstad, Smith, Banilower, Nelson, & Horizon Research, Inc., 2013). Additionally, when surveying for teachers' pedagogical beliefs, this study found inconsistencies between teachers' beliefs and what is known about effective science instruction. For example, 40% of teachers reported that the teacher should explain a scientific idea before having students consider evidence for that idea and more than 50% believed experiments should be used to reinforce the ideas taught prior. This belief runs counter to inquiry practices in which experimentation and investigation lead to the development of scientific concepts.

The result, therefore, of current teacher preparation programming is elementary school teachers who are ill-prepared to teach science and few who have enough confidence to implement complex teaching methods (Swars & Dooley, 2010) such as inquiry-based instruction. It is probably not surprising therefore that elementary teachers often end up deferring to textbook modules with "cookbook" experiments to guide the overall structure and content of their science units (Forbes, 2011; Trygstad, Smith, Banilower, Nelson, & Horizon Research, Inc., 2013). If teacher preparation programs are to prepare elementary school generalists to teach science through inquiry, they must address these deficits through coursework focused on both science content and PCK for teaching science in the elementary school.

My goal as a teacher educator is to implement practices that enhance preservice teachers' comprehensive science content knowledge as well as to address the authentic instructional challenges they will face in their elementary classrooms. To address the inadequacies of preparation courses that focus narrowly on either content or PCK, I partnered with a colleague to design a semester-long course aimed at merging science content instruction with elementary school instructional techniques. Though our areas of expertise vary, his in physics and mine in effective teaching methods at the elementary school level, our well-aligned orientations to and beliefs regarding the purpose of and methods for teaching science have helped to make us a strong co-teaching team (Shibley, 2006). As teacher educators, we believe our job is to prepare PSTs with the science-based content knowledge, PCK, and understanding of how students' learn necessary to teach science effectively.

The teaching model and curriculum was piloted in the spring 2015 semester. Collaboratively, we designed a course (See Appendix A: Course Syllabus) in which our curriculum would allow us to facilitate both PST's acquisition of science content and understanding of PCK for teaching elementary school science. We used a *parallel teaching model* (Jones & Harris, 2012) in which we each taught one section of the course independently.

Prior to teaching each week, we met to discuss the course content and methods for addressing it. My partner would inform me of the content he planned to cover and I would offer insight as to how we could incorporate methods and concepts such as curriculum integration, questioning techniques, and methods of assessment into our class. He taught and modeled the pedagogy for teaching each science concept and I offered readings and authentic examples from my own practice that would provide our students with additional information to support and deepen their PCK. Like teacher educators who have conducted cases studies on co-teaching (Dugan & Letterman, 2008; Higgins & Litzenburg, 2015; Jones & Harris, 2012; Shibley, 2006; Vogler & Long, 2003), we benefited from opportunities to collaborate and share our diverse experiences and areas of expertise. However, by not teaching in the classroom together, our students' instruction was limited to the expertise of only one instructor.

In the fall 2015 semester we followed an *interactive co-teaching model* in which we were both present for, and played a role in, teaching each class meeting (Dugan & Letterman, 2008). Instructors who practice this model and students who are taught through it report finding it to be advantageous in offering different teaching perspectives and opportunities to learn from varied areas of expertise (Dugan & Letterman, 2008; Higgins & Litzenburg, 2015; Jones & Harris, 2012; Shibley, 2006; Vogler & Long, 2003). This study was designed to see if this interactive co-teaching model might be a way to help PSTs in elementary education gain both the content knowledge and pedagogical practices necessary for teaching elementary school science. This study also aimed to discover what aspects of the curriculum students say helped them in developing their understanding of science content and scientific reasoning, how to implement inquiry practices to teach science, and how their understanding of each changed over the semester. Findings from this study provide insight as to how to improve the curriculum design and future implementation of this and other science methods courses aimed at preparing elementary school teachers. The research questions that guided this study are as follows:

1) What do PSTs learn about science content in a co-taught science methods course aimed at combining the teaching of science content with the teaching/modeling of inquiry-based instruction?
    a. What disciplinary core ideas of the NGSS do students learn?
    b. What are PSTs' scientific reasoning skills pre and post experiencing a co-taught science methods course as measured by the Lawson Test?
2) What do PSTs learn about pedagogy for teaching elementary school science in a co-taught science methods course aimed at combining the teaching of science content with the teaching/modeling of inquiry-based instruction?
    a. What do students learn about inquiry-based instruction?
    b. What do students learn about scientific and engineering practices?
3) What are PSTs' experiences and evaluations of the co-taught science methods course aimed at combining the teaching of science content with the teaching/modeling of inquiry-based instruction?
    a. What aspects of the curriculum do PSTs say help them learn science content and PCK?
    b. What do PSTs say about the co-teaching model of instruction?
    c. How do PSTs say the class might be improved?

CHAPTER TWO: REVIEW OF THE LITERATURE

In order to understand how to best prepare elementary school teachers to teach science, I explored four bodies of literature. First, I studied the research literature on science instruction and the science content knowledge and pedagogies for learning elementary school science in accordance with the NGSS. Within the broad topic of science content knowledge there are two narrow areas of focus: disciplinary core ideas and cross-cutting scientific concepts. The second body of research explored the pedagogies within which students should engage to learn elementary school science. Literature on pedagogy focuses on science and engineering practices and scientific modeling. These two larger concepts are synthesized through research on pedagogy for teaching science through learning progressions and inquiry-based instruction. Lastly, as it is central to understanding current practices in addressing the content knowledge and PCK of elementary school teachers, I reviewed research on teacher preparation programs and, more specifically, on preparation courses for elementary school science.

Science Content Knowledge

The design and development of the NGSS has ignited a dialogue about the focus of science instruction in schools Kindergarten-12th grade. The foundation for the NGSS is the *Framework* developed to communicate the "view of science as both a body of knowledge and an evidence-based, model, and theory building enterprise that continually extends, refines, and revises knowledge" (NGSS, 2013). The content of the NGSS consists of three interwoven dimensions: disciplinary core ideas, science and engineering practices, and cross-cutting concepts. The disciplinary cores ideas and cross-cutting concepts create blueprints for understanding the science content knowledge on which elementary school teachers should focus their instruction.

Disciplinary Core Ideas

The disciplinary core ideas, as articulated in the NGSS, explain the specific science concepts that teachers should target through instruction and assessment practices. They answer the question: *What should students know about science at the end of this learning experience?* These core ideas make up the body of knowledge students should acquire, and thereafter, build upon each year.

There are three main science disciplines in the NGSS (2013): 1) physical science, 2) earth and space science, and 3) life science. The disciplinary core ideas of each help teachers to understand how to address each of these broad disciplines. Physical science core ideas address topics related to matter and its interactions, forces and motion, and physical energy. Earth and space science topics include ideas about the relationships between Earth, the moon, and the sun, the Earth and its place in the universe, and the surface of the Earth, its resources, and the weather it experiences. Life science core ideas focus on both plants and animals, their traits, growth, reproduction, and overall survival processes. This discipline also addresses the relationships between plants, animals, and their environments, and their places in ecosystems.

Though the core ideas are identified by standards in each discipline, a few core ideas are listed within each standard to promote opportunities for cross-disciplinary instruction or to address cross-cutting concepts. Teachers can facilitate activities in which students acquire the core ideas specific to each discipline in ways that naturally show how the sciences are interconnected. For example, in one journal article, co-written by a science teacher and career biologist, primary students explored frog calls across ponds to connect physical science core ideas about wave properties of sound (PS4.A: Wave Properties - *Sound can make matter vibrate, and vibrating matter can make sound*) with life science core ideas about the social interactions and group behaviors of frogs (LS2.D: Social Interactions and Group Behaviors – *Being a part of a group helps animals obtain food, defend themselves, and cope with changes*) (Lee & Lubischer, 2014). As the core ideas taught in the elementary school are foundational to students' conceptual understanding, teachers should use them as objectives for students' learning within each discipline while also aiming to teach them in ways that promote understanding of how they interplay across disciplines.

Cross-cutting Concepts

Cross-cutting concepts, as articulated in the NGSS, identify ways in which all science disciplines are conceptually interconnected (NGSS, 2013, Duncan & Cavera, 2015). Emphasis on the cross-cutting scientific concepts, or broad scientific themes, foster students' abilities to connect important ideas across science disciplines as well as to enable them to make predictions about new scientific phenomena because they address science concepts as they are observed and experienced in the world (NGSS, 2013; Marshall, 2014; Michaels, et al., 2008; Roseman & Koppal, 2014). The cross-cutting concepts identified in the NGSS are patterns, causes and effects, scale, proportion and quantity, systems and systems models, energy and matter, structure and function, and stability and change.

Activities focused on cross-cutting concepts help students to understand how foundational knowledge and understanding builds from one year to the next (NRC, 2007). For example, teaching children to identify and analyze observational patterns can help them learn to describe natural phenomena that take place, review data for similarities and differences, and to sort, classify, and analyze natural phenomena and designed products (NGSS, 2013). Observing and using those patterns as evidence to support scientific explanations are foundational to developing scientific literacy. Students' prior knowledge of a cross-cutting concept like *patterns* can be used as a starting point for deeper understanding and analysis of more challenging science concepts (see Table 1) (Achieve, 2013). For example, content learned and skills attained in collecting data about weather patterns in a Kindergarten science class could later be used in 2nd grade to help students draw conclusions about patterns regarding weather-related causes and effects on the Earth's surface.

Table 1. *Cross-cutting Concepts: Patterns*

Grade	NGSS Examples
K	K-ESS2-1. Use and share observations of local weather conditions to describe patterns over time.
1	1-LS1-2. Read texts and use media to determine patterns of behavior of parents and offspring that help offspring survive.
2	2-ESS2-2. Develop a model to represent the shapes and kinds of land and bodies of water in an area.
3	3-PS2-2. Make observations and/or measurements of an object's motion to provide evidence that a pattern can be used to predict future motion.
4	4-PS4-3. Generate and compare multiple solutions that use patterns to transfer information.
5	5-ESS1-2. Represent data in graphical displays to reveal patterns of daily changes in length and direction of shadows, day and night, and the seasonal appearance of some stars in the night sky.

The teaching of science content must be coupled with the development of students' understanding of the nature of science (NOS as it contributes to students' scientific literacy (Hawkins & Park-Rogers, 2014). These cross-cutting concepts might also be used to teach students about the more general values and beliefs associated with the NOS and the development of scientific knowledge. For example, the cross-cutting concept *cause and effect* could be addressed through the systematic testing of variables in designing a clay rocket (Hawkins & Park-Rogers, 2014) while also addressing NOS ideas associated with collecting data and using evidence in scientific inquiry. The teaching of the NOS can be both embedded in scientific inquiry experiences and explicitly taught as teachers openly explain the purpose of the activities and decisions made during scientific investigations. In this way, elementary school science teachers have a dual focus – "to increase children's knowledge of science disciplinary core ideas and their skill in practices and conducting scientific inquiry" (McCormick-Smith & Trundle, 2014).

Pedagogical Content Knowledge

Pedagogy for teaching and learning science must be modeled after the values, beliefs, and methods used to conduct science in the field. The habits, skills, and behaviors practiced by scientists are not recipes or procedures to be followed. Instead, science activities in the elementary school need to instill the values and broad goals associated with getting students to think like scientists. Though teaching practices need to be adjusted depending upon contextual variables, teachers must facilitate student-centered inquiry experiences. These experiences engage students in science and engineering practices and utilize scientific modeling to communicate what they know and understand about science.

Science and Engineering Practices

The combination of science content knowledge and the skills needed to engage in science are referred to as *science practices* (Bybee, 2011). "Science involves doing something and learning something in such a way that the learning cannot be separated" from the doing (Michaels et al., 2008, p. 34). The concept of science practices implies that in order to become proficient in the knowledge and skills associated with *doing* science, repeated exposure to and *practice* with specific science knowledge and skills is required.

Practices related to doing science include 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, and obtaining, evaluating, and communicating information. Science and engineering practices parallel the skills associated with inquiry. "When students engage in scientific practices, activities become the basis for learning about experiments, data and evidence, social discourse, models and tools, and mathematics and for developing the ability to evaluate knowledge claims, conduct empirical investigations, and develop explanations" (Bybee, 2011, pg. 10). These practices can also be viewed in gradients by developmental levels. Table 2 shows one example of this.

Table 2. *Science and Engineering Practices: Analyzing and Interpreting Data*

Grade	NGSS Description
Analyzing data in K-2 builds on prior experiences and progresses to collecting, recording, and sharing observations.	
K	K-PS2-2. Analyze data to determine if a design solution works as intended to change the speed or direction of an object with a push or a pull.
1	1-ESS1-2. Make observations at different times of year to relate the amount of daylight to the time of year.
2	2-PS1-2. Analyze data obtained from testing different materials to determine which materials have the properties that are best suited for an intended purpose.
Analyzing data in 3-5 builds on K-2 experiences and progresses to introducing quantitative approaches to collecting data and conducting multiple trials of qualitative observations. When possible and feasible, digital tools should be used.	
3	3-LS3-1. Analyze and interpret data to provide evidence that plants and animals have traits inherited from parents and that variation of these traits exists in a group of similar organisms.
4	4-ESS2-2. Analyze and interpret data from maps to describe patterns of Earth's features.
5	5-ESS1-2. Represent data in graphical displays to reveal patterns of daily changes in length and direction of shadows, day and night, and the seasonal appearance of some stars in the night sky.

The practices involved in doing science are parallel with and complementary to practices in the field of engineering. Like scientists who identify questions about the natural world and propose answers through evidence-based explanations, engineers identify problems and aspirations and propose solutions (Bybee, 2011). As science and engineering are clearly connected, elementary teachers can embed the teaching of one within the other (Hawkins & Park-Rogers, 2014). Students may begin to understand that the evolution of scientific discoveries are dependent upon the engineering of tools and materials that help to make those discoveries possible, and vice versa (Bybee, 2011). Standards specific to engineering practices are included in the NGSS so teachers consider how they can teach and model this complementary relationship.

Science and engineering practices go beyond the basic explanations of scientific knowledge and require students to be able to explain their ideas with evidence. For example, instead of asking 6^{th} grade students to explain the steps in cellular respiration, the teacher might ask why exhaled air has less oxygen than inhaled (Reiser, Berland, & Kenyon, 2012). The answer would require students to be able to explain their understanding of cellular respiration and “produce a causal chain that fits the evidence that leads to a claim about why oxygen is needed” (Reiser, et al., 2012, p. 35). In order to develop scientifically literate students who are capable of this, teachers must facilitate methods of instruction that prompt students to consistently use science and engineering practices.

Scientific Modeling

Scientists develop and use scientific models as ways to generate new knowledge and to communicate their understanding of scientific phenomena (Kenyon, et al., 2011). “A scientific model is an abstract, simplified, representation of a system of phenomena that make its central features explicit and visible” (Harrison & Treagust, 2000 as cited in Schwarz, Reiser, Davis, Kenyon, Acher, Fortus, Shwartz, Hug, & Krajcik, 2009). Models might include particle models, force models, life cycles, or bar graphs. They can be used as tools to predict and explain scientific phenomena and as the means by which to demonstrate how understanding of a concept has evolved and/or changed (Schwarz et al., 2009). Learning to design scientific models builds science content expertise, epistemological understanding of science practices, and skills necessary for evaluating scientific information (Schwarz et al., 2009).

In order for students to understand how to represent their scientific thinking through modeling, teachers must provide examples and allow students to discuss and debate how to do so effectively. Students benefit from constructing, using/testing, evaluating, revising, and explaining their scientific models to peers and to the teacher (Kenyon, et al., 2011; Lott & Wallin, 2012; Micheals et al., 2008; Schwarz et al., 2009). Opportunities to develop multiple models and to compare their ideas with those of their peers allows them to constantly reflect on and evaluate how they understand a science concept. Through continued exploration and discourse with peers and the teacher, students gain information that contributes to a more sophisticated understanding and potential reshaping of their model. This growth and development as seen through their scientific modeling makes students' thinking visible and, therefore, assessable.

Through scientific modeling, teachers are able to assess how students organize their understanding of a science concept and whether and where they make connections between one idea and another (Lott & Wallin, 2012). Though young children often create models that concretely represent their data, continued exposure to and discourse that critically examines the use of multiple scientific models affords students opportunities to refine and improve their scientific reasoning and modeling skills (Lott & Wallin, 2012; Michaels et al., 2008). Students' capacity to design abstract scientific models increases as their knowledge of science content, practices, and understanding of the NOS grows, and as they are able to compare and contrast the effectiveness of one model to another in communicating their understanding (Michaels et al., 2008; Schwarz et al., 2009).

In their journal article, Lott and Wallin (2012) described their work on scientific modeling with first graders learning about the states of matter. In addition to explaining the interactive activities used to develop students' understanding of the concept, they identified the ways in which they helped the students create scientific models of the states of matter using Play-doh. The teacher began by reading a poem and book on the topic to provide some background information. The students then collaboratively explored different materials to consider how they could be sorted and categorized into the three states of matter (i.e. gas, liquid, and solid). Over two weeks, the students circulated through centers with their peers learning more about each of the states of matter and their characteristics. In the end, the majority of students were able to sort objects into the three states of matter and to depict, through a scientific model using Play-Doh, how the molecules in each state behaved. The teacher was able to assess students' understanding of this concept through performance tasks in which they both sorted and modeled.

To truly assess their scientific reasoning skills and practices, teachers must shift their analysis of students' work from solely focusing on accuracy of content knowledge to analysis of representation, communication, and argumentation of scientific ideas using evidence. Likewise, teachers need to be cognizant of the how the scientific models created by the students show their depth of understanding.

Teaching Science

To acquire a deep conceptual understanding of science content and the NOS, and to be able to conduct scientific investigations using the skills and habits of real scientists, students need to be taught by skilled educators whose values and practices mirror those engaged in the field. It is critical, then, that elementary school teachers understand science as interconnected concepts and ideas that cross disciplines and grade levels. This can be accomplished if teachers view and teach science through learning progressions. To do this, teachers must be confident enough in their content knowledge and PCK to create learning environments that facilitate students' use of science and engineering practices through inquiry-based instruction. Simply put, in order to develop scientifically literate, critical thinkers, elementary school teachers must plan through learning progressions and teach using inquiry-based instruction.

Learning Progressions

Moving students, incrementally, from novice to more expert in both their scientific understanding and practice requires teachers to calibrate their instruction so there are clear connections between what came before and what comes after a particular point in understanding a concept (Heritage, 2008). This is known as *learning progression. Learning progression* is the adding and developing of ideas so they build upon and support one another in a coherent way (Corcoran, Mosher, & Rogat, 2009; Fortus, Sutherland Adams, Krajcik, & Reiser, 2015; Heritage, 2008; Michaels et al., 2008) to facilitate a more sophisticated and scientifically accurate understanding of a concept (Fortus et al., 2015). In this way, each scientific concept children need to learn is viewed on a continuum of understanding from novice to expert.

As explained previously, in order for students to understand how Earth experiences day and night, they first need to understand the concept of reflected light. Similarly, they cannot fully understand that the Earth revolves around the sun until they understand that motion must be identified using *perspective*, as the description of motion changes based on the viewer. Because we see the sun move across the sky, east to west every day, students might say that the sun moves around the earth. From our perspective on Earth the sun moves, not the Earth, so this might seem plausible. To fully explain this concept, students need to be able to talk about our perspective on Earth as compared to an astronaut's perspective from an orbiting space shuttle to discuss the motions of the Earth and sun. Here, physical science and earth science intertwine for a deeper conceptual understanding. Students must understand the physical science concept of motion and viewer's perspective before being able to comprehend the earth science concept. It is, therefore, important to appreciate the foundational knowledge needed to fully understand a scientific concept; otherwise, teachers run the risk of focusing on teaching science as disconnected, discrete facts to be memorized (Corcoran, Mosher, & Rogat, 2009; Fortus, et al., 2015).

In order to achieve movement across each continuum, teachers must assess each student's understanding of a concept in order to determine how to make connections between prior knowledge and successive learning (Heritage, 2008). Planning instruction through the analysis of students' learning progressions requires teachers to think "about the underlying concepts that need to be developed before a student can master a topic" (Michaels et al., 2008, p. 64). In order to think this way, teachers need not only to understand the science concept fully, but to know where students are in their understanding of the concept, how to fill the gaps in their understanding, and build upon it (Corcoran, Mosher, & Rogat, 2009; Hertiage, 2008). They must constantly stay focused on the trajectory of students' understanding of each science concept and about how best to set the groundwork for future understanding (McCormick-Smith & Trundle, 2014). This focus on progress requires teachers to emphasize the use of formative assessments to guide instruction as opposed to using summative assessment to judge students' learning for a grade. Evidence from students' performance in class discussions and investigations should be used to determine how students' learning is evolving and how to provide feedback (Brookhart, 2007, as cited in Heritage, 2008) and scaffold instruction to develop their learning further (Hertiage, 2008).

As science in the elementary school is most commonly taught as isolated units of study often using premade science kits (Slavin et al., 2013) there is little evidence that elementary teachers even know about learning progressions in science, let alone how to use them instructionally. However, research on the use of learning progressions in middle school science suggests that there are benefits to planning instruction through this broad, conceptual model. To examine the effects of inter-unit coherence on learning over time, a longitudinal study was conducted to analyze students' understanding of the cross-cutting concept, *energy*. Fortus, Sutherland Adams, Krajcik, & Reiser's (2015) national study used multiple quantitative measures to compare middle school (grades 6-8) students' learning prior to and following the implementation of an inter-unit reform-based middle school curriculum. Their study aimed to determine if there were positive relations between energy-related ideas learned in earlier units and students' understanding of these concepts in later units. The study found that increased exposure to the concept of energy and teaching and learning in a broad range of contexts over the course of several years facilitated the development of deeper understandings than could be accomplished in stand-alone units of study. The researchers were able to make explicit connections across students' posttest scores in various units to support this claim. For example, students' achievement on tests assessing their understanding of light's ability to heat soil and water were predictive of scores associated with students' understanding of photosynthesis and cellular respiration. They were also able to determine that some foundational understanding of energy was not helpful in transferring it to different contexts. For example, the posttest scores involving students' understanding of light's ability to heat soil and water were not predictive of their understanding of heat transfer by conduction and convection. This aligns with research that recommends the use of diagnostic and formative assessments to determine how to scaffold instruction for each new unit of study.

Although this study was based on middle school science, findings suggest that elementary school instruction focused on curriculum coherence might increase students' depth in understanding cross-cutting science concepts as well as increase proficiency in science and engineering practices. Connecting the science units taught years prior to successive units allows teachers to reap the benefits of a *coherent* curriculum (Fortus, et al., 2015). To accomplish this, teachers must be fully aware of the connections between and among science units of study, otherwise often taught as isolated topics (Slavin, et al., 2013), and receive training and support to develop an understanding of the conceptual goals and of the trajectories of students' learning (Fortus, et al., 2015). This calls for the preparation of teachers who understand how to plan and teach science through learning progressions.

Inquiry-based Instruction

Research suggests the teaching of science content is equally as important as the instructional context through which it is taught (Smith, Maclin, Hougton, & Hennessey, as cited in Hawkins & Park-Rogers, 2014). To develop students' scientific literacy elementary school teachers of science must be capable of facilitating inquiry-based instruction (Abdi, 2014; NGSS, 2013; Lewis, et al., 2014; Marshall, 2014; Schoering, Hand, Shelley, & Therrien, 2014; Slavin et al., 2013). The knowledge and understanding of science students gain from this type of instruction shapes their views of the world of science and what it means to *practice* and *do* science.

Bodzin and Beerer (2003) identified five essential elements that define this practice based on how the learners engage with the content. They are as follows:

1) Learners are engaged by scientifically oriented questions.
2) Learners give priorities to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
3) Learners formulate explanations and conclusions from evidence to address scientifically oriented questions.
4) Learners evaluate the explanations in light of alternative explanations, particularly those reflecting scientific understanding.
5) Learners communicate and justify their proposed explanations.

Colburn (2000) identified four levels of inquiry designated by students' ownership in the learning experience. He defined *structured inquiry*, the first level, as being an investigation with a teacher-generated problem. Here students are given materials and procedures with which they will work to solve the problem. This approach mirrors traditional "cookbook" science activities. However, it differs from structured experiments with preprinted worksheets, typical of traditional hands-on science, in that students decide what data to collect and how to gather and report it. The second level, *guided inquiry*, is described by Colburn (2000) as an investigation in which students are given a problem to solve and materials to investigate the problem without formal procedures to follow. They are therefore able to experiment with the materials to solve the problem using a variety of strategies that they get to choose. The third level is *open inquiry*. This approach is similar to guided inquiry but with the addition of a student generated problem. Lastly, in the *learning cycle*, analogous to the authentic work done by scientists, students are engaged in an activity in which a new concept is introduced and with which the students are expected to connect across contexts and potentially across disciplines. What they investigate, research, and present to peers is guided by their own inquiry. Each level of inquiry on the continuum addresses varying levels of cognitive skills. The more involved the students are in shaping their scientific investigations, the more opportunities they have to increase their scientific reasoning skills.

Inquiry-based instruction has shown to both increase students' science content knowledge (Abdi, 2014; Slavin et al., 2013) and improve their attitudes toward learning about and doing science (Le, Lockwood, Stecher, Hamilton, & Martinez, 2009; Tomas, Jackson, & Carlisle, 2014). In their three-year study, Le, Lockwood, Stecher, Hamilton, and Martinez (2009) used multiple measures of achievement and classroom practices to examine the longitudinal relationship between reform-oriented instruction in teaching math and science and student achievement. Reform oriented instruction was defined in this study as constructivist teaching in which teachers pose tasks that foster the reorganization of students' conceptual understanding of content through social interaction and problem solving. They followed over 27,000 elementary and middle school students in three school districts over the course of three years. Analysis of student achievement data, teacher surveys, and descriptive daily logs found that prolonged exposure to reform-oriented practices in math and science resulted in creating stronger, more positive student understandings of, and relationships with, math- and science-related open-ended problems.

The research base on student achievement in science, however, is limited as most studies do not target the outcomes of instructional practices on student achievement. To examine the outcomes of all types of instruction to teach elementary school science, including inquiry-based instruction, Slavin et al. (2013) conducted a systematic review of research. They reviewed a total of 332 published and unpublished articles to find only 23 that met the rigorous credibility standards. The study's inclusion criteria included the use of student achievement data independent of the experimental treatment, randomized or matched control groups, and at least 4 weeks of duration for the study. In reviewing these studies, researchers compared the outcomes of teachers who implemented inquiry-based instruction with and without the use of premade science kits. They also compared student achievement outcomes of teachers who had, to those who had not, received professional development or training on inquiry-based instruction.

Researchers in this study found that although teachers who use science kits are more accurate in their facilitation of content, there is limited evidence of how the use of premade science kits (i.e. FOSS< Insights, Teaching SMART programs, etc.) affects student achievement (Baumgartner, 2010; Slavin et al., 2013). In addition, when teachers implement these kits, studies showed their focus is often on implementing the materials instead of developing deeper understanding of science concepts (Baumgartner, 2010; Slavin et. al, 2013) or considering how what was learned years prior contributes to future learning. In contrast, this review of research found that teachers who received training on practices for implementing inquiry-based instruction were more successful in increasing students' understanding of science than those who use science kits aimed at aiding teachers in implementing inquiry-based practices. All ten of the studies reviewed for this finding found "significant positive effects of inquiry-oriented professional development on conventional measures of student achievement" (Slavin et al., 2013, p. 895). This finding supports research on the importance of teacher preparation coursework focused in inquiry-based practices.

Challenges to implementing inquiry. Even with training on inquiry-based instruction, this shift from teacher to student-led investigations is not an easy one for teachers who have been taught using traditional methods of instruction (Luera, et al., 2005). Commonly, teachers believe that science is a subject of facts and that scientific investigations should be used as a means by which to support those facts (Trygstad, et al., 2013). Without having experienced inquiry in practice themselves, teachers may lack the necessary understanding of the nature of science and depth in content knowledge gained from these experiences. They may perceive teaching students to acquire science facts to be their primary teaching responsibility. There are, therefore, several challenges that both novice and experienced teachers face in implementing inquiry without prior experience or training.

Research suggests many beginning and experienced elementary teachers have naïve, unsophisticated, or uninformed understandings of scientific inquiry (Capps & Crawford, 2013; NRC, 2007). They also report having low teaching efficacy in reform-based methods of science instruction, or a lack of belief in their abilities to successfully execute instruction in difficult or challenging situations (Davis, Petish, & Smithey 2006; Knaggs & Sondergeld, 2015; Sharp, Hopkin, James, Peacock, Kelly, Davies, & Bowker, 2009). Inquiry-based practices often deviate from the teacher's intended lesson plan or investigative outcomes because student generated questions may lead to the collection and analysis of data in unforeseen directions. Teachers express a desire for certainty in scientific knowledge so that the work is consistent, especially since school assessments often focus on normative conceptual knowledge (Baumgartner, 2010; Mijung, 2011; Windschitl, 2006). Teachers who have not experienced inquiry in practice are inevitably concerned about allowing students to leave the classroom without fully understanding that which they believe to be scientific fact. This makes the implementation of open inquiry-based methods, where experimentation may lead to varied outcomes and conceptual understandings, intimidating to many.

Additionally, studies examining practicing teachers' abilities to teach science using inquiry-based practices find they have several concerns regarding the students' acquisition of necessary science content knowledge (Windschitl, 2006). Some are concerned that the students will not gain the necessary scientific content knowledge if their inquiry takes the lesson off-course (Braaten & Windschitl, 2006). Others who have not been taught using inquiry-based instruction report not knowing what to do when students already know the answer the scientific investigation is designed to address (Baumgartner, 2010; Davis, Petish, & Smithey, 2006; Forbes, 2011; Mijung, 2011; Swars & Dooley, 2010). Still another concern involves the challenge of motivating students who have prior knowledge and understanding of the scientific content (Baumgartner, 2010; Mijung, 2011). Some teachers are fearful their role as facilitator makes their instructional expertise superfluous (Windschitl & Thompson, 2013).

To illustrate teachers' concerns related to inquiry, Baumgarnter (2010), a teacher educator of a biology methods course aimed at preparing PSTs to teach science through inquiry, conducted a study that addressed her students' concerns about the lack of guidelines in teacher preparation and resources regarding what to do when "things go wrong" (Baumgartner, 2010, p. 55). When the original lab she had prepared to conduct did not go as planned she modeled how her PSTs could adjust the plan and use strategies to cope with an unforeseen issue. In this case, most of the termite cultures Baumgartner had ordered for her experiment were delivered dead due to cold weather in transit. Instead of hiding this issue from her students and simply replacing the termites with mealworms, she prompted her students to think about how they would handle this issue if they were teaching. In the end, the students agreed that although using mealworms would change the outcomes of the investigation, the same skills and concepts could be covered with this accommodation. Through this teachable moment, what PSTs might formerly have perceived as failure became an understanding of the scientific process. After all, scientists often learn more from the experiments that do not go as planned as it creates opportunities for genuine scientific inquiry (Baumgartner, 2010). Teacher preparation experiences like these may help to address concerns regarding unforeseen issues in practice although few studies exist that investigate the impacts of such methods.

The concerns expressed by teachers are often due to the differences between how they experienced science as students themselves which was typically more teacher-directed and traditional in format, and what research suggests are best practices (Luera, et al., 2005). Engaging students in lessons that may have uncertain conclusions, however, mirrors authentic scientific practice. Reformists argue that the science community deals in uncertainties and scientists accept and use explanations that arise through open discourse until they are displaced by better explanations thereby advancing science (Braaten & Windschitl, 2010; Windschitl, 2006). Thus, teacher preparation work must afford PSTs opportunities to experience, practice, and engage in discourse on inquiry-based, and other science-specific methods so they may become familiar with both the benefits and challenges associated with this approach in developing scientific practices.

Research on Teacher Preparation Programs Preparing Elementary Teachers to Teach Science

Research in the preparation of elementary teachers to teach science is sparse. Only one national study has been conducted to examine the content of elementary science methods courses in teacher preparation programs. Smith & Gess-Newsome (2004), examined the syllabi of 50 science methods classes to compare the content of the syllabi to examine the similarities and differences in science methods courses taught throughout the country. These syllabi were compared to *Science Teaching Standards* established by the National Research Council (1996, as cited in Smith & Gess-Newsome, 2004) and examined for curricular alignment among course objectives, activities, and assessments. The study found that there was no universal inclusion of the standards among the syllabi nor were there clear linkages between the course goals, activities, and assignments in most (Smith & Gess-Newsome, 2004). It is probably no surprise, then, that studies find most elementary school pre- and in-service teachers are not confident in the teaching of science (Anderson & Clark, 2015; Avery & Meyer, 2012; Baumgartner, 2012; Braaten & Windschitl, 2010; Davis, Petish, & Smithey, 2006; Luera, Moyer, & Everett, 2005; Mijung, 2009; Parker, 2004; Slavin et al., 2013; Tomas, Jackson, & Carlisle, 2014; Swars & Dooley, 2010).

Though limited, the research base includes qualitative and mixed methods case studies conducted by teacher educators who seek to examine various aspects of their practices. A review of these studies showed three lenses through which teacher educators address and/or examine the teaching of science content and pedagogy to elementary PSTs: 1) program structuring, 2) in-depth topic instruction, and 3) focus on practices.

Program Structuring

Because elementary school teachers are responsible for teaching across science disciplines, university teacher preparation programs are responsible for developing courses that teach physical, earth, and life science and address the pedagogies needed to teach each. Some universities attempt to address this programmatically. The literature on teacher preparation practices in science finds great discrepancies among the programming structures and methods used to address the teaching and learning of science content knowledge across disciplines.

Some require multiple discipline-specific (i.e. biology, environmental science, astronomy, etc.) and methods courses for PSTs (Beiswenger, Stepans, & Clurg, 1998; McLoughlin & Dana, 1999; Luera, et al., 2005; Varelas, Plotnick, Wink, Fan, & Harris, 2008). Though this training structure provides PSTs with the necessary content knowledge, most universities would find enrolling PSTs, being certified as generalists at the elementary school level, in multiple science courses to be unrealistic. Additionally, because science is not a standardized-testing subject, funding allocated for science instruction and training for elementary school science is limited (Varelas, et al., 2008).

Acknowledging the time constraints on course work in teacher preparation programs, one university combined the teaching of science and math methods courses to promote an interdisciplinary approach (Lewis, et al., 2014). The teacher educators who conducted the qualitative study on this course found it to be beneficial in developing PST's understanding of the value in integrating science with other subjects in authentic ways, yet failed to report on how it affected PSTs' understanding of science content. Additionally, this course did not address the need for elementary school teachers to be trained to teach multiple science disciplines.

Few studies in teacher preparation research examine the use of a comprehensive approach to teach all science disciplinary core ideas in one course. One university, however, used this approach to address growing concerns about the need for increased teacher preparation training in standardized-testing subjects (i.e. literacy and math) in accordance with the enactment of NCLB (Guziec & Lawson, 2004). This university, which formerly required PSTs to take multiple science courses, addressed the lack of personnel and resources needed to teach these courses by creating one comprehensive elementary science methods course for PSTs (Guziec & Lawson, 2004). To report the outcomes of this transition, the teacher educators, who taught two sections of the course using a parallel co-teaching model, published an article containing the general course objectives by discipline (physics, chemistry, biology, and geology) and a list of the collaborative activities within which they engaged their students. Activities found in literature or on the Internet used in science K-5th grade classes were modified and implemented to teach science and model the methods that could be used to teach elementary school students.

The teacher educators reported finding the interactive teaching model to be beneficial to students' learning when compared to lecture-type science courses taught formerly at the university. Students' final grades, standardized college course evaluations, and a course-specific reflective survey were used to assess the course outcomes. Because overall grades, averaging 82% and 81%, were used, however, there is no way to assess the growth specific to PST's content knowledge. An attempt was made to assess students' content knowledge prior to and following the course but disparities between what the teachers planned to teach and the enacted curriculum prevented these tests from accurately measuring growth in students' learning. Data collected from the students' surveys proved to be the most helpful in examining the course's effectiveness. Surveys showed even though 85% found the course to be harder than others they were taking, 71% reported increased comfort in science as a result of taking the course. Qualitative data from the surveys indicated that the format and the culture of the course made for "a successful approach to teaching science to childhood education majors" (Guziec & Lawson, 2004, p. 38). The organization of this course and the benefits reports by teacher educators suggest that the use of a comprehensive course to teach multiple disciplines through situated practices in inquiry-based instruction should be considered as a means by which to address the challenges associated with preparing PSTs to teach elementary school science.

In-Depth Topic Instruction

PSTs' science content knowledge and backgrounds in science contribute to their beliefs and attitudes toward and self-efficacy in teaching science (Luera, et al., 2005). Most PSTs lack the necessary content knowledge and understandings of science needed to teach science confidently (Anderson & Clark, 2015; Avery & Meyer, 2012; Braaten & Windschitl, 2010; Davis, Petish, & Smithey, 2006; Parker, 2004). The research base to support these assertions, however, is limited in that most studies aimed at studying the growth and development of PSTs' science content knowledge narrowly focus on specific topics within one area of a science discipline (Bulunuz & Jarrett, 2009; Trundle & Bell, 2010; Ucar & Trundle, 2011), such as teaching what causes day and night (Atwood & Atwood, 1995), or teaching biology with insects (Haefner, Patricia, & Zembal-Saul, 2006). Though their mixed methods approaches find evidence that supports inquiry practices used to increase PSTs' content knowledge in specific topics, they do not address the broader conceptual understandings of the discipline from which they originate, nor do they address the discipline as a whole.

For example, findings from Parker's (2004) review of empirical subject-specific research on the preparation of PSTs and practicing teachers suggests the synthesis of teaching content with teaching pedagogies in each science discipline is important to developing teachers' abilities to teach science. However, the studies included in her review are limited to physical science. More specifically, her review focused on conceptual areas of electricity, forces, and basic astronomy only. Broader assertions, therefore, cannot be made regarding PSTs' understanding of physical science as a whole, or the multiple disciplines that elementary science teachers are tasked to teach.

Because elementary school teachers teach across science disciplines and may teach in multiple grades throughout their careers, PSTs must be exposed to scientific inquiry using multiple science disciplines across grade levels. Experiencing inquiry in a physical science lesson, for example, might require hands-on experimentation where students investigate the movement of motorized vehicles to observe patterns they can use to explain the relationship between force and motion. This type of inquiry, however, will look different in a life science lesson in which students will use texts, visual media in the form of videos and pictures, and recorded data to develop possible explanations for the patterns in their observations about animals. They will not be able to manipulate and test the materials as they would in the physical science lesson. Thus, research on preparing elementary science teachers recommends experience and training on scientific investigations across disciplines.

Similarly, it is recommended that scientific modeling be experienced and practiced in multiple contexts. A research project study conducted across three universities, with approximately 25 students at each site, on preparing PSTs to construct, test, and evaluate scientific modeling found that experiences with and practice in scientific modeling can teach PSTs about the authentic use of modeling in the field of science (Kenyon et al., 2011). In this study, the three sites implemented four phases of instruction in which PSTs were taught to 1) construct a model, 2) evaluate scientific models, 3) revise and generate explanations and predictions using scientific models, and 4) to connect scientific models to the process in inquiry-based instruction. PSTs created and evaluated models on topics such as insects' life cycles, the solar system, electrical currents, and stages of the water cycle using dew on blades of grass. Findings from this collaborative study suggest that experiences across disciplines and in different contexts benefit PSTs in understanding how to implement this method of instruction and assessment with students based on learning progression and purpose (ie. generative models that allow for explanation and predictions and models that change as new information is gained)

(Kenyon, et al., 2011). Thus, PSTs must be prepared to design lessons that best match the pedagogical practice within the science discipline. Coursework that covers one science discipline will not provide PSTs with comprehensive training; nor will instruction that focuses on elements of inquiry or scientific modeling isolated from content.

Focus on Practices

In order to know what variables to consider when making instructional decisions, PSTs need to understand the pedagogy for teaching and learning each content area. Teachers must be prepared to teach using a “substantial amount of subject-specific examples, analyses, and practice” within their training (Shulman, 1992, p. 14). Thus, educating teachers requires training in thinking about practice through experience, reflection, and discourse about practice. PSTs need to experience inquiry as students and reflect on their experiences as well as to plan and practice these methods so they can be deconstructed and explicitly discussed.

Windschitl, Thompson, Braaten, and Stroupe (2012) refer to the core set of practices for teaching science as *high leverage practices* that make up the core repertoire of *ambitious teaching*. In science, this requires PSTs to facilitate instruction in which students are able to use science and engineering practices to engage in inquiry. Science methods should teach PSTs how to help students generate coherent explanations using evidence, understand how claims are justified, how to represent their thinking to others through scientific modeling, appropriately and critically critique others’ ideas, and revise their ideas in light of new evidence (Windschitl et al., 2012).

Studies on the preparation of PSTs to teach science examine the processes and outcomes of using inquiry-based approaches in elementary science classes. Studies in this research base are conducted by teacher educators who aim to examine instructional practices that best prepare elementary school science teachers to teach science to young children. Though they tend to focus on one topic within one science discipline, these mixed-methods (Davis & Synder, 2012; Forbes, 2011; Knaggs & Sondergeld, 2015; Parker, 2004; Mijung, 2011; Trundle & Bell, 2010; Ucar & Trundle, 2011) and quantitative studies (Luera, et al., 2005) collectively find experiencing inquiry as students increases PSTs' science content knowledge and helps them to engage in discourse about their future practice. For example, Luera, Moyer, and Everett (2005) studied the midterm exam scores of 234 students in their science methods course to determine the level of science content knowledge needed to design inquiry-based science lessons. In examining the data, they found there was a significant positive relationship between the number of inquiry-based science content courses complete by PSTs and their scores the midterm exam administered in the methods course. More specifically, students who took three inquiry-based courses scored 2.5 points higher on the midterm than students who took traditional courses only.

Teacher educators who conduct research on science teacher preparation stress that PSTs must understand not only *what* to do but *why* they are doing it (Davis & Snyder, 2012; Trundle & Bell, 2010). Even skilled science teachers who report using an inquiry-based approach have been found to be lacking implementation in the essential features of inquiry in practice (Capps & Crawford, 2012). Research on high quality teacher training asserts teachers must engage in authentic teaching practices and the analysis of practices aligned with that which is taught in the classroom (Baumgartner, 2010; Braaten & Windschitl, 2006; Forbes, 2011; Putnam & Borko, 1996). It is, therefore, important to understand how this pedagogy for teaching science should be taught to PSTs so that they are efficacious in implementing inquiry-based methods (Braaten & Windschitl, 2006; Davis & Snyder, 2012).

Explicit and reflective scientific inquiry. Case studies conducted by teacher educators aimed at examining strategies for increasing PSTs understanding of science content and of the NOS find an *explicit* and *reflective scientific inquiry approach* to be most effective in aligning PSTs' understanding of the NOS with scientists in the field (Akerson, Weiland, Park-Rogers, Pongsanon, & Bilican, 2014; Gess-Newsome, 2002). This method requires PSTs to engage in scientific inquiry as students and then to reflect explicitly afterward on how what they experienced could be tied into their future classroom and how what they have learned connects with their understanding of science (Akerson et al., 2014). Likewise, mixed methods studies aimed at examining methods effective in facilitating growth in PSTs' content knowledge find inquiry-based methods of instruction to be most effective (Davis & Synder, 2012; Forbes, 2011; Parker, 2004; Mijung, 2011; Trundle & Bell, 2010; Ucar & Trundle, 2011). These studies also assert the importance of PSTs experiencing inquiry as students, engaging in discourse on practice, and practicing the implementation the inquiry-based methods of instruction about which they learn and experience in a contextual setting similar to that within which they will teach (Bodzin & Beerer, 2003, Etkina, 2010; Gess-Newsome, 2002).

To develop confidence in implementing inquiry-based instruction, PSTs first must understand this approach from the learner's perspective. The facilitation of authentic inquiry-based experiences in teacher preparation affords PSTs opportunities to empathize with how students feel during the process and to observe and discuss how to facilitate and adjust instruction using this approach (Baumgartner, 2010; Luera, et al., 2005; Davis & Snyder, 2012). Teacher educators must model strategies to work through challenges associated with implementation of science instruction and explain the thinking involved in decision making (Etkina, 2010). A teacher might, for example, spread experiment groups out of the classroom and into the hallways so that they cannot see the planning and construction of the experiments of their classmates. This would later allow groups to compare their designs and scientific explanations or solutions to those proposed by their peers. This deliberate decision made by the instructor might be overlooked as a classroom management technique if not formally deconstructed and discussed as one that facilitates the planning and carrying out of an investigation, analysis and interpretation of data, and engagement in an argument among peers from evidence (all of which are science and engineering practices). Continued exposure to and engagement in science practices, however, does not guarantee PSTs' understanding will be developed enough to design instruction to engage them.

In her science methods course, Ricketts (2014) examined 19 preservice teachers' ideas about scientific practices through a qualitative study. She found that although they had promising ideas about some science practices (e.g. argumentation and communication between scientists) they also held problematic ideas (e.g. confusion regarding scientific modeling and conflation of argumentation and explanation building). She provided one example where PSTs' those Oreo cookies as the tools to model the phases of the moon. The use of whole and broken Oreo cookies to depict the phases of the moon implies the PSTs' emphasis on students' memorization of moon phase illustrations/visual representations and/or the names of the phases as opposed to their in-depth understanding of the configuration of the Earth, moon, and sun that creates them. Oreo cookies used to model moon phases, would assess low levels of conceptual understanding. It also would not provide opportunities to learn about students' scientific reasoning skills. Additionally, when assessing PSTs' implementation of these practices in model lessons, Ricketts (2014) found that though PSTs' lesson plans may have listed activities that would engage students in science practices, they were not always implemented in practice.

Though a small scale study, these findings support broader assertions regarding PSTs' weak, or lack of knowledge in science practices (Capps & Crawford, 2013; Kenyon, Davis, & Hug, 2011). This study also supports the need for training in strategies to assess students' understanding of science content in meaningful ways. Thus, PSTs' must be trained and practiced in methods to develop and assess students' science and engineering practices and scientific reasoning skills. Open discourse and deconstruction of instruction affords PSTs opportunities to understand *how* and *why* to implement inquiry in practice.

Materials and resources. When faced with the complexities of today's classroom, however, even teachers whose pedagogical views align with inquiry-based instructional practice feel that required textbook programs and strict curriculum guidelines prevent them from approaching science in this way. Researchers working in teacher education argue that even well trained teachers struggle to translate ideas into inquiry-based instructional approaches in practice due to these discrepancies (Forbes, 2011; Windschitl, 2004). Those without training in inquiry, often blindly follow textbook tasks and investigations and, therefore, run the risk of implementing *simple inquiry tasks* that do not reflect authentic science practices or improve students' scientific reasoning skills (Chinn & Malhotra, 2002).

To examine the differences between *authentic* inquiry practiced in the field of science and *simple* inquiry often practiced in school, Chinn and Malhotra (2002) examined 468 inquiry tasks in nine elementary and middle school textbooks to determine to what extent they incorporated features of authentic inquiry. None of the activities in the tasks they examined required students to develop their own questions, only 2% of the activities required students to choose their own variables, and few provided opportunities for students to consider controlling variables. Developing science-related questions and deciding which variables to consider are all core attributes of scientific reasoning. Without the knowledge and training to adjust these activities so they reinforce the practices in authentic scientific investigations, teachers continue to create contrived environments in which students develop inauthentic views of how science works. Likewise, scientific modeling is seldom used in elementary and middle school as the curriculum materials use modeling solely for illustrative purposes, not to teach scientific reasoning or to make sense of scientific phenomena (Kenyon, et al., 2011). Thus, teacher professional development researchers and teacher educators, alike, posit that teacher preparation should create opportunities for pre-service teachers to engage in curriculum design and discourse surrounding knowledge in practice using authentic teaching materials and resources (Cochran-Lytle & Smith, 2011; Forbes, 2011; Smith & Gess-Newsome, 2004).

Case study research conducted by teacher educators suggests the use of several strategies in adapting a traditional lesson to produce a more inquiry-based plan (Forbes, 2011; Smith & Gess-Newsome, 2004). Practices include asking students to justify their existing explanations for scientific phenomena, facilitating opportunities for students to produce, engage with, and analyze data, creating engaging, motivating, relevant, and student-directed questions, using multiple authentic tools and scientific modeling for investigations (Kenyon, et al., 2011; Schwartz, et.al., 2008), and prompting students to communicate and compare their conclusions with those of their peers (Forbes, 2011). Teachers must be skilled in evaluating science curriculum materials and instructional plans to determine how to realistically adapt them so they can be used as resources for scientific inquiry (Forbes, 2011; Smith & Gess-Newsome, 2004).

Luera, et al. (2005) found a correlation between the amount of inquiry-based experiences had by PSTs and their ability to adjust and adapt traditional teaching materials to be more inquiry-based. Data was collected from an exam in which PSTs had to adapt a science activity from a traditional textbook to be used as the basis for an inquiry-based lesson. Researchers found a significant positive correlation between the number of inquiry-based science content courses and PSTs' exam scores. Though further research must be conducted to determine whether there is a causal relationship between the two, this study suggests that repeated exposure to inquiry-based instruction facilitates PSTs' ability to adapt traditional instructional materials to facilitate inquiry-based science instruction.

Conclusion

In summary, although there is a variety of studies focused on the preparation of PSTs to teach science, each body of research contains gaps in addressing some aspect of the training needed to thoroughly prepare PSTs for their future work. Studies on program structuring attempt to address the challenges associated with designing a course that will provide PSTs with both the vast content knowledge and pedagogies they need to teach science confidentially. None, however, provide a realistic model for universities whose PSTs are required to take only one comprehensive elementary science methods course that addresses both content and pedagogy. To address this gap in the research, this study aims to examine how co-teaching can be used to address the content and pedagogy in one comprehensive science methods course.

Secondly, though studies on in-depth topic instruction examine the importance of PSTs' science content knowledge, they neglect to address the fact that elementary school generalists are required to be able to teach multiple topics in multiple science disciplines. These studies also lack data concerning how/if PSTs will use their content knowledge to teach science. Conversely, studies conducted to examine the practices used by teacher educators to teach science content and/or methods to elementary PSTs address the need for inquiry-based learning environments in the elementary school but often neglect to examine PSTs' science content knowledge. To address the gaps in these bodies of research, this study aims to measure growth in PSTs' scientific reasoning skills and examine PSTs' science content and pedagogical content knowledge, as well as to examine their perceptions of the practices used to teach them.

CHAPTER THREE: METHODOLOGY

The purpose of this case study was to examine a required methods course offered through the university's Graduate School of Education aimed at preparing PSTs to teach science in the elementary school. Data collected was used to determine how students' experienced the co-teaching model, what aspects of the curriculum PSTs said helped them learn science content and PCK for teaching science, and how their scientific reasoning skills evolved throughout the semester. The research questions that guided this study were:

1) What do PSTs learn about science content in a co-taught science methods course aimed at combining the teaching of science content with the teaching/modeling of inquiry-based instruction?
   a. What disciplinary core ideas of the NGSS do students learn?
   b. What are PSTs' scientific reasoning skills pre and post experiencing a co-taught science methods course as measured by the Lawson Test?
2) What do PSTs learn about pedagogy for teaching elementary school science in a co-taught science methods course aimed at combining the teaching of science content with the teaching/modeling of inquiry-based instruction?
   a. What do students learn about inquiry-based instruction?
   b. What do students learn about scientific and engineering practices?
3) What are PSTs experiences and evaluations of the co-taught science methods course aimed at combining the teaching of science content with the teaching/modeling of inquiry-based instruction?
   a. What aspects of the curriculum do PSTs say help them learn science content and PCK?
   b. What do PSTs say about the co-teaching model of instruction?

c. How do PSTs say the class might be improved?

d. How do PSTs say the curriculum might be improved?

In order to provide a comprehensive analysis of the research problem, this case study of my class was conducted using a concurrent mixed methods approach (Creswell, 2009). A quantitative measure was used at the beginning and end of the course to determine whether there were any changes in students' scientific reasoning skills (Creswell, 2009). Qualitative data was derived from several sources including course assignments, instructor's journal reflections, and two focus group interviews. The data collected through these methods provided a rich description of the class and students' interpretations of their experiences (Merriam, 2009). Data was collected over the course of the 2015 fall semester. In the spring of 2015, aspects of this design were piloted and studied.

Pilot Study

A qualitative pilot study was conducted with the students in my *Science in the Elementary School* course during the spring 2015 semester. Research questions guiding the pilot study were:

1) What methods do PSTs say are influential in shaping their understanding of science content and pedagogical content knowledge for teaching elementary school science?
2) What do PSTs learn about how they learn?
3) How do PST feel about teaching elementary school science?

Data was collected through analysis of 13 students' documents including assignments submitted throughout the semester and open-ended surveys taken at the beginning and end of the semester. Analysis of students' experiences in the class found that sustained exposure to inquiry-based instruction helped to provide PSTs with opportunities to learn both science content and the pedagogy for doing science. PSTs reported they learned science content, in part, because they began to believe they could over the course of the semester, whereas they had formerly believed the subject, overall, was too challenging for them to learn. Continued experiences and discourse on practice appeared to turn their trepidation and resistance into curiosity and engagement.

This pilot study informed the design of the current study in several ways. First, because the pilot study aimed to examine what aspects of the curriculum and instruction helped students learn science content and PCK, pre- and post- course reflections were collected to gather qualitative data on students' perceptions of their experiences. These documents were helpful in understanding what students believed helped them to learn the science content and, therefore, will also be used in this study. However, since the pilot study did not address students' understanding of science content and PCK, specifically, weekly checkpoint assignments, quizzes, and focus groups were added as qualitative data to study *what* students learn about science content as well as to provide more specific insight as to *how* they learned it.

Second, my pilot study was a qualitative design which allowed me to examine how students interpreted their overall learning experiences (Merriam, 2009). However, because this study aimed to examine student growth in understanding of content and in scientific literacy skills, a quantitative measure was added to help determine how much/if their science reasoning skills changed over the course of the semester.

Lastly, because only a few students gave specific details on their perceptions of the course curriculum and instruction in their reflection papers, focus group interviews were added to this study's design. Focus groups provided all students the opportunity to consider and share their thoughts about the co-teaching model, course curriculum, and methods of instruction. In keeping with the social constructivist framework, focus group interviews also afforded the students a chance to share “their own views in the context of the views of others” (Patton, 2002, p. 386, as cited in Merriam, 2009, p. 94).

Theoretical Framework

Several theoretical constructs guided the design of the curriculum and this study. First, I drew on core practices in teacher preparation, Lev Vygotsky’s social constructivist theory, and the NGSS to highlight the need for particular methods to be used in the curriculum. Second, I reviewed the research on co-teaching models to explain the benefits of this approach to teaching a course aimed at merging science with PCK for teaching elementary school science.

Teacher Education Curriculum & Instruction

Grossman, Hammerness, and McDonald (2009) assert that teacher preparation coursework should be focused on *core practices* for teaching. *Core practices* are defined as those which occur with high frequency in teaching across content areas, allow novices to learn more about students and teaching, and have the potential to improve achievement as they preserve the integrity and complexity of teaching (Grossman, Hammerness, & McDonald 2009). These core practices include the development of a classroom culture with the establishment of peer acceptance and tolerance, classroom routines, classroom management, and group work norms. Learning about how students learn and utilizing this understanding to lead classroom discussions and determine which questions to ask, how to phrase them, and how to assess students’ understanding using them are also presented as a core practices that can be taught in teacher education methodological coursework. These practices aid in creating learning environments in which students feel safe collaborating with peers and challenging themselves and their peers to take academic risks.

Research on effective teacher education has informed the curriculum for the methods course in this study as course readings, assignments, and classroom discourse is content focused on fostering classroom learning environments in which elementary school students work collaboratively to investigate scientific phenomena. Instructional approaches such as cooperative learning, which aid in facilitating social interaction among students, are modeled in an effort to help PSTs learn from these experiences as students and engage in discourse deconstructing these methods from a teaching perspective. Instruction on these core practices attempted to foster PSTs' understanding of and experiences in the complex set of skills required of educators in the field (Grossman, et al., 2009). Though grounded in research on how students learn and how best to teach content, these core practices must also address the challenges involved in teaching each subject area.

Practices in this science methods course were also, therefore, informed by research on preparing teachers through experiences in inquiry-based instruction. Teachers who practice this approach use questions about scientific phenomena to guide instruction and employ experiments and technology to support students in their quest to understand the scientific concepts. Though instruction on science might begin in one particular science discipline this experience acts as a starting point on which connections are later built across multiple disciplines. Thus, the science content covered in the course curriculum connected the science disciplines in relevant and authentic ways. Investigations in this methods course were framed so that PSTs worked collaboratively to identify science oriented problems or questions, collect evidence in response to the problem/question, use evidence to develop explanations, link the explanation to prior scientific knowledge, and communicate their scientific understanding. As a result, it was expected that PSTs would become part of a discourse community aimed at learning by doing science, reflecting on collaborative investigations, and discussing how learning experiences could be used to teach young students about science (Knaggs & Sondergeld, 2015; Lewis, et al., 2014).

These exchanges are grounded in research on Lev Vygotsky's social constructivist learning theory (Palincsar, 1998). Vygotsky believed that the disequilibrium that results from social interaction among children and their peers/significant others creates powerful opportunities for learning (Hus & Aberšek, 2011; Palincsar, 1998; Vygotsky, 1978). He believed this disequilibrium forces the child to consider different ways of thinking and knowing that result in cognitive growth (Hus & Aberšek, 2011; Palincsar, 1998; Vygotsky, 1978). Because students come to science class with preconceived ideas about the scientific phenomena they experience daily, science teachers must create opportunities in which they question these ideas and test them against the understandings shared by others. This theory undergirds the norms and practices of the science community and the collaborative work of scientists' in which they co-construct new knowledge (Lewis, et al., 2014).

Engaging in arguments from evidence and communicating information, for example, are two scientific practices promoted by the NGSS and the NRC. The argument structure in inquiry provides "a guideline for how a scientific explanation can be organized, as well as the kinds of contributions considered appropriate when talking science in the classroom" (Zembal-Saul, 2009, p. 693). In constructing an argument, students' thinking is made visible and teachers are therefore able to engage students in open thinking strategies that are communicated and evaluated publically (Zembal-Saul, 2009). As the students engage in scientific practices that allow them to construct scientific arguments using evidence, they "adopt norms for talking, writing, and reading in science that reflect social practices of science" (Zembal-Saul, 2009, p.

693). These experiences require the kind of social exchanges Vygotsky describes in which children communicate their ideas and prior knowledge to peers, consider evidence from investigations, and collaboratively reshape their understandings of science concepts. Constructivist teachers of science facilitate opportunities for students to engage in discourse that brings about advancement in scientific conceptual understanding. Though the content and specific investigations change during each class meeting, the process of developing evidence-based scientific knowledge as modeled, as depicted in Zembal-Saul's *Teaching Science as Argument Framework* (See Figure 1), is consistent.

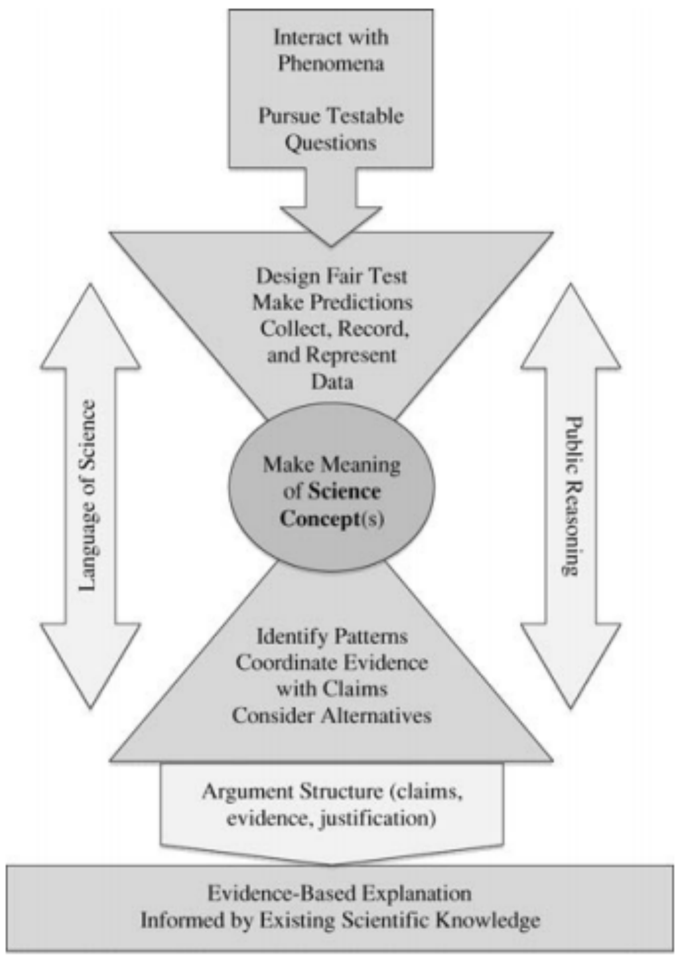


Figure 1. Teaching science as argument framework.

In addition to facilitating students' interactions in a social constructivist model, the teacher mediates their work to foster cognitive advancement. In Vygotsky's view, true cognitive development necessitates social interaction with a peer or teacher whose knowledge and/or abilities could further those of the learner (Hus & Aberšek, 2011; Palincsar, 1998; Vygotsky, 1978). He refers to the area in which a learner is not yet able to work independently but is capable with the assistance of another whose knowledge and/or skills are superior as the *zone of proximal development*. In order to be able to move students forward in their understanding of science content and pedagogy, teachers must be knowledgeable and skilled in science. This supports research on the importance of the teacher's science content knowledge, scientific reasoning skills, and PCK in developing scientific literacy. The co-teaching model was selected as the means by which to teach this course so that the instructors' diverse areas of expertise could be used to further students' knowledge and understanding of both science content and methods for teaching. Through this collaborative teaching approach, students learned about and conducted science within the zone of proximal development.

Co-Teaching

To date, I have not found research on an interactive co-teacing approach to teaching a science methods course. However, research on co-teaching in higher education, often reported as small case studies conducted by teacher educators, suggests that this approach benefits both students and teacher educators in several ways (Higgins & Litzenburg, 2015; Shibley, 2006; Vogler & Long, 2003). Students in these studies reported co-teaching to be beneficial as it helped them develop critical thinking skills through the synthesis of the diverse perspectives of the instructors (Higgins & Litzenburg, 2015; Shibley, 2006; Vogler & Long, 2003), provided increased opportunities for individualized instruction (Vogler & Long, 2003), and allowed them to experience teacher collegiality (Higgins & Litzenburg, 2015; Shibley, 2006; Vogler & Long, 2003). Case studies conducted by teacher educators who practice co-teaching have reported with a shared pedagogy for teaching, open communication with their partner teachers, and clear responsibilities and expectations for instruction and assessment, co-teaching can be a very rewarding professional experience (Higgins & Litzenburg, 2015; Shibley, 2008; Vogler & Long, 2003). Although there are different models of co-teaching, an *interactive co-teaching* model was chosen for this course as the instructors participate equally in class discussions and activities (Dugan & Letterman, 2008) fostering a great deal of interaction and dialogue between the teachers and their students.

The design of this study drew from core practices in teacher preparation, social constructivist theory, and inquiry-based science practices in several ways. First, the curriculum was designed to merge the teaching of science content aligned with the NGSS with the core practices of elementary school teachers. In accordance with research on effective practices in teacher education, these practices were experienced, deconstructed, reflected upon, discussed, and practiced by the PSTs. Inquiry was used as the main instructional approach as it required students to work collaboratively, discuss, and debate their understandings of science to investigate science-based problems. Second, the co-teaching model, chosen as the means by which to teach the *Science in the Elementary School* course, allowed students to benefit from interactions with teachers whose varied expertise furthered their levels of cognition in two areas of knowledge necessary for teaching science. Additionally, as higher education research on co-teaching asserts, both members of the co-teaching team experienced cognitive growth through discourse on planning for, implementing, and assessing instruction. It was assumed, then, that by creating a curriculum designed to engage PSTs in core practices for teaching and inquiry-based methods of instruction for teaching and learning science through a co-taught course, they would gain both the content and PCK needed to teach science confidently and effectively.

Sample

This study took place in the context of a required science methods course for undergraduate preservice elementary school teachers at a state university in New Jersey. A convenience sampling design was used as the PSTs in this study were those enrolled in my science methods course. The sample consisted of 14 PSTs, all females, who were a small group within a larger cohort of 91 elementary preservice teachers. All of the students were in the 5-year dual certification elementary education program and were enrolled in multiple methods courses in addition to the science methods course while also completing a practicum experience in local elementary schools once weekly. As can be seen in Table 3, each was also seeking middle school certification in a subject matter.

Table 3. *Middle School Subject Matter Certifications*

Student	**Subject Matter Certification**
Diana	Math
Leah	Social Studies
Missy	Math
Bree*	Math
Josie	English
Erin*	English
Karin	Math
Jen	Math
Maria*	Science
Cameron	Math
Ann	Math
Jodi	Math
Lydia	Math
Jane	English

*Nested case subjects

Only one student of the 14 enrolled was seeking a science certification, initially. All 14 students gave consent (See Appendix C) to take the measure of scientific reasoning and participate in focus groups interviews.

Of these 14 students, 3 were purposefully selected for deeper analysis in a *nested case study* (Merriam, 2009). Pre-course assessment scores were used to categorize the class into three groups based on scientific reasoning skills (i.e. high, middle, and low). One student from each category was selected to represent the widest possible range of abilities, or to achieve maximum variation, in the sample (Merriam, 2009). In addition, the three nested case subjects were chosen because they often sat at different tables, therefore working most frequently with a different group of classmates, because I perceived their class performances (i.e. volunteer participation, types of questions asked, comfort with science, etc.) to be distinctly different.

Data Collection Procedures

In keeping with a concurrent mixed methods research design, qualitative and quantitative data were collected simultaneously (Creswell, 2009). Because this study aimed to merge the teaching of science content with PCK for teaching elementary school science, a mixed methods approach afforded opportunities to measure what PSTs learned with regard to science content and scientific reasoning and to analyze their thoughts on what aspects of the curriculum and instruction helped them to learn the content and develop those skills.

Two sets of data were collected for this study. One set of data was used to examine the learning and experiences of the whole class, of 14 students. The second set, which involved the collection of qualitative data, enabled me to develop case studies of 3 students' experiences of the class.

Learning and Experiences of the Whole Class

Four data sources were used to examine what students learned. The Lawson Test was administered to collect quantitative data to measure growth in students' scientific reasoning skills. All students were also invited to participate in focus group interviews to elicit their perceptions of the science content knowledge and PCK they learned. Focus groups were also used to examine students' perceptions and evaluations of the course curriculum and instructional model. Coursework and focus groups were used to determine what students learned in terms of science content and PCK. Lastly, my reflective journal was used to provide a complete description of the class' overall experiences and capture any evidence related to the foci of this study.

Pre- and post- scientific reasoning test. To determine how and/or if students' scientific reasoning changes over the semester, the *Lawson Test of Scientific Reasoning* (See Appendix B) was used as a pre- and post- test measure (Creswell, 2009). The test is comprised of 24 two-tier, multiple-choice questions designed to test students' reasoning skills associated with conservation, proportional thinking, identification and control of variables, probabilistic thinking, and deductive reasoning (Carmel & Yezierski, 2013; Coletta & Phillips, 2009). The two-tier design required students to, first, choose a correct answer and, second, choose the correct reasoning for the answer (Carmel & Yezierski, 2013). The distractors for each item are correct answers for incorrect reasoning patterns shown to be representative of students' misconceptions in free response tests, interviews, and the literature on scientific reasoning (Carmel & Yezierski, 2013). Four items were removed for the purpose of this study as they were not aligned with elementary school NGSS content.

The Lawson test has been validated in several studies and has been found to show a correlation between deep understanding in multiple science disciplines, such as physics, and scientific reasoning skills (Carmel & Yezierski, 2013; Coletta & Phillips, 2009; Pyper, 2012). As this study aimed to examine the development of students' science content knowledge and PCK, this test was administered to help determine whether the course facilitated the development of the scientific reasoning skills which are prerequisite for scientific conceptual understanding (Pyper, 2012). A test of scientific reasoning was chosen as the means by which to measure students' growth in understanding instead of a traditional topic specific content knowledge test because there is no current, valid content assessment that measures growth in the all of disciplinary core concepts identified in the NGSS.

The Lawson Test was administered, via paper and pencil, to the students during the first class meeting. The assessment, however, did not count toward a course grade but students earned credit for their participation in this assessment and others throughout the course. On the final day of the 15-week semester, students were, again, administered this assessment using paper and pencil. Results from the Lawson Test conducted before and after the course were compared and analyzed to determine if/where their scientific reasoning skills improved (Creswell, 2009). This data was recorded electronically on an Excel Spreadsheet and organized by the scientific reasoning skills targeted in each two-tier item and the accuracy of students' responses to each tier in each item set.

Focus groups. In keeping with a constructivist theoretical framework, focus groups were selected for this study to capture the students' interactions in discussing their perceptions of their shared experiences in the science class (Merriam, 2009). In focus group discussions, participants get a chance to hear the responses of others and to make additional comments or elaborate on those shared (Patton, 2002). Thus, this method allows for the collection of socially constructed data (Merriam, 2009).

The focus group discussions in this study aimed to prompt PSTs to share their overall perceptions of their experiences as students in an interactive co-teaching environment in which the design of curriculum and instruction aimed at merging science content with inquiry-based instruction. The semi-structured interview guide allowed for both planned, open-ended questions (see Appendix D) and open discussions that invited participants to explain their ideas in detail and elaborate on their experiences (Creswell, 2009; Merriam, 2009; Patton, 2002). The planned interview guide helped to make use of the focus group interview time and keep the interactions focused on the purpose of this study while also allowing individual perspectives and experiences to emerge (Patton, 1990). The interviews began by asking participants to share their general experiences in the course and led to more specific questions regarding aspects of the co-teaching model and of the curriculum. Focus group data provided insight on students' perceptions of what they learned about science content and PCK. They also afforded students opportunities to share their perceptions and evaluations of the curriculum and co-teaching model of instruction.

Focus groups were conducted at the university's Graduate School of Education one week after the course was complete. All students were invited to participate. One student was unable to attend due to car trouble so the focus groups consisted of 7 and 6 students respectively. To avoid researcher influence, interviews were facilitated by a fellow doctoral student with experience facilitating focus groups (Merriam, 2009). The facilitator received a small stipend and participants were provided refreshments during the interview. Interviews were audio recorded and later transcribed.

Reflective journal. The purpose of this study was to gain insight on how students experienced the curriculum and instruction of this co-taught science methods class. Acting as a participant observer, I jotted hand-written notes about instances that stood out as being indicative of students' learning and instructional methods appeared to aid in students' growth in understanding of science or in the science practices. These participant observer's reflections of practice helped to provide context for and specific incidences as reference points for data analysis (Merriam, 2009).

Following each class meeting, I transformed my jottings into dated field notes recorded in a document on my password-protected laptop (Merriam, 2009). These field notes created a record of the class' experiences and documented events that might be forgotten by the semester's end due to extended time in the classroom (Emerson, Fretz, & Shaw, 1995). In these notes, I continually considered and reflected upon my understanding (Emerson, Fretz, & Shaw, 1995) of the planning and implementation of instruction using an interactive co-teaching model, the students' interactions in independent, partner, and group activities, and the class discussions including the kinds of questions asked and answered by the students and of the main discussion points ranging from specific details to overarching themes. I also reflected on the overall tone and climate of the learning environment. Both the observational and reflective data aided in creating highly descriptive depictions of the class (Creswell, 2009; Merriam, 2009) and allowed me to consider my processes for, and stages in, understanding them along the way (Emerson, Fretz, & Shaw, 1995).

Researcher's journal reflections were used to provide descriptive accounts of the students' experiences. I attempted to capture some of the exchanges between the students and, specifically, how their interaction with each other and the investigation materials constructed their understanding of the content. I recorded in my notes, statements made by students during our class closure activities in which students reported, aloud, what they learned during each class session. I also recorded interactions with my co-teacher in both our planning and teaching in action.

Table 4. *Research Questions & Whole Class Case Study Data Sources*

Research Questions	**Sources**
Whole Class Case Study	
1. What do PSTs learn about science content in a co-taught science methods course aimed at combining the teaching of science content with the teaching/modeling of inquiry-based instruction?	• Reflective Journal • Focus Group Interviews • Course Assignments • Lawson Test
1a. What disciplinary core ideas of the NGSS do students learn?	• Reflective Journal • Focus Group Interviews • Course Assignments
1b. What are PSTs' scientific reasoning skills pre and post experiencing a co-taught science methods course as measured by the Lawson Test?	• Lawson Test
2. What do PSTs learn about pedagogy for teaching elementary school science in a co-taught science methods course aimed at combining the teaching of science content with the teaching/modeling of inquiry-based instruction?	• Reflective Journal • Focus Group Interviews • Course Assignments
2a.What do students learn about inquiry-based instruction?	• Reflective Journal • Focus Group Interviews • Course Assignments
2b. What do students learn about scientific and engineering practices?	• Reflective Journal • Focus Group Interviews • Course Assignments
3. What are PSTs experiences and evaluations of the co-taught science methods course aimed at combining the teaching of science content with the teaching/modeling of inquiry-based instruction?	• Focus Group Interviews • Course Assignments
3a. What aspects of the curriculum do PSTs say help them learn science content and PCK?	• Focus Group Interviews • Course Assignments
3b. What do PSTs say about the co-teaching model of instruction?	• Focus Group Interviews
3c. How do PSTs say the curriculum might be improved?	• Focus Group Interviews

Course assignments. Throughout the semester, students were responsible for completing three assignments that assessed science content and PCK: *weekly checkpoints,* *quizzes, unit plans,* and, *reflections*. Weekly checkpoints, reflections, and unit plans were submitted to me electronically and compiled by student and date submitted. Quizzes were completed by hand in class, scanned into the computer as PDFs, and compiled along with weekly checkpoints and reflections by student and date completed. All documents were organized in each student's file in the order they were received. Compiling assignment data by the dates they were submitted helped to connect the data with the curriculum design.

Weekly checkpoints. Each week, the students were asked to submit an assignment answering two questions: 1) What have you learned in terms of content and how did you learn it? 2) What have you learned in terms of pedagogy and how did you learn it? These assignments were submitted to the instructor electronically a few days before the following class meeting. The instructor reviewed them for accuracy and depth of scientific knowledge and conceptual understanding and the acquisition of PCK and methods of practice. They were assessed for alignment between the claims made by the students and the evidence used to explain those claims (Allchin, 2011; Duncan & Cavera, 2015; Zembal-Saul, 2009). The students received feedback within two days after the assignment was submitted and before the next class session. Students were permitted and encouraged to resubmit these assignments until they demonstrated mastery of the content and/or pedagogical understanding using evidence from investigations and instructional modeling conducted in class. Therefore, these documents also showed the exchanges between the students' and instructors and provided documentation on how the co-teaching responsibilities were shared. In all, these documents helped to make meaning of the class events as experienced by the students (Merriam, 2009).

Quizzes. At various points throughout the course, unannounced quizzes were administered to the students. These quizzes were similar in format and function to the weekly checkpoints as they also contained two questions, one focused on content and the other focused on pedagogy, and student were allowed to resubmit them with improvements to facilitate high quality conversations between the students and the instructors. The quizzes, were used to provide qualitative data for analyzing students' understanding of science content and conceptual understanding of how their understanding could be transferred into an authentic classroom scenario. The content check items on the quizzes prompted students to plan an experiment or activity to model a concept about which they learned previously in class. The pedagogy check on the quizzes asked PSTs to analyze students' responses in a mock lesson and to determine how they would proceed given a student's response. For example,

> *In a lesson on density, the teacher asks students to conduct and experiment testing objects to determine if they sink or float. A student responds to the teachers request to share their findings in the experiment by saying, "Heavy things float."*

PSTs were required to evaluate the student's response and to determine how they might prompt the student to explain his thinking and support it with results of the experiment. PSTs also needed to explain how they would scaffold instruction to correct this misconception without stifling the student's eagerness to engage in experimentation and inquiry. This qualitative source provided in-depth, descriptive data regarding the content knowledge and PCK gained over the course of the semester (Creswell, 2009).

Unit plans. The development of an elementary science unit plan requires knowledge and conceptual understanding of science content and the methods that will afford students opportunities to practice science through inquiry. At the beginning of the semester, PSTs chose a unit topic for which they researched the NGSS that addressed the topic and the science content necessary to plan and teach it effectively. They considered the big ideas, enduring understandings, essential questions, and lesson objectives the unit addressed overall (Wiggins & McTighe, 2011). They then planned two detailed lessons that demonstrated their understanding of science content and the foundational knowledge required for students to be able to engage in the lessons. These two lessons also required PSTs to model the argument framework for teaching science through inquiry (Zembal-Saul, 2009). In addition, they composed multiple lessons in less depth that showed how they would conduct an entire unit. The scope and sequence of their unit planning provided evidence to examine PSTs understanding of the learning progression for their chosen topic (Fortus, et al., 2015; Micheals, et al., 2008).

To assess PSTs' understanding of scientific modeling through practical planning, they were also required to develop two scientific models that could be used to make students' thinking and understanding visible (Schwarz, et al., 2009). One scientific model represented how a student might view a science concept central to their chosen unit using common misconceptions. The second model represented the scientifically accepted conceptual understanding. PSTs were asked to create a script that explained how the teacher would mediate students' thinking by engaging them in arguments focused on scientific reasoning (Kenyon, et al., 2011; Lott & Wallin, 2012; Micheals et al., 2008; Schwarz et al., 2009; Zembal-Saul, 2009) from common misconceptions to scientifically accepted models.

Reflection papers. As this study aimed to understand what methods of instruction PSTs perceived helped them learn science content and how to implement inquiry-based instructional methods, PSTs were asked to compose an in-depth reflection paper both before and after the course. At the beginning of the semester, PSTs were required to compose a pre-reflection paper sharing their experiences as K-12th grade students of science. They were prompted to think and write about what they remembered from their elementary school science-related experiences and to articulate their science teaching philosophies. They were also asked to describe science courses they took as college students. These reflections helped to capture how differences in their science backgrounds may have contributed to their perceptions of the course (Merriam, 2009).

Their final assignment for the semester was to revisit this pre-reflection paper and consider if and how their thinking about science instruction in the elementary school evolved. In this final reflection they were asked to explain what methods of instruction they felt were most helpful in facilitating the acquisition of science content knowledge and PCK for teaching science. The reflection papers, in particular, created a snapshot of the nested case students' understanding of the NOS and the aspects of the curriculum and instruction they found to be important to their learning (Merriam, 2009). Both pre- and post- course reflections were collected electronically and organized by student.

Nested Case Study

In addition to data collected on the whole class, three students were selected for a nested case study so their work would provide varied and highly descriptive portraits of student learning. These three students were purposefully selected for maximum variation. Course assignments were used to qualitatively represent each student's understanding of the course content, specifically content knowledge and PCK for teaching elementary school science throughout the course. These assignments captured how students explained their understanding of a science concept and PCK, their perceptions of how they learned the content, and the feedback exchanges between the student and instructors (Merriam, 2009). The reflection papers also provided data regarding students' perceptions of the co-teaching model and the course curriculum. All documents collected used to obtain the thoughtfully composed language and words used to describe their learning experiences (Creswell, 2009).

Data collected from researcher's journal reflections helped to contextualize and create a rich, thick description of some of the activities students described in their coursework (Merriam, 2009). Focus group interviews also helped to examine students' perceptions of what they learned in the course and what aspects of the curriculum and instruction they felt were helpful to their learning. Their evaluations of the course were also captured through focus group interviews. Comments posed by these 3 students in focus group interviews also provided insight into their feelings about and interpretations of the co-teaching model and the curriculum (Merriam, 2009). These comments were pulled out of interview transcriptions and catalogued within each student's data folder. Data for these students were housed in separate files on my password-protected laptop and labeled with the each student's chosen pseudonym. Hard copies of the documents in these folders, also organized by student using pseudonyms, were kept in a locked cabinet in my home office.

In summary, these procedures resulted in the collection of both whole class case study data and nested case study data that were used to answer the research questions in this study (See Tables 4 & 5). The whole class case study data included pre- and post- course Lawson test results. This data set helped to more deeply examine the learning experiences of students who entered the course with differing levels of scientific reasoning skills. Documentary evidence in the form of course assignments including pre- and post- course reflection papers, eight weekly checkpoints, three quizzes, and one science unit containing lesson plans, two scientific models, and a lesson play offered data to analyze PSTs' learning of science content, pedagogy, and science and engineering practices. This documentary evidence and focus group interview data captured PSTs' perceptions and evaluations of the curriculum and methods used to teach them. Researcher's reflective journal notes were used to capture both general whole class experiences and specific accounts of the nested case study students' experiences. In total, I collected 14 weeks of journal notes.

Table 5. *Research Questions & Nested Class Case Study Data Sources*

Research Questions	**Sources**
Nested Case Study	
1. What do PSTs learn about science content in a co-taught science methods course aimed at combining the teaching of science content with the teaching/modeling of inquiry-based instruction?	• Course Assignments • Reflective Journal • Focus Group Interviews • Lawson Test
1a. What disciplinary core ideas of the NGSS do students learn?	• Course Assignments • Reflective Journal • Focus Group Interviews
1b. What are PSTs' scientific reasoning skills pre and post experiencing a co-taught science methods course as measured by the Lawson Test?	• Lawson Test
2. What do PSTs learn about pedagogy for teaching elementary school science in a co-taught science methods course aimed at combining the teaching of science content with the teaching/modeling of inquiry-based instruction?	• Course Assignments • Reflective Journal • Focus Group Interviews
2a. What do students learn about inquiry-based instruction?	• Course Assignments • Reflective Journal • Focus Group Interviews
2b. What do students learn about scientific and engineering practices?	• Course Assignments • Reflective Journal • Focus Group Interviews

Table 5. Continued

Research Questions	**Sources**
Nested Case Study	
3. What are PSTs experiences and evaluations of the co-taught science methods course aimed at combining the teaching of science content with the teaching/modeling of inquiry-based instruction?	• Course Assignments • Focus Group Interviews
3a. What aspects of the curriculum do PSTs say help them	• Course Assignments

learn science content and PCK?	• Focus Group Interviews
3b. What do PSTs say about the co-teaching model of instruction?	• Course Assignments (i.e. Reflections) • Focus Group Interviews
3c. How do PSTs say the curriculum might be improved?	• Course Assignments (i.e. Reflections) • Focus Group Interviews

Data Analysis

Data analysis took place in three phases to answer the research questions. First, I reviewed the whole class data set (see Table 4). Then I reviewed the data set for the nested case study (see Table 5). Lastly, I examined the two sets of data together to understand what students learned, what aspects of the curriculum and/or co-teaching modeled helped students learn, and what aspects did not. This analysis was used to make recommendations for future course improvements.

Phase 1: Whole Class Case Study

I began by examining quantitative data collected from the pre- and post- course Lawson Test to look at students' scientific reasoning before and after the course. Students were scored based on how many of the 10 two-tier, multiple-choice items they answered correctly at the beginning of the course as compared to their results at the end of the course. I organized students' data in an Excel spreadsheet. I then created descriptive statistics that examined if and how the different types of scientific reasoning skills improved from pre- to post- course results through analysis of each item. Findings from this measure were embedded into the primarily qualitative database providing statistical data to support or counter qualitative findings (Creswell, 2009). I also reviewed descriptive statistics in relation to demographic data on students such as the number of science courses they took as college students.

Second, I transcribed the focus group interviews. I then coded them in relation to the research questions focused on student learning, content, pedagogies, curriculum, and instruction, organized and labeled them in a Microsoft Word document (Creswell, 2009; Patton, 2002). I sorted the interview data deductively by these broader categories to learn what students said about them. For example, when deductively coding for content I looked at instances in which PSTs mentioned examples within each discipline: physical, earth and space, and life science. I used these codes to identify what students said about each discipline and found broader categories that suggested students learned from practices such as scientific investigations, questioning, and scientific modeling. Interview data was then sorted by these broader categories. Next, I inductively coded within each category to learn about which investigations students talked about most frequently and with the most detail and depth. I also coded across these categories to examine what about these practices students said helped them to learn and their perceptions and evaluations of how the curriculum could be improved.

Third, I used the coding scheme created for the focus group data to analyze my field notes. I coded for specific aspects of co-teaching and student learning and cross checked them with the focus group data to better understand the contextual variables that may have contributed to student learning and experiences. I also used the coding scheme to look across documentary evidence to better understand how students communicated their learning throughout the course. With coding complete, I looked across data sources from the whole class to answer research questions focused on examining what students learn about science and PCK for teaching science and what students said helped them to learn both content and PCK.

Phase 2: Nested Case Study

In the second phase of data analysis, I examined the accrued data for each of the three study participants selected for the nested case study (Merriam, 2009). I reviewed each student's data folder which included documents in the form of class assignments, reflective journals references to the students, focus group comments, and pre- and post- course Lawson Test scores. I focused on each student as her own case and conducted a qualitative analysis of the documents collected. Codes were focused on student learning of science content, PCK, and her evaluations of the curriculum and course design. I created a chart in which I organized comments that stood out from each data set in correlation to the codes. I listed them first by the documents from which they were collected. Then I looked across them looking for trends in how each student talked about science as a student and as a future teacher. Subcodes captured evidence of how each case study subject talked about learning and teaching science (i.e. discovery, collaboration, hands-on). I then reread the documents collected in each folder several times and coded for her learning over time. For example, I compared codes in pre- and post- reflections to examine how students talked about their self-efficacy in learning and teaching science before and after the course. I also looked at how/if the way case study students explained their understanding of science content and PCK evolved over the course of the semester and consistencies in those explanations that would shed light on how each expressed her understanding of science. For example, during this stage, I discovered trends in how Bree talked about science in relation to numbers or mathematical reasoning. This discovery prompted me to look into what subjects the nested case study students were specializing in, in their preparation programs, and then to review the data folders to look for evidence of the students' subject matter concentrations in their course assignments and focus group comments. Using the data set for each student, I created a portrait of her experiences as a learner in the class, what she learned, how she expressed her learning, and how/if her learning changed over time. Data analysis resulted in three small portraits of students as learners. This data helped to identify the contextual variables that mediated each student's learning related to content and pedagogy and her perceptions of the curriculum (Merriam, 2009; Yin, 2008).

Phase 3: Comprehensive Case Study

Lastly, I conducted a c*ross-case analysis* in order to inductively build generalizations across cases regarding students' experiences in the course and what aspects of the curriculum helped them to learn (Merriam, 2009). I reviewed the focus group data using the coding scheme and inductively constructed themes that capture what content students learned throughout the course (Creswell, 2009; Patton, 2002; Yin, 2008). Using this data, I attempted to explain the science content and PCK students learned. Challenges I experienced in identifying what students learned in terms of content prompted me to revisit this data and recode for science and engineering practices (i.e. developing and using models, analyzing and interpreting data, and constructing explanations) as they correlated to the skills students identified in relation to what they learned. Later, categories were inductively created within these codes to more broadly illustrate how students' experiences were mediated by the scientific processes (i.e. physical investigations and scientific modeling) they experienced as students of science. For example, several students cited the investigation on Newton's Laws in which Chris modeled the laws on roller blades. Though students did not explicitly state the laws in focus group interviews, they talked at length about the learning process in this investigation. They explained that having to discover the science behind the phenomena themselves by making observations and collaboratively developing claims based on their observations made them feel like scientists. Thus, it was the scientific processes (i.e. conducting investigations, making observations, developing scientific claims based on their observations, and explaining the reasoning that connected the evidence to the scientific claims through scientific modeling) that helped them to learn.

In discovering themes across artifacts collected, I was able to deduce how students talked about what they learned in terms of science and how to teach it to elementary school students, and their perceptions of the use of inquiry-based instruction to teach PSTs. I was also able to examine their perceptions of the co-teaching model.

Validity & Reliability

Qualitative research results are valid when "they are trustworthy to the extent that there has been some rigor in carrying out the study" (Merriam, 2009, p. 209). Creswell (2009) recommends the use of multiple validity strategies to ensure credibility of the research findings. To ensure the findings of this study are credible I incorporated three validity strategies (Creswell, 2009). These strategies include triangulation, rich description, and self-reflexivity.

Data triangulation is defined as the use of multiple methods and/or multiple sources to confirm emergent findings (Merriam, 2009). To triangulate the data in this study, I cross referenced the documents, focus group transcriptions, and researcher's journal with regard to how they linked to the research questions posed in this study (Creswell, 2009; Merriam, 2009; Patton, 2002). A matrix was used to compare quantitative data from the pre- and post- course Lawson Test with the qualitative data collected from each of the three students purposefully selected to achieve the maximum variation. The use of both qualitative data and a quantitative measure created opportunities to cross-check documents to ensure the credibility of my findings. Lastly, I specifically explained the data collection and analysis procedures, the development of themes based on evidence across data sources, and how and why more weight and/or credibility was given to themes or categories agreed upon by a larger number of participants (Merriam, 2009).

To maintain the integrity and rigor of the qualitative data collection and analysis process, I openly shared my professional and personal background, values, and assumptions as well as explicitly explained my role as both a researcher in this study and an instructor for the course (Merriam, 2009). To demonstrate researcher reflexivity in presenting the study's findings I also included any outlier data which ran counter to the themes and/or my own bias by revisiting my assumptions to determine if they should be reevaluated (Creswell, 2009) or included to capture the experiences of a particular case (Merriam, 2009).

Lastly, this study was peer-reviewed with my doctoral dissertation study group. This peer review served as an external check of my research (Creswell, 2013). Meeting bi-monthly, my peers reviewed my data collection and analysis processes, posed questions about my methods, meanings, and interpretations, and sympathetically aided me in navigating my first experience conducting research (Lincoln & Guba, 1985 as cited in Creswell, 2013).

CHAPTER 4: THE CO-TAUGHT SCIENCE METHODS COURSE

Much has been written about the inadequate preparation of elementary school teachers in science instruction (Baumgartner, 2010; Bodzin & Beerer, 2003; Bulunuz & Jarrett 2009; Swars & Dooley, 2010), and as a result, teacher educators and researchers alike have tried different approaches in an effort to better prepare elementary school teachers to teach science. Several have studied the outcomes of topic-specific courses within one area of a science discipline (Atwood & Atwood, 1995, Bulunuz & Jarrett, 2009; Haefner, et al., 2006; Trundle & Bell, 2010; Ucar & Trundle, 2011) while others have studied what PSTs learn when they are required to enroll in multiple discipline-specific and methods courses (Beiswenger, Stepans, & Clurg, 1998; McLoughlin & Dana, 1999; Luera, et al., 2005; Varelas, et al., 2008) or when the teaching of multiple subjects, like science and math, are combined into one course (Lewis, et al., 2014). Elementary science courses are often taught by one instructor whose area of expertise is narrowly focused in either a specific science discipline or in elementary school methods. This results in multiple areas of science or practical methods for implementation being left out of the curriculum. This study sought to build on this work and address these issues in two ways. First, this study documents the implementation of a curriculum aimed at the teaching of a range of science topics, rather than a single discipline, in the elementary school across one semester. Second, this study examines what happens when an expert in elementary school methods of instruction and an expert in physics instruction collaborate in an interactive co-teaching model to merge the teaching of content and pedagogy.

In this study, I examined what PSTs learned from this course and which aspects of the curriculum they attributed to their learning. In what follows I begin with a description of the curriculum and course design to illustrate the activities within which PSTs engaged and how the co-teaching model was implemented. Following this account of the curriculum in action, I examine turn to the PSTs' evaluations of the curriculum and course design.

Curriculum and Course Design for an Elementary School Science Methods Course

There is currently no research on what science content should be addressed in methods courses that prepare elementary school teachers to teach science. There is no universal inclusion of the NGSS or scientific practices among them, nor is there clear alignment between the course goals, activities, and assignments in most (Smith & Gess-Newsome, 2004). The disciplines and topics addressed in the curriculum are often determined by the area of expertise and/or preferences for content and/or experiments held by the professor conducting the course (Lewis, et al., 2013). The accrued evidence would suggest this haphazard approach to curriculum design has created inconsistencies in preparing most teachers of elementary school science and allowing few to acquire the pedagogical skills and content knowledge required to teach science of multiple disciplines confidently (Anderson & Clark, 2015; Avery & Meyer, 2012; Baumgartner, 2012; Braaten & Windschitl, 2010; Davis, et al., 2006). Thus, the curriculum for this course was designed to provide our students with interdisciplinary experiences that would facilitate the discovery of a wide range of foundational science concepts central to each discipline. This course was also designed to have students practice doing science through inquiry-based methods of instruction; thus attempting to merge the teaching and learning of science content with the modeling of pedagogical practices best for teaching elementary school science.

The vignette that follows illustrates how this played out in our co-taught science methods classroom.

> *The lesson begins with Chris wiping rubbing alcohol on the chalkboard with a paper towel... "What happened to the alcohol?" he asks the students. Some say that the*

alcohol "went away" another says it "disappeared." When prompted for more detailed observations, Erin suggests that the alcohol floated away and Ann offers the idea that the "wind" took it away. Generally, the students agree that the alcohol gradually went away and that it did not disappear all at once. They also agree that the alcohol smelled when it was wiped onto the board and that the students closest to it could smell it the strongest. Following this discussion, Chris prompts the students to consider how they might show what happened to the alcohol in a model. Seated in teams of four, the students draw, on their group marker boards, what the alcohol might look like under a very high powered microscope.

Chris and I circulate the room while, students debate and discuss how to model their observations. Once most groups finish, Chris asks them to hold up their boards to show their classmates their drawings. All of the groups drew the alcohol as dots in an oval shape with more dots on one side of the shape and gradually less leading to the other. Chris asks, "Why did you draw the alcohol as small dots and not one big blob?" Students help each other to come to the conclusion that they decided to represent their observations this way because the alcohol slowly moved away in stages, not all at once, so there had to be pieces disappearing a little at a time.

"What claims can we make given what we observed?" I ask. The students agree that the alcohol was made of small pieces, or particles, and that went away, or moved from the board because the students closest to it could smell it. Students identify that making observations was the first step in all of the investigations we carried out. We discuss the importance of the teacher's role in creating situations in which students develop shared observations as points of reference to discuss the science

concepts. Students identify that questioning from the teachers and discussions with peers helped them to critically analyze how to represent what was observed. They explain that the models they created and the discussions that focused on the models helped them to make claims about what they thought explained why the alcohol would behave the way they depicted in their models. These claims helped to consider bigger questions related to the underlying science concepts the investigations were designed to address.

I explain that these steps, making observations, creating ways to represent them, and developing possible explanations for them, were part of the inquiry process through which we would conduct our investigations. To transition into the next investigation, I ask them to consider how observations and explanations from one experiment might be applied to their understanding of other phenomena that represent the same science concepts in other investigations.

In our lesson, we had planned to present an authentic scenario in which students might be able to use the claims they developed about how the particles of alcohol move to explain what happened in another situation, but we hadn't discussed the specifics. I gesture to Chris to continue the lesson with the scenario. He says, "Would you do it?" I jump in, adlibbing the scenario a bit: "Imagine you were in the school cafeteria covering lunch duty. The cafeteria is full of students, eating, talking, and moving around the room. Suddenly, a student drops his tray of sloppy joe in the front of the cafeteria. You call the custodian and she comes in with a mop and cleaning solution. She sprays the cleaning solution all over the mess in the front of the cafeteria. At first, only the students at the tables closest to the spill notice the mess but soon more students start to realize that something has happened. Using your observations and the claims you came up with *about how matter moves, draw a scientific model of what would happen to the cleaning fluid in the cafeteria." Chris chuckles as I tell the story and commends me for phrasing the scenario in such a relevant way. It felt good to be able to jump in and I credit our planning and pre-class discussions for our ability to organically take turns leading the class.*

The students quickly get to work. They use their boards and markers to design a model that shows how they understood the smell of the cleaning fluid would travel around the cafeteria. While they discuss and draw, Chris and I circulate and ask probing questions about their illustrations: Why did you draw these squiggly lines? What are they supposed to represent? Why do you have more dots in the front of the room than in the back? How does your model of the alcohol swipe on the board connect with your drawing of the cleaner in the cafeteria? Though the students answer our questions, they do so with hesitation. Their faces contort showing their confusion in being asked detailed questions that require them to explain their choices in creating the model. When asked about what the squiggly lines were supposed to represent, one student answers, "The smell?" as if she was questioning my question. As I visit each group, I prompt the students to consider how they depicted the matter in the experiment earlier as compared to the squiggly lines they were using to represent the smell of the cleaning fluid. This causes two groups to change their squiggly lines to dots. When I ask about the change, students in these groups say they thought about how the alcohol particles were represented by dots in a micro model so they were applying that concept to this scenario.

After their models are complete, I ask the groups to hold up their boards and show each other their models. I select a few to explain the decisions they made in *determining how to draw them. One group explains they drew more dots closest to the spill to show that the smell was concentrated around it but that the particles would move away from it to other areas of the room. They explain that they knew others would smell the cleaning fluid even if they weren't close to the spill but it would take longer to get to the students farther from it.*

Whilst the focus of the content and pedagogy changed from week to week, each class meeting followed a similar format as portrayed in this vignette. The class began with students exploring a scientific phenomenon through observation of a demonstration or experiment conducted by one of the instructors, or observations of a natural occurrence. Moving into groups they would then discuss and develop several possible explanations for what they thought explained their observations. Further exploration and experimentation would result in the disproval of possible explanations until they arrived at the one most plausible given the evidence which would lead to the development of claims that could be more broadly applied to other scenarios in which similar science played out. Using this experiential learning approach to teaching inquiry, we also simultaneously addressed the teaching of science concepts central to each discipline.

In what follows, I first illustrate the curriculum and pedagogical practices employed in the course practices using the course syllabus and my own lesson plans for teaching. I take the reader through course activities by describing how each of the science disciplines, cross-cutting concepts, and engineering practices that were addressed through inquiry-based instruction.

Content for Teaching Elementary School Science PSTs

The NGSS used to plan the science content curriculum and the investigations designed for the course targeted specific science and pedagogical practices necessary for learning and teaching science content in the elementary school. The course, therefore, addressed all three science disciplines – physical, earth, and life science – as well as standards in engineering and cross-cutting concepts. In Table 6, the science discipline, NGSS disciplinary topics, and elementary school science pedagogical topics addressed in each class meeting is identified. Although the content addressed was focused on topics in the NGSS in elementary school, the investigations were designed to challenge students at more advanced levels.

Table 6. *Week-by-week Discipline, NGSS Disciplinary Topics, and Pedagogy Topic*

Week	**Science Discipline**	**NGSS Disciplinary Topics**	**Elementary School Science Pedagogy Topic**
1	Physical Science	Matter & Its Interactions Structures & Properties of Matter	Thinking Like A Scientist Inquiry-Based Instruction
2	Physical Science	Matter & Its Interactions Structures & Properties of Matter	Learning Progression Scientific Models
3	Physical Science	Matter & Its Interactions Structures & Properties of Matter	Control of Variables Types of Inquiry-Based Instruction
4	Physical Science	Forces & Interactions	Science & Engineering Practices
5	Physical Science	Forces & Interactions	Evaluating & Modifying Premade Lessons
6	Earth Science	Earth and The Solar System The Universe & Its Stars	Unit Planning Question Techniques
7	Earth Science	Earth and The Solar System The Universe & Its Stars	Evaluation & Assessment of Student Learning
8	Earth Science	Weather & Climate	Curriculum Integration Using Evidence to Make Claims
9	Life Science	Structure & Function Growth & Development of Organisms	Evaluation and Modification of Prepackaged Science Kits (i.e. FOSS)
10	Life Science	Inheritance & Variation of Traits Social Interaction & Group Behavior	Science Classroom Safety Scientific Models

Table 6. Continued

Week	Science Discipline	NGSS Disciplinary Topics	Elementary School Science Pedagogy Topic
11	Energy as a Cross-Cutting Concept		Authentic Assessment
	Physical Science	Relationship Between Energy and Forces	
	Life Science	Cycles of Matter and Energy in Ecosystems	
	Earth Science	Natural Resources	
12	Earth Science	Human Impacts on Earth Systems Natural Resources	Authentic Assessment Using Evidence to Make Claims
	Engineering	Defining and Delimiting and Engineering Problem Developing Possible Solutions Optimizing the Design Solution	
13	All Disciplines	Student-Designed Lessons	Microteaching
14	All Disciplines	Student-Designed Lessons	Microteaching

Physical science. There are two reasons why physical science is the first discipline addressed in the course. First, the syllabus was originally designed by my co-teacher and his mentor who are experts in physics. They view concepts in this discipline, like those associated with characteristics of matter, as foundational to understanding the science of other disciplines. As such, teaching this content also affords opportunities for students to make connections across disciplines throughout the semester. For example, in order to understand that the moon shines because it reflects the light of the sun (earth science), they must first understand how light behaves (physical science). Second, because most teachers are least prepared to teach physical science (Trygstad, et al., 2013), topics in this discipline were used to set the stage for the science practices PSTs engaged in throughout the semester.

In the vignette above, we addressed the 5th grade NGSS physical science DCI of *Matter & Its Interactions* that states:

> Matter of any type can be subdivided into particles that are too small to see, but even then the mater 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 (NGSS, 2012).

This topic was explored in the first two weeks of class. In the first session, we addressed the exact concept depicted in the 5th grade standard by leading students through the inquiry process as they considered why a balloon makes a sound when it pops. We began the second session's investigations by asking students to observe what happened when rubbing alcohol was wiped onto the classroom chalkboard. Our questions in these sessions were designed to lead PSTs toward discovering the Disciplinary Core Idea (DCI). In this lesson, the objectives were for PSTs to use evidence from the experiment, their prior knowledge, and the discussion with peers to conclude: 1) the cleaner is made up of molecules or particles 2) the particles move 3) as the particles move apart they start to spread out. These DCI are not only key organizing concepts within the discipline but have broad importance across multiple sciences (NGSS, 2013).

Moreover, immersing PSTs in the investigation of content with which most are least comfortable also provided opportunities to reshape what they thought about science and how science is conducted. Teaching this content first, allowed us to create the disequilibrium that Vygotsky asserts forces learners to consider different ways of thinking and knowing that result in cognitive growth (Hus & Aberšek, 2011; Palincsar, 1998). Because both the methods for exploring science and the science content were unfamiliar to and/or uncomfortable for most, the students were forced to trust in the process as they deferred to the instructors for guidance and support in understanding both content and the methods used to explore it.

Earth science. DCI addressed in the earth science curriculum included those central to understanding the relationships between the Earth, moon, and sun. These DCI were chosen because they provide "key tools for understanding and investigating more complex ideas and solving problems" (NGSS, 2013). Understanding of the relationship between the Earth, moon, and sun is built upon each year as students investigate aspects of the core concept in more depth.

In this course, PSTs worked with 3D manipulatives to explore the relationship between the Earth, moon, and sun and multiple data sources to make claims about how Earth experiences the seasons. Unlike physical science where experiments often began with a teacher demonstration, however, the investigations in this discipline began with observations of pictures of phases of the moon and the collection of data on how temperature varies and changes around the globe. Inquiry in earth science topics was, therefore, used to teach PSTs how to creatively utilize a variety of resources to explore science.

Topics in this discipline were also used to address students' misconceptions about key concepts. For example, PSTs hypothesized that a shadow from the Earth creates the phases of the moon and that fluctuation in Earth's distance from the sun causes the seasons. These are common misconceptions difficult to disprove; thus the course was designed to model how to confront and disprove misconceptions of science using evidence while also teaching the PSTs about the science behind these concepts. Testing possible explanations in earth science is different from investigating hypotheses in physical science. Physical science core ideas can be experienced in students' everyday lives as they observe and analyze evidence of matter and movement. However, experiences students have observing the relationship between the Earth and sun might run counter to the scientific explanations we have come to know. From our perspective on Earth, the sun moves across the sky. One might then assume that it is the sun that moves, not the Earth. History tells us this was also the shared belief among scientists and philosophers for centuries. Disproving this misconception is challenging as, short of traveling with astronauts, we cannot *see* this phenomenon from our perspective. Experiences like this provided PSTs with opportunities to learn content and develop methods for helping students to understand phenomena using a variety of approaches.

Life science. Life science is the discipline with which elementary school teachers are often most comfortable. This may be, in part, due to the fact that most have taken college level courses in this discipline (Trygstad, et al., 2013) or because it is the most relevant to, and concretely observable, in our daily lives. Accordingly, this area of content was discussed least in focus groups interviews. PSTs did not offer information about new learning about science that occurred from their work in this discipline. Ann offered an explanation as to why this might be the case:

> I think I felt more comfortable with, at least, life science beforehand. I think it was the most relatable to us….I think that's why, at least for me, learning about physical and earth science kind of really stood out and put it in a new perspective for me.

Because the science concepts core to this discipline are known and understood by most elementary school teachers, these sessions focused more heavily on elementary school methods of instruction instead of science content. For example, FOSS kits were used as the guide for students to examine the structure and function of plant parts as students dissected and investigated vegetables and sorted seeds using observable properties. However, instead of discussing the science content, reflective discourse that followed focused how the FOSS kit could be modified to address the NGSS more specifically and what aspects could be omitted or adjusted to make the investigations more inquiry-based.

Likewise, safety in the science classroom and controversial topics in science, like evolution, and authentic instruction and assessment were the focus of the lesson in which students observed four species of turtles and made claims about how their traits, and the traits of other animals, affect their survival. Reflective discourse focused on methods to authentically assess students' understanding of the overarching concepts and alignment among objectives, assessments, and instructional activities. Again, students were taken through the inquiry process exploring and developing questions that could later be investigated, however, the objectives of instruction were based more in learning how to teach this content to elementary school science students than learning science content.

Cross-cutting concepts. All DCIs are "teachable and learnable over multiple grades at increasing levels of depth and sophistication" (NGSS, 2013). In order to teach the concepts confidently, PSTs' conceptual understanding must be more advanced and deeper than that of the content they are tasked with teaching their elementary school students. Cross-cutting concepts, such as *patterns, energy and matter,* and *cause and effect*, bridge the disciplines blurring the lines among them while also building upon prior knowledge and conceptual understandings of science. Therefore, in the session in which we focused on cross-cutting concepts, PSTs were required to apply previously acquired knowledge in all three science disciplines and an understanding of the inquiry process to conduct their investigations.

Energy is considered a cross-cutting concept because, for example, energy transfer in the food chain could be categorized with core ideas in earth science, life science, *and* physical science. Thus, the investigations in this session were fluid, crossing the disciplines in ways that blurred the lines between them. For example, when exploring how energy is transferred from one organism to another through the food chain, students discovered the plants eaten by some animals are dependent on the sun for energy to produce their food through photosynthesis. Moreover, when the animals who have eaten the plants die, their bodies decompose and break down, changing both physically and chemically, enriching the soil that provides nutrients to the plants.

Teaching these concepts presents students with "organizational schema for interrelating knowledge from various science fields into a coherent and scientifically-based view of the world" (Achieve. Inc., 2014) and increases their overall scientific literacy. They can be revisited throughout elementary school science and beyond increasing in depth and complexity. Cross-cutting concepts are overarching in that they require more complex understandings of DCI and connections other fields. Specifically, teaching cross-cutting concepts, like energy, bring about an understanding of how the natural and designed worlds of science connect through engineering. It is, therefore, important that elementary students understand how scientific discoveries are dependent upon the engineering of tools and materials that help to make those discoveries possible, and vice versa (Bybee, 2011; Hawkins & Park-Rogers, 2014). To accustom PSTs to these concepts, each was assigned to two science and engineering practices to be researched and then presented to the class. They were asked to share examples of how the cross-cutting concept they were assigned could be viewed through multiple science disciplines.

Engineering. There are two engineering standards at the elementary school level in the NGSS. They focus on students' abilities to solve problems by designing solutions and evaluating multiple solutions to determine the characteristics that make one design solution better than others. They can be addressed through lessons on DCI, like the physical science lesson in which students figured out how to reshape a clay ball that sunk into a clay boat that floated using their understanding of density. They can also be used to address cross-cutting concepts. For example, we addressed these standards through discussion on authentic assessments and performance tasks in the energy lesson. An example of the connection between science and engineering was modeled as students were read a children's book and viewed a TED Talk that told the story of a boy from Africa who used materials found at a local garbage dump to create a windmill to confront an energy crisis in his village. Students considered this and other renewable energy sources in addition to reviewing multiples sources of data on fracking, a controversial method for retrieving natural gas from shale rocks. After examining multiple sources of data on fracking and other methods for harnessing energy, they debated and discussed which characteristics made one method better than another. A performance task that required students to develop a solution for a town in need of new energy sources was used to assess students' understanding of these concepts as well as to apply their understanding of how energy could be harnessed and transferred. In reflecting on this lesson, Ann said,

> The day we did energy in the world, like the different uses of energy and electricity…really stuck with me and that's when I realized how interconnected everything can be. Cuz I think we really did connect all of the three disciplines together.

This lesson was designed to explicitly connect engineering with all three science disciplines and this approach was used to teach PSTs how learning about one can enhance understanding of the other.

Pedagogy for Teaching Elementary School Science PSTs

Content-related DCIs addressed only half of each class session's curriculum. As can be seen in Table 6, each session targeted a particular pedagogy. Some pedagogical foci were selected based on research for teaching science while others addressed elementary methods for teaching. Inquiry-based instruction was taught as the pedagogy for teaching science. Questioning and scientific modeling were used as the means by which PSTs communicated their understanding of content knowledge and explored their ability to teach science and assess students' understanding of it. Learning progression was examined as part of the pedagogy for teaching elementary school science as elementary school PSTs are trained to teach students in grades K-5th grade and, therefore, must be aware of how students' understanding of science content is addressed over time. Instructional planning and materials were also explored to prepare PSTs to navigate the authentic tools and resources provided to teachers in the elementary school setting.

Science instruction through inquiry. PSTs repeatedly navigated through the inquiry process beginning with observations to consider the science behind what they experience in the natural and designed worlds around them. Through inquiry, it was anticipated that students learned science content while employing science practices that helped them begin to develop an understanding of the nature of science needed to teach science confidently and to think like scientists. This laid the foundational knowledge and understanding needed to discover answers to challenging questions in science.

Though each class involved processes aligned with investigation through inquiry, the science discipline and topic determined how students would go about their exploration. For example, the physical science investigation in the third class meeting began with students' observations of a can of Coke and a can of Coke Zero in a tub of water to investigate why some things sink and some float. Students' developed multiple possible explanations including, *heavy things sink*, to explain why the can of Coke sunk and Coke Zero floated. They were then required to consider other methods for testing their hypothesis. Weighing them to determine if one is heavier (more massive) was one way students offered to disprove or find support for this hypothesis. In this case, the Coke does have more mass; thus, this experiment supported their hypothesis.

To further test students' theories, they were given materials (i.e. a block of wood, PVP pipe, a marble) and permitted to choose from a supply of other miscellaneous items (i.e. a tin can, rubber ball, metal spoon) to test in tubs of water to determine if they sunk or floated. They were also given scales to measure the mass of each item. As they tested items for sinking and floating and collected data on the results, they quickly discovered that their hypothesis was incorrect (i.e. the marble sinks and the wood floats yet the wood has greater mass) and that they needed to consider other characteristics of the materials to figure out: *Why do some objects float and other sink?* Although PSTs had seen things float and sink before, using their misconception about *why* things floated seemingly made exploring this concept through the inquiry process new and exciting.

Though the inquiry process was applied to learning about earth and life science, it played out differently due to differences in the content and how it could be addressed. For example, in the life science lesson where students examined the interaction and group behavior of turtles, the investigation began with students circulating from one turtle to another recording observations. Afterward, students were provided with descriptions of multiple species of turtles and asked to use their observations to determine the species of each. Also, from their observations, students were asked to consider how the behaviors exhibited by the turtles (i.e. hiding in their shells, active, aggressive) might affect their survival in a habitat in which multiple species are present. This discussion culminated in students discussing how invasive species, like the red-eared slider, could affect the survival of smaller, less aggressive species of turtles and, therefore, how humans' impact on the arrival of invasive species could be addressed. This helped to establish the overarching question: *How do humans impact animals' survival?*

Addressing content that students found interesting and fun inspired them to think about and talk about the processes through which they explored the content outside of class with friends and family. For example, Erin used social media to communicate with friends about what was happening in our science class and then later explained the inquiry process to them.

> Also, I know a lot of the experiments we did I would, like, record it and put it as my Snapchat story and if I saw my friends later they'd be like, "That's what you do in science?!" and they'd be like, "Why are you using turtles in science?" and I would explain, like, this is what we did. And I was like, wow, this is cool. I wouldn't normally talk about science with my friends but I would just tell them what we did in science class.

Both the investigation of floating and sinking and of the turtles took students through inquiry processes for exploring science using relevant topics and authentic materials. Each lesson began with students exploring a scientific phenomenon or object through observation and discussing and developing several possible explanations for what they observed. These explanations were later tested, either through experimentation or further research, to develop broader claims that could answer bigger, more overarching, scientific questions. Students discovered answers to their testable questions by recording and analyzing their observations and then representing their understanding through scientific modeling.

Experiencing how the inquiry process could be applied to multiple disciplines better prepares PSTs to use this approach to teach all of the sciences and connect what they learn in science class with their lives outside of school. Though the structure and organization of the learning environment changed based on the content being addressed, methods for teaching inquiry, like the use of questioning to facilitate students' discovery of the content, were used consistently.

Questions. Research suggests 94% of the questions asked by elementary school teachers address lower levels of cognition requiring answers that promote rote memorization or simply confirm students are paying attention (Hus & Aberšek, 2011). Developing and knowing how and when to pose questions that promote deeper understanding and analysis of content and thinking are, therefore, pertinent skills for elementary school teachers of science. Also, as questioning is essential to scientific inquiry, questions were used to assess students' learning and to get them thinking about different aspect of science content and concepts. Questioning both encouraged reflection by students and allowed us to assess their understanding of the content and any misconceptions along the way. Open-ended questions asked in each lesson were designed to facilitate achievement of the learning objectives, addressing both the science content and the science practices and processes.

As discovered in the focus group interviews, PSTs initially struggled to answer probing questions. More specifically, they experienced frustration in having teachers ask questions in response to their questions. One focus group member's comments captured their shared frustration.

> Like, in the beginning of the semester asking a question and getting a question made me want to scream. I never experienced that. It takes up too much time to answer a question with a question and so in 40 minutes in my high school classes it was like alright this is the way it is, write it in your notebook and remember it. Now, it's like, "What about this? Why did this happen?" And they're like, "Why do you think it happened?"

Although others agreed that learning through questioning was a barrier they felt they had to overcome at first, upon reflection at the end of the semester PSTs appreciated that continued experiences with these processes taught them how question posing facilitated students' critical thinking and the chance to discover the science for themselves. Karin's reflective comments in the focus group interview captured the feelings generally shared by the PSTs.

> I think we were all kind of used to having science classes where our teachers just told us. So in the beginning we kind of rejected the fact that we had to do all this. We have to answer these questions? I remember when they would ask us questions like, "What do you mean by that? Can you explain that?" We all just started laughing in the beginning, like, is this serious? You can't just tell me what we are trying to understand? Towards the end of it, our questions to their answers and even our questions to each other were, like even in small group discussions, we would ask each other, "What do you mean by that?" We would start using their practices. So that barrier was in the beginning we were all just, like, were not gonna do this. Like, you're eventually going to tell us and they made it very clear we're not telling you anything. You're gonna figure it out yourselves. So that barrier was hard to break in the beginning but after we all kind of realized this is a

> meaningful practice to implement, we started asking great questions and responding in ways where they were like, "Wow that's such a great plan. Does anyone else have anything to say about that?" And it just kind of brought the class to a whole 'nother level.

Although some seemingly struggled with not being told what to know about the content, they eventually learned that questioning was used to facilitate deeper thinking about scientific phenomena.

Because questions were used as part of our instruction and assessment, many we asked in class were considered prior and recorded in our lesson plans. For example, in the second class session we focused on matter and finding evidence that air is something, as opposed to the misconception that air is nothing because it cannot be seen. To facilitate this understanding, we placed a piece of paper in the bottom of a beaker and then place the beaker, open-end down, into a tub of water. The water does not go up into the beaker and the paper, therefore, stays dry. This supports the idea that air is something as it prevents the water from being able to go up to wet the paper. During this lesson we use planned questions such as the following:

- How can we find out if air is made up of the something?
- What are some ways to investigate the hypothesis – *air is something*?
- Have you ever been in a bathtub or pool with a cup? What happens when you turn the cup upside down and push it into the tub?
- If you assume that air is made up of something (particles/molecules) what will happen to the paper?
- If you assume that air is nothing, what would happen to the paper in the beaker? How do you know?

We then tipped the beaker inside the tub and asked:

- When I tip the cup in the water what do you observe?
- What are those bubbles?
- Which idea did the results of this experiment support?

Through these questions, students considered their observations and used them as evidence to explain which hypothesis is most plausible. They discovered that air is something.

Other questions were developed in the moment as students explored and interacted. Not giving them answers to their questions transferred the responsibility of learning to the students and, therefore, prompted them to figure out the science behind what they observed or experienced. Moreover, this method mirrors the work scientists conduct in the field as they do not have answers to their research questions but are using inquiry processes in an effort to answer them. If teachers of elementary school science hope to teach students to think like scientists, they must be skilled at developing questions that help them discover science for themselves and using questions to assess students' understanding of content.

Scientific modeling. Scientific models, or abstract, simplified, representations of systems, help generate new knowledge and communicate understanding of scientific phenomena (Kenyon, et al., 2011; Schwarz, et al., 2009). Thus, learning to design scientific models builds science content knowledge and understanding of science practices and inquiry processes (Schwarz et al., 2009). Scientific models also serve as visual representations of what students know, understand, and think about the science behind their observations. Scientific models make students' understanding of content visible and, therefore, can be used to mediate discussions about content and help teachers develop questions to extend children's learning.

In every class meeting, students were asked to design a scientific model to explain their understanding of content. In addition to the example in the vignette in which students drew their understanding of how the cleaning fluid behaved as the matter traveled around the cafeteria, students were taught to draw force diagrams, make 3D models of the Earth, moon, and sun, draw pictures of their observations of turtles, and organize different species of birds in a way that demonstrated their understanding of the concept: survival of the fittest. Maria explained how modeling birds' physical traits helped her to explore their survival in different environments.

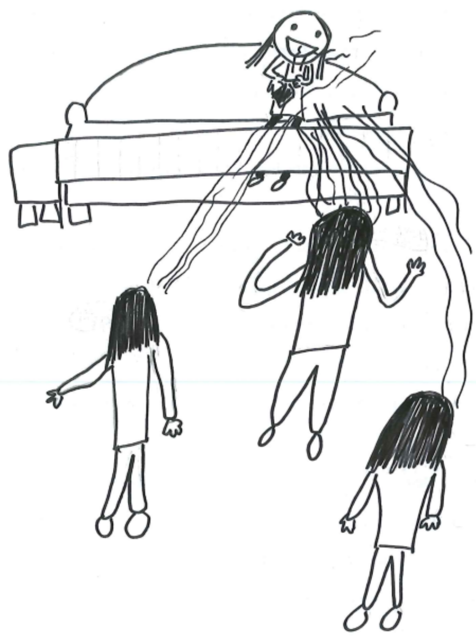
> We talked about what animals survive better in some environments. The way we learned about it was we created our own bird and we had different characteristics for each, like one would have long beaks and one would have short beaks…and then we put them in different environments and figured out why our bird would survive or why it wouldn't and tried to explain why. So that was a simple but really effective way to learn about that topic.

In the lesson Maria described, students were randomly assigned genotypes, like Bb, to represent phenotypes like long/short beaks, long/short wings, and red/green feathers of birds. They drew their birds to represent the traits they were assigned. They were then asked to consider which birds would survive in an environment given, for example, that one might have red flowers making it safer for red feathered birds to survive predators than another environment with only green foliage.

They were also required to review each other's models to examine what content knowledge and understanding could be assessed. For example, after creating 2D models of the Earth, moon, and sun to show their understanding of how Earth experiences day and night, students were asked to switch their models with a peer. They analyzed their peer's model and determined what could be said about their peer's understanding of this concept. In my researcher's journal on this session, I noted PSTs made comments in class about not only understanding how to assess students' work but also the kinds of details they needed to include in their own models to show what they knew and understood. Students' comments align with the research that suggests experiences with and practice in scientific modeling prepares students for the work conducted by scientists in the field (Kenyon, et al., 2011) as they are often used to communicate their understanding of scientific phenomena.

To extend PSTs understanding of how scientific models could be used to assess students' content knowledge and conceptual understanding, examples of elementary aged children's scientific models were used for analysis. For example, in a quiz administered in the fourth class meeting, PSTs were required to consider the following scenario: *In teaching a 2nd grade lesson on particles, you light a match and ask your students to tell you when they smell the sulfur. You then instruct them to create a scientific model to show their understanding of the investigation and its results.* They were provided with an example (Figure 2) of a 2nd grade student's model of the investigation and her understanding of what happened.

Figure 2. *Example of student's scientific model*.



They were then asked to review the student's work to do the following:

a. Record three things you can assess about the student's knowledge and understanding based on her model. What are you confident the student understands?

b. Provide this student with feedback based on your evaluation of her work. Give her some positive feedback (that you would either record on her paper or say to her about her work) and pose a question that would challenge her thinking or further assess her understanding.

This assignment helped PSTs to consider what could be assessed about a student's understanding of content through a scientific model. They also had to consider how they would guide this student using written and/or verbal feedback.

Elementary school methods for teaching science. Because PSTs were being taught science at advanced levels, it was pertinent that we explicitly addressed how what they were learning could be taught to elementary school students. Methods for understanding how to teach science in today's elementary school classroom, like instructional planning and the use of materials and resources, were both modeled and then discussed through reflective discourse. Also, because elementary school teachers are expected to be able to teach multiple grade levels, learning progression was used to examine how science is addressed across grade levels.

Learning progression. The NGSS are designed so that all DCIs are addressed in multiple grades at increasing levels of depth (NGSS, 2013). Therefore, what students learn about each discipline in Kindergarten, for example, is foundational to what they will learn in years to come. The concept of learning progression was addressed in this course in two ways. First, each class meeting lasted three hours providing us with enough time to perform several investigations about one DCI topic. Knowing that elementary school classes spend, on average, 18-23 minutes daily on science instruction (Trygstad, et al., 2013), we explained that the lessons covered in one day in our class could be taught over the course of a few weeks in an elementary school class and the content addressed might constitute an entire unit of study. To model the progression of learning, the investigations we conducted in class progressively increased in complexity.

Second, we addressed learning progression by discussing how teachers at different grade levels might address one DCI. For example, after students explored the science behind how matter moves, they split into three randomly assigned groups and each read and reported on a different teaching scenario (Michaels, et al., 2008). All of the scenarios were focused on the same topic but addressed teaching about states of matter at different grade levels. This led to discussions about the learning progression involved in developing young scientists' understanding of matter, its structures and properties, and their interaction. Table 7 shows the NGSS DCI addressed and the teaching scenarios from grades 2 and 5, and middle school physical science that students read in class.

Table 7. *Learning Progression: Structures & Properties of Matter*

Grades	NGSS DCI	Teaching Scenario Described
K-2	2-PS1-1. **Structures & Properties of Matter**: Different properties are suited to different purposes.	A Kindergarten teacher shows her students forks and spoons made of different materials: wood, plastic, and metal. She chooses one to put inside a "mystery" box and hides the rest from the students' view. She then prompts the students to ask questions that would help them to discover which utensil is in the box and the material the utensil is made of. Students ask questions like, "Is it plastic?" that help them to eliminate utensils to figure out which utensil in the mystery box. This lesson helps students begin to understand that properties that can be used to describe objects. This led to further investigations in which students explored the differences between and functions of these properties.
3-5	5-PS1-1. **Structures & 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.	To explore the way air behaves, a 3rd grade teacher prompts students to compare the weights of two volleyballs. The balls were the same size and made of the same material. They differed only in color. After weighing the balls and discovering they weighed the same, the teacher asked the students to make predictions about what would happen if he pumped more air into one of the balls. The 3rd graders debated and discussed what they thought would happen using their prior knowledge and experiences. An ELL student offers a comparable scenario to defend his prediction. He explains that his Papi used a pump like the teacher had to put more air into the tire of his truck and the truck was lifted. His peers helped to explain what he was trying to say by providing additional prior experiences putting air into tires of bikes and cars. One student explained that the tire was getting bigger because more "stuff" was being pumped into it so this must mean that the weight would increase. More stuff would result in more weight. Students drew inferences from their own experiences and prior knowledge to develop working theories about properties of matter.

Table 7. Continued

Grades	NGSS DCI	Teaching Scenario Described
6-8	MS-PS1-4. **Structures & Properties of Matter:** · Gases and liquids are made of molecules or inert atoms that are moving about relative to each other. · In a gas, molecules are widely spaced except when they happen to collide. · The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter.	7th and 8th grade students in an after school science club explore how air molecules behave when their teacher equates the behavior of air molecules to the behaviors exhibited by puppies. He refers to them as Air Puppies and using this analogy, he presents a thinking experiment to his students. He asks them to imagine a room with 10 Air Puppies and asks them to describe how the puppies might behave (i.e. bumbling around and bouncing off of the walls). He then asks them to consider what would happen with 25 Air Puppies in the room, then 100 Air Puppies. This teacher also uses a simulation to show students the scenario using circles to represent the Air Puppies in the model. He also adds more complex scenarios to the model like a mobile dividing wall with Air Puppies on both sides for students to consider how the wall would move. The students concludes the side with more puppies would move the wall because they would be bumbling and bouncing into the wall more frequently than the side with fewer puppies. This thinking experiment requires students to consider the movement of molecules in air and how the movement changes when more air is added, or the air pressure changes. This will later lead to discussions about changes in behavior of molecules in varied temperatures.

After reading about one of the scenarios presented, PSTs met in groups of three where in turn, students presented their specific teaching and learning scenario and discussed how the teacher facilitated students' understanding of the central DCI. Through this expert jigsaw, PSTs examined how the work conducted in elementary school contributes to deeper conceptual understanding of science in years to come.

Instructional materials. In addition to teaching PSTs about how to think about science and foster the development of scientific thinkers, we also addressed how to utilize elementary school instructional materials to teach science in practice. Because up to 77% of teachers use commercially published science textbooks and programs (Trygstad, et al., 2013), teaching PSTs how to navigate these materials is a necessary part of preparation for elementary school science instruction (Forbes, 2011). The aim of exposing PSTs to these materials was to help them learn how to utilize and adapt them in practice to mirror the pedagogical practices they were learning about in class. Likewise, because large chunks of time in the school day are often dedicated to literacy instruction (Trygstad, et al., 2013), curriculum integration must be considered as an approach to addressing science instruction.

Pre-made lessons and programs. The FOSS kit experiments were used in the lesson focused on exploring the how characteristics of plants and animals could be used to classify and/or organize them. To model the implementation of the kit, my co-teacher and I followed the FOSS kit experiment procedures as if they were steps in a recipe. PSTs made observations of green beans, peppers, cucumbers, tomatoes, and apples. They dissected them, counted and described their seeds, and used the seeds to classify them into different groups based on their characteristics. Following, PSTs analyzed their experiences as students and discussed how they felt the cookbook experiment could be modified to make it more exploratory. In this case, PSTs offered having students first identify the scientific questions then allowing them to explore the foods to discover answers to them.

They then reviewed the remainder of the kit's lessons, experiments, and supplemental materials and discussed and debated how they would modify, omit, and utilize the tools to teach science. For example, in my researcher's journal, I noted that PSTs suggested some of the experiments in this FOSS kit could be omitted because they felt they were misaligned with the overarching concepts addressed in the initial investigation or because they involved the use of animals (i.e. snails and crayfish) they might not have access to in school. Being able to analyze and evaluate how to utilize premade materials and solve potential problems with implementation makes elementary school teachers more confident teachers of science (Forbes, 2011).

PSTs conducted a similar analysis of lesson plans they found on the internet and evaluated the alignment of the objectives, assessments, and activities. Figure 3 shows a lesson plan retrieved from a website, HotChalk Lesson Plans, where teachers can share their lesson plans for others to download.

Figure 3. *Sample lesson plan for teaching phases of the moon*.

Phases of the Moon
Objective: Students will be able to show their understanding of the phases of the moon.
Materials:
· One pre-made paper plate with moon phases attached
· 8 Oreo cookies, split per student
· One plastic spoon per student
Activities and Procedure: Each student will be given 8 split Oreo cookies and one plate with the phases of the moon on the bottom of the plate. The student will use their spoon to move the cream off the cookie to model the correct phase of the moon. After completing eight correct moon phases with their cookies, the student will label each phase of the moon with the correct name strip (new moon, full moon, waxing crescent, waning crescent, first quarter, waxing gibbous, waning gibbous). Once the student has correctly labeled the 'moons', they may eat the cookies and take the plate home, where it can be used to track the moon from their own neighborhood.
Closure: The teacher will review the correct phases of the moon in the correct order before allowing the students to eat their moon phases. The teacher will also show each student that their moon phase plate can be hung in a window so students may follow the phases of the moon from their own window.
Assessment: The teacher will continually walk around and assist students with the activity. The teacher will be checking for understanding and making sure that each student is on track with their moon phases during the activity. The teacher will informally assess each student as she walks around and a formative assessment will be noted upon the completion of the activity. Students will be given a check plus for completing the activity to the best of their ability, a check for work that is complete, but not to the best of their ability, and a check minus for work that is below their working ability.
Accountability: Each student is responsible for modeling the phases of the moon using cookie cream. The phases should closely resemble the phases of the moon, as noted on the bottom of the moon phase's plate.
Differentiation:
Below Level: The teacher will make rounds during the activity to assist all students. Below level learners will be completing an activity that is modeling and using direct, applicable manipulative. The teacher will also offer assistance in placing the moon phase names with

struggling learners.
Above Level: Above level learners will be challenged with the placement of the earth. Above level learners will need to place their Sun in the correct location without teacher assistance. Above level learners will also be challenged with the placement of the moon phase names under their cookie cream moon phases.

Moskal, J. *Phases of the moon*. Retrieved September 9, 2015 from http://lessonplanspage.com/phases-of-the-moon/

PSTs found that though the objective was written in a way that would suggest an assessment of students' understanding of the overarching science concept, the lesson's activities and formal assessment only assessed whether students could follow the directions to accurately complete the cookbook-type project. In my researcher's journal, I noted PSTs agreed that although the lesson activities might be fun, they were not effective in facilitating scientific thinking or in developing students' conceptual understanding of the content. Though elementary school teachers are tasked with making learning science fun, the focus of science instruction should also be to increase students' content knowledge and understanding.

Curriculum integration. Of the 881 elementary school teachers surveyed in Trygstad's, et al., (2013) study on teachers' preparation for teaching of elementary school science, 27% of elementary school teachers felt their school schedule did not allot sufficient time to teach science. PSTs also reported that during their visits into elementary school classrooms as part of the teacher preparation program, little to no time was spent on science instruction. In order to understand how they might address science even with restrictions on the time allotted for it in school, PSTs had to consider multiple methods for integrating science topics into other subjects (i.e. literacy, math, and social studies, etc.). Therefore, ways to integrate science with literacy were explored in this course.

Teaching science through the use of children's literature is one way to make more time for science without removing instructional time from any other subject area as an average of 85-90 minutes of every elementary school day (Trygstad, et al., 2013) is allotted for literacy. During one of the class sessions focused on earth science, I exposed PSTs to several children's books that addressed the phases of the moon in different ways. In pairs, PSTs took turns reading or skimming the books, analyzing, evaluating, and making note about what literacy and science topics could be addressed through each. Table 8 shows some examples of the books that were used in class and they ways in which PSTs determined they could be used to teach literacy through science and vice versa.

Table 8. *Teaching Science through Literacy*

Book Title & Author	**Description**	**Literacy/Science Content**
If You Decide to Go to the Moon by Faith McNulty	Fictional story about a boy astronaut who travels to the moon and back home	This book includes many accurate facts that can be used to teach about space and the moon. The way the boys feels and what he thinks as he travels makes the content relevant and connected to the students' lives. Text-to-self connections could be addressed through this text.
Moonshot: The Flight of Apollo 11 by Brian Floca	Non-fiction story about the preparation for and adventures in space exploration	Much of what we know about the relationship between Earth, the moon, and the sun has been discovered through space exploration. The details of the complex work conducted by scientists in the field are explored through this book.
Thirteen Moons on Turtle's Back: A Native American Year of Moons by Joseph Bruchac & Jonathan London	A collection of lyrical poems tell of the Native American legend, the thirteen scales on turtle's back, which represent the thirteen cycles of the moon	The moon appears differently throughout the course of the year. This text could be used to discuss these differences and explore how different cultures explain scientific phenomena experienced by all.

Table 8. Continued		
Book Title & Author	**Description**	**Literacy/Science Content**
The Moon Book by Gail Gibbons	Non-fiction book in which old and new claims about the phases of the moon are presented; multiple models of the Earth, moon, and sun configuration are presented	This non-fiction story could be used to teach students about how to disprove some of the claims made by philosophers in the past and well as to provide them with some understanding of the nature of science. The multiple models presented attempt to show the Earth, moon, and sun configuration and their somewhat confusing nature could be used to help students understand why 3D modeling in preferable depicting this relationship.
Faces of the Moon by Bob Crelin	Poetry about and the personification of the phases of the moon	Science vocabulary presented (i.e. waxing, waning, crescent, quarter) can be explored through morphemic analysis. Viewing the moon as a person might help students to see the moon from a different perspective.
The Man on the Moon by William Joyce	Fictional story about the man on the moon	Students examine the stories developed to explain scientific phenomenon. In this case, we see only one side of the moon from Earth and when it is full some say they always see the face of a man.

The review of these books and the discussions that followed brought awareness to how instructional materials and resources could be evaluated, modified, and utilized to teach science. They also sparked deeper analysis about what was most important for students to know and understand and how to best assess their learning.

Instructional planning. Likewise, because the time spent teaching science is often limited in the elementary school curriculum, planning is important as a teaching strategy to ensure instructional time is used purposefully. Pedagogy for creating high quality lessons began with PSTs considering what they hoped students would know or be able to do at the end of the unit. Utilizing the NGSS, PSTs created objectives that included both content and science practices or skills and methods of assessment that focused on conducting science, instead of completing rote tasks. This approach, also known as backward planning, aided them in focusing on overarching conceptual understanding, as opposed to memorization of "facts" (Wiggins & McTighe, 2011). In this approach, PSTs first utilize the DCI, scientific practices, and performance tasks articulated in the NGSS as guideposts for planning overarching concepts and objectives for what students should know or be able to do by the end of a unit. They then plan assessment methods for determining whether students have learned the content and are able to complete the tasks assigned. Instructional tasks planned, thereafter, targeted the development of students' content understanding and science practices and skills that would allow them to be able to reach the long term goals of the unit.

In addition to creating lessons from scratch, PSTs analyzed and evaluated lesson objectives, assessments, activities, and experiments of lessons they found online and examples they were given in class. They determined whether the objectives, assessments, and activities were aligned and if the lesson encouraged pedagogical practices we had modeled and analyzed in class. PSTs also explored their beliefs, values, and attitudes toward elementary school science instruction and goals related to the teaching of science to ensure they were planning lessons that would positively communicate them to their future students.

Student assessment. Traditional tests that focus on memorization and regurgitation of science vocabulary definitions and "facts" do not challenge students' thinking as performance tasks or authentic assessments do. Thus, instructional planning in this course also addressed methods for creating performance tasks that would require students to use science practices and skills in applying their science content knowledge. As articulated in the NGSS, assessments in science should mirror the work conducted by scientists in the field and emphasize the importance of the skills required to conduct science. To facilitate the acquisition of scientific literacy skills, elementary school science instruction and assessment should challenge students to utilize their science content knowledge and evidence to do something related to science outside of the classroom or to inform others to increase awareness on a science topic. Throughout the course, we consistently reminded PSTs to find ways to connect science to careers in science or everyday phenomena that would make the concepts relevant. For example, we asked students to consider how their assertions regarding fossil fuels, the effects of fracking, and clean energy might affect their choices in a presidential election. We discussed how the information they gathered in this lesson could be used to compose a persuasive letter to elected officials to promote or share their disapproval of fracking. Teachers of science hoping to teach deeper understanding of content instead of the memorization of surface science "facts" should consider which methods of assessment most effectively assess the same. PSTs were required to be able to both evaluate the alignment of assessment and instruction in sample lessons and create their own well-aligned lesson plans and assessment methods.

Figure 4 is an example of the summative assessment/performance task created by Ann in her unit plan. In it, she planned for students to collaboratively create posters that would help scientists to solve a problem about the life cycles of animals.

Figure 4. *Sample performance task for a science unit.*

There are 4 scientists that need your help:

1. Professor Zoolander works at the zoo with many different types of animals. He writes the descriptions of the animals and places them in the front of the cages for people to see. However, a new set of animals came in the other day and he's not sure how they will grow.

2. Dr. House is a 9th grade science teacher. He teaches life science in high school because he loves animals. He wanted to teach life cycles to his class but wasn't sure how to make it relatable for the students. Are there any things in his own home that he could use to teach life cycles?

3. Mr. Park takes daily walks with his son at the park with a playground. Every morning, he would sit at the bench and watch his son run around the playground. One morning, he noticed that there was a gradual change in certain things he saw. What were these things? What was happening to them?

4. Mr. Shrek is angry because construction workers are planning to demolish his swamp for a new mall! He needs to give a good reason to prevent his swamp from being taken over. The lawyers told him that the only way to keep his swamp was to prove that there are living things and in the swamp. Does Shrek have enough evidence to take his swamp back?

You will work in groups of 4 or 5 on this project and the teacher will assign which scientist your group will assist. In order to help these scientists, you will need to provide the following:

A colorful poster which includes:
- A picture of the scene where your scientist works
- The life cycles of the assigned animals
- On the back include:
  - Similarities and differences between the life cycles
  - Compare the life cycles to a human life cycle (If applicable: You do not have to compare a human life cycle to another human life cycle).

A presentation about your poster
- Each member will contribute to presenting parts of the poster
- Note cards can be used to help what you would like to discuss. They need to be handed in with the project.
- Discuss the life cycle of animals, how you determined these life cycles, and whether or not they go through metamorphosis and why.

Feel free to use past worksheets, the models around the classroom, and the computers to help you! This project will be due and presented 2 days after it was assigned (Insert date here). Please remember that this is a group project and that every member needs to give equal participation!

As can be seen in the diverse descriptions of the fictional characters she designed, Ann embedded implicit messages about who a scientist is. She identified several different people who are not "typical" scientists working labs, wearing lab coats, etc. Ann also included several scenarios in which the science content could be applied in authentic ways outside of the classroom. In doing so, she implicitly exposes her students to different views of how science can be used to solve real world problems or increase opportunities for the development of scientific literacy.

In her performance task, Ann also included science and engineering practices. For example, in all of the scenarios students are required to develop and use scientific models to communicate how they understand the science behind what is happening. In the fourth scenario, students are instructed to plan an investigation and explain how the data from it could be analyzed and interpreted. Including these practices in authentic scenarios helps students to see the different ways in which science can be applied to our everyday lives.

To assess their future students' performance and understanding in these summative assessments, PSTs were asked to create a rubric aligned with the overarching unit goals. In preparation, they reviewed and critiqued sample rubrics. In my researcher journal, I noted that PSTs determined the criteria included in these tools should assess students' science content knowledge, abilities to practice science, and their use of evidence to support their scientific claims. For example, when examining a rubric used to assess students' work on a poster about animal life cycles, PSTs determined that criteria like "creativity" and "attractiveness" should not be included. Instead, they suggested that the criteria should focus on accuracy of science content and conceptual modeling. Figure 5 shows how Ann planned to assess students' science content knowledge and conceptual understanding of the life cycles performance task.

Figure 5. *Sample rubric for life cycle performance task.*

	Criteria	Advanced Proficient	Proficient	Needs Improvement
Content Goals/ Objectives	Life cycle	*Student is independently able to develop models of various organisms' life cycles.*	*Student is able to develop models of various organisms' life cycles. Student could need assistance.*	*Student is not able to develop models of various organisms' life cycles.*
	Patterns	*Student is independently able to use patterns to make predictions.*	*Student is able to use patterns to make predictions. Student could need assistance.*	*Student is not able to use patterns to make predictions.*
Science Practice and Skills	Interpret data	*Student is independently able to analyze and interpret data to form evidence for explanations.*	*Student is able to analyze and interpret data to form evidence for explanations. Student could need assistance.*	*Student is not able to analyze and interpret data to form evidence for explanations.*

Ann included two criteria focused on assessing students' understanding of the disciplinary core idea in the life science unit and the cross-cutting concept addressed in the NGSS in conjunction with the DCI, *Patterns*. In designing the rubric's criteria and performance descriptors, Ann highlighted the DCI, science practices, and cross-cutting concepts.

The performance task Erin created also highlighted science and engineering practices and cross-cutting concepts in life science. Students in her unit's summative assessment would work collaboratively, each with an assigned job, to research and represent multiple aspects of an ecosystem (e.g. marsh, desert, tundra, etc.). They were required to show, through scientific modeling, how the organisms (plants and animals) get their food by labeling them with *producer, consumer,* or *decomposer*. They were also asked to include information regarding the geographic location of the ecosystem they chose and a description of the weather experienced there and the impact of it. Lastly, her task required 2nd graders to consider how humans impacted the ecosystem.

Erin's performance task was designed to address the overarching concepts of the unit she designed. She described those concepts as follows:

> Ecosystems are communities of organisms that interact with each other and their physical environment; all organisms have needs that are met by their environment; basic interactions in ecosystems are food chains and food webs in which matter cycles and energy flows; overtime, ecosystems maintain a balance, but that balance can be changed positively or negatively by natural and human actions.

Embedded in her unit, Erin has also included science and engineering practices and several cross-cutting concepts. Second graders in her unit would be required to work collaboratively to *develop and use scientific models* to communicate how they understood how the smaller systems within the ecosystem interact. In the ecosystem model, Erin planned for her students to identify how the animals and plants get/make their food (*Energy and Matter*). She asked students to consider how the weather, including seasons, and humans impact the ecosystem. In thinking critically about these factors, students can begin to understand how *Patterns* in the seasons created change, the *Cause and Effect* of the weather patterns and human impact, and the effects of both on the *Stability and Changes* of the ecosystem. Comprehensively, her 2nd grade unit helps students to gain an understanding of how life science plays out through several cross-cutting concepts: *Patterns, Cause and Effect, Systems and System Models, Energy and Matter, Structure and Function,* and *Stability and Change*. As can be seen in Figure 6, Erin, like Ann, created a rubric that focused, specifically, on students' science content knowledge and understanding of the overarching and cross-cutting concepts related to this unit.

Figure 6. *Sample rubric for ecosystem performance task.*

	4 pts	3 pts	2 pts	1 pt
Animals and Plants Name animals and plants in the ecosystem, including noting any that are endangered. Note whether any human populations are also present and their impact.	A model or power point of a wide variety of animals and plants in the ecosystem was included, as well as information about endangered species. Human populations in the ecosystem and their impact were also addressed.	A list and pictures of several animals and plants in the ecosystem was included, but information about endangered species was not included. Human populations and their impact were included.	A list of several animals and plants in the ecosystem was included, but information about endangered species was not included. Human populations and their impact were not noted.	A couple of animals and plants in the ecosystem were included somewhere in the presentation, but no additional information was given.
Food Web and Food Chain Create at least one food web in the ecosystem, also including a minimum of three food chains.	A model or power point produced by the student(s) of the flow of energy in a food web for the ecosystem was included, with pictures of species whenever possible. More than two different food chains were included.	A picture (non-original work) of a food web represented the flow of energy in the ecosystem. A minimum of two different food chains were included.	A list of the food web for the ecosystem was included with no pictures. Less than two different food chains were included.	A food chain rather than a food web was included, or vice versa.
Environmental Concerns Note any environmental concerns and/or efforts toward conservation of	Detailed information was included regarding environmental concerns and efforts toward	Detailed information was included regarding environmental concerns and efforts toward	Minimal information was included regarding environmental concerns and efforts toward	Minimal information was included regarding environmental concerns and no mention of

species or habitats.	conservation of species and habitat. A call to action was included.	conservation of species and habitat.	conservation of species and habitat.	efforts toward conservation of species and habitat was made.
Climate and Location Describe the climate and location for the ecosystem, including at least one map.	A detailed description of the climate and location for the ecosystem were included. Map and pictures included in the powerpoint or other visual presentation greatly added to viewer's understanding and research was evident.	A detailed description of the climate and location for the ecosystem were included. Map and pictures included in the powerpoint or other visual presentation did not add to viewer's understanding. Some research was evident.	A brief sentence describing the ecosystem was included. Poorly done map included but no pictures. Minimal research was evident.	No description of the ecosystem was included. No map was used in any aspect of the presentation. Minimal research was evident.
Visual Display Content A display must be prepared by each group. Additional visual presentations should add meaning to the overall project.	A display including the above-mentioned areas was well-prepared by all students involved. Work was completed on time and research was evident. Additional visual presentations (more than one) added to the meaning of the project.	A display including the above-mentioned areas was well-prepared by all students involved. Work was completed on time and research was evident. Additional visual presentation (one) added to the meaning of the project.	A display including the above-mentioned areas was well-prepared by all students involved. Work was completed on time and research was evident. Additional visual presentation was not meaningful or was not presented.	A Powerpoint including the above-mentioned areas was prepared by all students involved but with lack of care. Work was completed on time and research was evident. No additional visual presentation was evident.

Summary

Teaching science to young learners requires a complex set of knowledge and skills. It is not enough to be a science content expert or an elementary school methods expert. Teachers of science must be able to facilitate the acquisition of content knowledge and understanding in ways that require their students to construct their own knowledge of the topic under investigation. Inquiry-based instruction was the pedagogy students experienced to help them both learn the content across disciplines needed to be confident teaching science and the methods that would allow them to facilitate the discovery of content they feel benefited them as learners in this course. Being able to do this in the elementary school, specifically, requires teachers to know and understand how learning from one year is built upon in years to come. Therefore, teachers' understanding of learning progression is critical as it helps to plan instruction that builds on what students already know, understand, and are able to do. Instruction and assessment should facilitate the acquisition of science content and skills as well as the benefits associated with discovery learning through inquiry. Thus, teachers of elementary school science must be trained as students of science, teachers of science, and teachers of elementary school instruction. Courses designed to train PSTs elementary school teachers of science should, therefore, merge the teaching of all three.

Merging Content & Pedagogy through Co-teaching

Merging science content and pedagogy for teaching elementary school science is challenging for one instructor whose expertise is often limited to one area or the other. An interactive co-teaching model was implemented as a way to overcome this challenge. In studies on the effects of co-teaching, students reported that the co-teaching approach helped them develop critical thinking skills through the synthesis of the diverse perspectives of the instructors

(Higgins & Litzenburg, 2015; Shibley, 2006; Vogler & Long, 2003). Accordingly, PSTs in this course referred to the co-teaching relationship they experienced as a "science marriage" where they were the children and my co-teacher and I played the roles of "Mommy and Daddy." Karin's focus group comments effectively summed up how many students described our efforts to achieve that balance.

> I really enjoyed it, especially because Chris and Amy brought two completely different aspects to the classroom. It was very clear that Chris was like the expert science guy. If you had a question that you needed to know about sciency material - go to Chris. But then in terms of teaching science and being able to bring the classroom to life, that's where Amy was expert. Anything that you wanted in terms of teaching science and making something fun and interactive, she was there. So it was a great balance between the two and I thought that they worked extremely well together…it was like they had a science marriage and it worked so well because they really bounced off each other. Amy would definitely monitor us and if Chris got a little too in-depth with the science content, Amy would be like, "Okay, let's think about how we would do this in the classroom," and would bring us back in. So it was definitely a great balance. I didn't think one dictated the classroom over the other at all.

As co-teachers we had to consider how we would divide the roles and responsibilities involved in preparing for, planning, and implementing our lessons. Although decisions related to things like grading had to be discussed and determined prior to the semester, our roles in teaching were not explicitly decided and, instead, happened more organically. In what follows, I attempt to explain our roles and responsibilities and how they were defined through my field notes and the voices of our students.

Roles in preparation & planning. Since we had both independently taught the course prior to this semester, my co-teacher and I quite naturally divided the work and responsibilities in preparation for each class meeting. Chris would prepare the materials needed to conduct the science experiments and I would design the instructional aides (i.e. Powerpoints and handouts) and make copies of the materials students would use to examine the pedagogical aspects of our lessons (i.e. NGSS, examples of lesson plans, readings for class). We also met weekly to discuss our lesson plan for the upcoming class and in these meetings we debated and discussed both larger changes and smaller adjustments to instruction based on the outcomes of our prior course offerings and on new experiences we had or updated research we explored.

How we handled assessing assignments, like weekly checkpoints, lesson plans, lesson plays, and quizzes, was also determined prior to the start of class. We broke the class into two groups, A & B, and for each assignment we would assess the work submitted by one group; switching the group we assessed each week.

In order to get an overall picture of how our students' were engaging with the content, I would often email Chris with general comments about how my group of students had performed. For example, after a lesson on sinking and floating, students' comments on their Weekly Checkpoints made me worry about whether we were connecting the science content to the elementary school methods for practical implementation effectively. I emailed Chris:

> In reviewing my students' checkpoints I found that many were concerned about not being able to measure the density of water and objects as we did in class with young students. I'm glad that we got the chance to give them a deeper understanding of the content, but I'm not sure that we did well to explain that this is not how we would teach young students about density (2nd graders cannot be expected to accurately measure, multiply,

> or divide). So, I'm hopeful that the clay activity will help to model another approach but I'd like to creatively tie in the discussion about science practices with the lesson on density by asking them to come up with ways that they would help students to find more evidence to support their findings about sinking/floating. I think we should hold off on the quiz until they've had a chance to work through this. I also want to make sure that we discuss curriculum integration through the social studies video and book. So, is it cool that I start tomorrow's lesson with that stuff and then we give the quiz, and then go onto motion? I figure we can assign them to find sample motion lessons as part of the homework and then analyze/revise them for inquiry-based methods the following week. Eager to hear your thoughts.

He responded:

> I think that is a good idea. I think the question of how to teach this to younger students is an important one and you are right, we didn't do much regarding this in class. I am surprised that none of the students that I responded to had the same questions.
>
> I think we can move the quiz to later, but I am not sure they need to have the discussion of how to teach the material to younger students before they do it. My concern is that if we give it in the middle of class, it will take longer and we have a lot to go over, but I think we will be okay either way. I really think we should spend some time with the curriculum integration and thinking about how they would teach density to younger students.
>
> As far as the NGSS standards, there is really no standard that directly addresses density. In middle school they are supposed to be able to use the change (or lack of) in density to determine if a chemical reaction occurred and as evidence that substances change during

> chemical reactions. This is one of the downfalls of the NGSS in that there are things that the students need to learn which aren't explicitly stated in the standards. This is something that is going to be particularly difficult for elementary and middle school teachers with less content knowledge.

Because we decided students' understanding of the content was not affected by their concerns, in this instance, we chose to administer the quiz as planned at the beginning of the lesson. We did, however, change the questions on the quiz to include examples that could be used to address PSTs' concerns. Formerly the content-related question on the quiz was stated as follows: *You have 3 different liquids of unknown density. Design an experiment that would enable you to figure out the relative densities of each of the liquids (which one was the densest, the least dense, etc.).* To prompt PSTs to consider different ways of thinking and talking about density, we changed the question so that it said: *You place a solid plastic PVC cylinder into a bucket of water. It floats. What would happen if you cut the PVC cylinder in half? Use your understanding of sinking and floating in water and density to explain your response.* Students answered the question using a variety of strategies. One used mathematical calculations to identify how the proportion of mass to volume was unchanged, while others simply explained that the amount of "stuff" compacted in the pipe was unchanged.

I also incorporated some curriculum integration ideas by likening density in science to population density in social studies. We prompted the students to stand closely together in one area of the room and then to stand far from each other to compare high and low levels of density. Students reported that using our bodies to visually represent this abstract concept helped them to understand multiple means through which it could be addressed at the elementary school level. It also helped them to be able to explain their understanding of density. In her weekly checkpoint, Brandy explained this activity.

> To reinforce this idea [density], we all stood up and acted as human particles. When we all stood close together we modeled a dense object, the "particle" in the middle said she felt squished, like she couldn't breathe. Then we all spread out to represent the larger objects with a smaller density. In this model we all had plenty of space to breath and more around.

Although the concept of density is not addressed, explicitly, until middle school, Chris discussed how learning progression was involved in our decision to teach it. He explained that science in the elementary school is foundational to this complex concept and that instruction at this level helps to develop deeper understanding if handled appropriately. In this case, for example, preschool and kindergarten teachers often allow students to explore sinking and floating in water tables in the classroom. They need to be able to scaffold students' thinking about this concept and question misconceptions like "heavy things sink" that students might have acquired. In including density in our curriculum, we facilitated experiences that would prepare PSTs for discussions about sinking and floating with young students that would not encourage the acceptance of misconceptions.

Adjustments to our instructional plan like these were consistently based on students' work and performance. How to modify and adjust the curriculum to best balance the teaching of science and elementary school methods of instruction and both substantial changes and small adjustments were made jointly. As in any strong "marriage," we checked in with each other before making big decisions.

Roles in the classroom. The teaching in action, however, was often split based on our areas of expertise. Chris conducted the majority of the experiments and demonstrations in physical science and I led investigations in life science. Though we both circulated, observing and posing questions to students when they worked collaboratively, students seemingly picked up on the different approaches we took to this role. The exchange between Michelle, Ann, and Samantha in the focus group shows how students perceived this.

> Michelle: Even, like, them answering your questions. They would come around the room while we were in groups and ask us questions and it was interesting because they were both a little bit different in what they were asking.
>
> Ann: Yeah, and it was never like, oh Chris just asked me that question. They always asked different things. I was like, did they talk about this before?
>
> Samantha: Also, if you didn't understand an explanation from one of them the other would explain in another way where you would understand it. So that would really help us.

Likewise, although the students were not made aware of who was reviewing their work, our feedback seemingly gave us away. They noticed the foci of the feedback provided by each instructor differed as it tended to align well with the instructor's areas of expertise. Karin explained this in more detail in the focus group, saying:

> In terms of science, Amy would look more at the overall picture and what you were trying to accomplish she'd be like, "Wow, this is great but there are a couple things you could fix in terms of science." When Chris would evaluate our work, he would say things like, "You used this word incorrectly and so in order for you to get 10/10 you need to change this word," but it would just be like one word…so, yeah, we definitely could tell who graded.

In class, Chris focused much of his teacher talk on his science content knowledge while I tended to talk more about my experiences in the classroom and in teaching science to young students. This may be why students often directed questions about advanced levels of science content toward Chris, while I answered questions about how to make the science they were investigating appropriate for younger students. Erin's focus group comment explains this balance in more detail.

> I feel like Chris was more of the doing the experiments, like dropping bowling balls, riding on roller blades. But then when we got into, like, group work they both were good at coming around and questioning us. And then Amy was more of, I feel like she brought more of like, not her own personal experience, but more of like this is what happened in science class with these kids and this is how my daughters would describe it. She gave us more of the aspect of how kids would go about learning these things or going about the activities we were doing. So I liked that balance.

As we taught, we organically took turns addressing the topic at hand. Missy saw that this worked to create a more complex learning experience as we helped each other by offering our expertise wherever it fit.

> They kind of balance each other out. They are both very strong teachers but they focus on different things so where one may lack a little more, for lack of a better term, but the other one could kind of bounce them right back and kind of fill in the gap.

These different roles afforded our students opportunities to experience the importance of being able to merge understanding of science content with methods for teaching elementary school in practice. This is, seemingly, the *balance* students consistently described in reflecting on and evaluating the co-teaching model. Maria said,

> Because, we had Chris and he really made sure that we were understanding the science concept. So I thought that was really good. He kind of focused on the content and Amy kind of focused on the pedagogy and I really thought that was important because, okay we know the science content but do we know how to teach it? Or, we know how to teach it but do we really know the science content?

Erin agreed that having two instructors meant double the resources. She said:

> Well you have two people to get information and resources from and even if you went to one, in general, they could like help you out and if they wanted to get another opinion you had two people. And then also thinking about the future, like, when we're in the classroom we could email two people if we have questions.

Overall students reported feeling as though they gained from having two instructors in one class as they were able to learn how to teach science from two perspectives. However, they also complained of being exhausted at the end of each class and perceived this to be, in part, due to the fact that they had two instructors who could take turns leading the class and were therefore more energized for the three-hour session. Bree explained her perspective on this.

> I don't know if it's because we had two teachers…after science I feel like your brain is just so tired because, it's like, you have two fresh brains teaching you in that three hour period so I found that they kind of had to squeeze in the material we had to learn in that three hours so sometimes it was just a bit mentally exhausting. They both have their own opinions, their own thoughts and stuff, and they wanna teach it to us and, I don't know sometimes I just felt tired.

Likewise, a few students expressed feelings of frustration as they felt as though the workload in our course was greater than those in other sections with only one instructor. A few students perceived the number of course assignments to be intense and numerous due to having two instructors. Missy explained.

> We had a lot of work in the class. Like in comparison to the other cohort I know they don't always have weekly checkpoints and lesson plays and quizzes and so while I totally understand that it's trying to reinforce our knowledge and understanding of what we got in the class, I think, it tended to sometimes be a little bit overwhelming with the amount of work we had all going on at the same time. And I'm not sure if that's because we had two teachers with differing thoughts and differing opinions in what they wanted to do differently, or not, but that's just one of my opinions.

Josie even suggested that the fact that the course was co-taught resulted in double the work, saying, "I was talking to people in other cohorts that didn't have the double teachers and I think they were like, I want to do this many homeworks, and I want to do this many assessments - so let's just do all." One the contrary, no changes were made to the course assignments from when we taught the course individually prior but it seems our co-teaching approach made students feel overwhelmed at times.

Even with the perceived increase in workload, however, students valued the co-teaching model as it provided them with experiences that merged the teaching of content and pedagogy while offering an example of how two professional educators could work well together in one classroom. Though many focused on the merging of teaching science and elementary school pedagogy, others talked about what they learned from to co-teaching model, in general. In the focus group, Bree highlighted a conversation she and I had after class one day in which we discussed roles involved in the co-teaching approach. She said:

> Amy even told me that they were learning how to work with each other…trying to figure out a happy medium. So I realized that sometimes things may not have gone as smoothly, but like, I know that they were trying to work it out as well and I think they did a really great job. Some co-teachers don't even like, I know in elementary schools, sometimes they don't even get along with each other like they butt heads and it's really annoying. But I thought that these two had a really great relationship in the classroom and you could tell.

Josie also expressed a new understanding of how co-teachers could balance the roles involved in teaching.

> I think when you have two teachers in the classroom you always kind of have that favorite, that go-to. In our class it was not like that. If you had a question I felt like we all felt comfortable going to Amy or Chris. It wasn't like, oh I don't want to ask Amy this question because I know that I'm not gonna get the answer I want. Both of them had the right answer and if they didn't they would be like, "Okay why don't you talk to Chris about this and explore this further with him." So it felt like they really appreciated each other and so it helped us appreciate them on the same level.

Cameron's focus group comment suggests we achieved the balance we were seeking in our classroom roles saying, "I think they both left an imprint, like an impression on us. It wasn't just one teacher, like, stole the show. They gave both attention, they both, like we considered both of them our teachers."

The comments shared by our students regarding the benefits of this approach are echoed in research on co-teaching in higher education. This research, often reported as case studies conducted by teacher educators, suggests that this approach helps students develop critical thinking skills through the synthesis of the diverse perspectives of the instructors (Higgins & Litzenburg, 2015; Shibley, 2006; Vogler & Long, 2003), provides increased opportunities for individualized instruction (Vogler & Long, 2003), and allows PSTs to experience teacher collegiality (Higgins & Litzenburg, 2015; Shibley, 2006; Vogler & Long, 2003). Case studies conducted by teacher educators who practice co-teaching have report that with a shared pedagogy for teaching, open communication with their partner teachers, and clear responsibilities and expectations for instruction and assessment, co-teaching can be a very rewarding professional experience (Higgins & Litzenburg, 2015; Shibley, 2008; Vogler & Long, 2003).

Modeling for PSTs how a professional "marriage" with colleagues could work was an unintended outcome of this study. We had hoped they would benefit from learning from us as a team but did not assume they would be so aware of the work it took to do so effectively in practice. The goal of our co-teaching approach was to be able to teach them what they needed to know in terms of content and pedagogy and assess their understanding of both in authentic ways.

Assessment of PSTs' learning. The overarching goal of this course was to teach and assess PSTs' understanding of science content, pedagogy for teaching science, and elementary school methods of instruction. These understandings were assessed through their participation in class activities, discussions, and multiple course assignments.

Class activities and discussions afforded PSTs opportunities to self and peer assess as they worked collaboratively through scientific investigations and engaged in discourse focused on communicating and debating their understanding of the science content. Questions, asked by instructors and peers, helped facilitate this learning and the assessment of learning. PSTs received individualized instruction via feedback loops conducted through the review and resubmission of course assignments. PSTs' work was assessed by one instructor each week and the instructor who assessed the work of each student alternated weekly. Although PSTs earn points toward their course grade, these points were fluid as they were permitted to resubmit their work after reviewing the feedback provided by the instructor and making suggested changes/improvements. Feedback on coursework facilitated constant dialogue between the instructors and PSTs and between instructors about student learning. This dialogue fed into our teaching in that we would adjust the instruction based on the assessment results and questions posed by PSTs in these feedback loops.

Throughout the semester, students were responsible for completing five assignments that integrated science content and pedagogy: *weekly checkpoints, quizzes, lesson and unit plans, lesson plays,* and *reflections*. Weekly Checkpoints required PSTs to answer two questions: 1) What have you learned in terms of content and how did you learn it? 2) What have you learned in terms of pedagogy and how did you learn it? They were assessed for alignment between the claims made by the students and the evidence used to explain those claims (Allchin, 2011; Duncan & Cavera, 2015; Zembal-Saul, 2009). Unannounced quizzes were similar in format and function to the weekly checkpoints as they also contained two questions, one focused on content and the other focused on pedagogy. Lesson and unit plans required PSTs to plan long- and short-term instructional goals and assessments and activities aligned with them. Lesson plays, scripts containing student-teacher lesson dialogue, were used to assess PSTs' knowledge of possible students' responses, given the grade level and content assigned, and how they should promote students' scientific thinking through questioning and scaffolding and their content knowledge and understanding. PSTs also composed two in-depth reflection papers, analyzing and reflecting on their experiences as students of science prior to and after the course.

Knowledge and understanding of science and teaching science. Weekly checkpoints required students to be able to both explain the key concepts of the topic as well as to explain the processes through which they went to discover them. In this way, students were creating records of the science content they learned and the pedagogical practices used to teach them. They served well as an assessment of students' understanding of both as we were able to utilize their work to determine what content we needed to revisit or pedagogical practices we needed to discuss further or model more. In the focus group interviews, students unanimously agreed weekly checkpoints were the assignments that best aided them in assessing their own understanding of science content. Likewise, we used the weekly checkpoints most to formatively assess students' science content knowledge and plan subsequent instruction/support as needed. Ann and Michelle explained these assignments.

> Ann: Usually it was like two questions. The first would be, "What did you learn in class in terms of science content?" and it was good because we would have to give the, "I learned that the moon revolves…," and then you'd have to say how you learned it. You couldn't just say that's what I learned you had to explain how you learned it. So it was like, "I learned this because this," and if you didn't you wouldn't get the full credit.
>
> Michelle: And the second part was what did you learn in terms of pedagogy and how did you learn that. And it was like, "I learned that modeling is important because…," and the last part was where we had to ask two questions, two questions that we still had after that week about science, or teaching science, or anything about that week.

PSTs composed lesson plays to help us assess what students knew and understood about the content and how they would teach the content to elementary school students. In these assignments, students were required to compose a script that depicted a few minutes of teacher-student dialogue in a science lesson. It required the writer to consider the goals of the lesson in terms of science and the learning progression they sought to target in a specific grade level, considering consider prior knowledge and long-term goals. Karin described this assignment by saying in, "the Lesson Plays we had to do to get the student from one way of thinking to the next." This assignment also afforded opportunities to practice and assess PSTs questioning techniques that could be used to scaffold students' learning. Focus group data suggested most students thought the lesson plays helped them to analyze how they would teach science as they were required to consider what they would actually say in a lesson as well as how students would respond. Some students felt that composing the script helped them to critically think about teaching science while others felt that reviewing the script created by a peer, which helped them to revise their first draft, was most beneficial. Ann and Diana's exchange highlights these two opinions.

> Ann: The first time I submitted it [lesson play] I got an 8/10 and they put really good comments like, "Would your student really say this?" "Is this something your student would really say?" And I was like, no, probably not. That's just what I would hope my student would say.
>
> Diana: I liked reading through people's but that's just because I didn't do well on my lesson play and I liked reading through someone else's to see their examples then going back to work on mine. It made it easier.

A few students struggled with the lesson plays because they had a tough time figuring out what students might say or a lack of content knowledge that made them fear they would not provide accurate information. In the focus group interview, Erin expressed feelings of trepidation.

> I didn't love doing the Lesson Plays either. It was hard. I don't know what students are gonna say. I don't know if I have all the content knowledge or enough of the content knowledge to be able to answer their questions thoroughly.

This comfort or discomfort in knowing what students think was assessable as this assignment required PSTs to be able to talk through a lesson that guided students in understanding content. If the PST was not confident in the content, the dialogue might wander from the lesson's objective or be surface in terms of the questions asked and content addressed. As such, this assignment acted as a valid assessment of students' confidence in and understanding of teaching science.

Assessing for knowledge and understanding of elementary school planning and instruction. Students were asked to select a partner with whom to plan a science unit and the pair was permitted to choose the discipline, topic, and grade level of their unit from a list of options not otherwise addressed in the course curriculum. This assignment was designed to take PSTs through the thinking and planning required to develop a science unit. The unit had to include two detailed lesson plans including pre-planned questions, etc., while the remaining 8-13 lessons were only required to include objectives, a summary of the procedures, and methods of assessment. Instruction in class meetings focused on *Evaluating & Modifying Premade Lessons, Unit Planning, Question Techniques, Evaluation and Assessment of Student Learning,* and *Authentic Assessment* was designed to provide PSTs with the experiences, examples, knowledge, and skills to design a coherent and effective unit plan.

The pairs were also required to teach one of the lessons they had planned to the class. Microteaching, which has been shown to significantly improve the teaching skills of PSTs in science instruction (Bakir, 2014), was implemented to provide immediate feedback to the students as they were teaching. Those who practice this method believe professional skills can be taught through modeling and discourse about practice (Bakir, 2014). Thus, in this approach, PSTs modeled a lesson in an artificial environment (using their peers as students) and received feedback in the moment that prompted them to reflect and reteach as needed. The feedback provided engaged all PSTs, including those acting as students, in professional reflective discourse about practice. PSTs were expected to model inquiry-based methods for teaching science to elementary school-age students as well as to demonstrate mastery of the science content. These demo lessons served as multi-purpose assessments helping us to understand and evaluate PSTs' science content knowledge and knowledge and understanding of how to plan and teach science to elementary school students. Acting as co-teachers, we were able to provide PSTs with feedback concerning both their understanding of content and practice.

Conclusion

This study sought to learn about PSTs' experiences in a co-taught methods course. The data gathered from students' focus group comments suggests PSTs found benefits in the co-teaching model. Data analysis found that being taught by two teachers afforded PSTs opportunities to learn from professionals with different areas of expertise. They described my co-teacher and I as resources able to address their challenging questions using advanced levels of content knowledge and professional experience. We also learned from each other as we worked to collaboratively navigate the challenges we faced as teacher educators. It seems our students were aware of how being taught by two teachers benefited them as they viewed the course as well balanced.

Secondly, it seems, in addition to the co-teaching model, PSTs found particular aspects of the curriculum beneficial to their learning. Opportunities to conduct science as students through inquiry-based instruction aided PSTs in developing an understanding of science as a process for learning instead of a specific set of knowledge and facts to be memorized. Thinking critically about their understanding through teacher questions and questions posed by peers helped them to think through investigations like scientists do. Likewise, creating scientific models aided them in developing methods for communicating their understanding and critically analyzing other's understandings of science. Reflective discourse about these practices helped them to transfer their experiences as students to their future practices as teachers of elementary school science.

Reading about and discussing examples of learning progression across grades, work with instructional materials, and analysis of methods for curriculum integration also aided PSTs in thinking about and planning for how they could teach science to the future.

PSTs evaluations of the curriculum and course design suggest they experienced this course as both students and future teachers of science. What follows is an analysis of what PSTs learned in terms of science from their course experiences and what they learned about how to teach science upon reflection of those experiences.

CHAPTER 5: STUDENT LEARNING

Effective elementary school science teachers are proficient in *both* their science content knowledge and pedagogical content knowledge (PCK) (Anderson & Clark, 2012; Avery & Meyer, 2012). However, a national survey conducted to determine the status of science education in our nation found most elementary school teachers are underprepared for teaching science in multiple disciplines and the pedagogical beliefs held by most are inconsistent with what is known about effective science instruction (Trygstad et al., 2013). Since elementary school teachers rarely specialize in science they often view the content as too difficult to master (Davis, et al., 2006; Swars & Dooley, 2010) and therefore "not my forte." As a teacher educator in elementary education, I am concerned about the status of teacher preparation in the area of science. Teachers who lack the competence and confidence to teach science through inquiry may deliver instruction void of experiences necessary for students to become scientifically literate citizens. This study was conducted to explore this problem of practice by examining what preservice teachers (PSTs) learned in my co-taught science methods course where science content was deliberately integrated with pedagogies for teaching science to children 5-12 years of age.

The *Science in the Elementary School* course had two main goals. First, the course was designed to provide PSTs with experiences that would enable the acquisition of science content knowledge and professional growth of PCK for teaching science. Second, as research suggests inquiry-based experiences conducting science with peers is more likely to result in increased self-efficacy in learning and teaching science (Avery & Myer, 2012), this course was also designed to build the confidence of PSTs who may hold negative feelings toward science or doubt themselves as scientists. To accomplish these goals, the course curriculum and activities integrated the teaching of science content with the teaching and modeling of inquiry-based instruction and methods for teaching elementary school students.

In the last chapter, I outlined the curriculum, course design, and co-teaching approach to illustrate what PSTs' experienced in the science methods course. This chapter details student learning more specifically in two main ways: analyzing what all 14 PSTs enrolled in the course learned in terms of science content, science-related skills, and pedagogy. I then delve more deeply into the learning of three focal students, what each experienced and reported she learned in the course.

What Students Learned about Science, Scientific Reasoning Skills, and Pedagogy

The research questions in this study focused on three areas of PST's learning: 1) scientific reasoning skills, 2) science content knowledge, & 3) pedagogy for teaching science. In what follows, a comparison of PSTs' pre- and post-course Lawson Test results, course assignments, and focus group interviews are used to explore each of these areas of learning.

Scientific Reasoning Skills

If elementary school teachers are to engage students in experiences that mirror work conducted by scientists in the field, they need to develop skills and practices that help them think like scientists. This course aimed to facilitate experiential learning opportunities in which future teachers gained these science-related skills. To begin examining what the 14 PSTs learned in terms of science, I first looked at the Lawson Test results that PSTs' scientific reasoning skills measured before and after the course. The reasoning skills assessed in this measure are associated with conservation, proportional thinking, identification and control of variables, probabilistic thinking, and deductive reasoning (Carmel & Yezierski, 2013; Coletta & Phillips, 2009).

As can be seen in Table 9, students' scores did not change significantly from the beginning of the class to the end of the class. Five of the thirteen students' overall scores were, in fact, unchanged. However, a review of each of these 5 students' tests evidenced changes in their answers, without changes to the overall Lawson test scores. As the Lawson Test is scored cumulatively, if a student's score increased in one area and decreased in another area of scientific reasoning it still resulted in the same overall score, pre- and post-course. Likewise, because the Lawson Test contains two-tier assessment items, the overall scores do not capture how specific changes within each test alter the cumulative outcome. For example, Student A answered one more question correctly post-course than pre-course, yet, her overall score is unchanged because she did not answer both parts of the question correctly. Her score falsely suggests her responses were unchanged. The opposite, however, could be said for Student E who answered one more question incorrectly on the post-course test. Answering one part of a two-tier item incorrectly resulted in a decrease of her overall score. Therefore, the cumulative scores of this test cannot be used to conclusively examine whether and/or how students' scientific reasoning skills changed.

Table 9. *Lawson Test Pre- & Post- Course Scores*

Student	**Pre-Course Score (10 Possible Points)**	**Post-Course Score (10 Possible Points)**
A	9	9
E	9	8
B	8	8
C	8	8
D	7	8
F	6	7
G	6	7
K	6	6
M	6	4
H	5	7
I	5	7
J	5	6
L	5	5
N	/	4

Key	
Score Change	**Color**
Increase	
Decrease	
No Change	

There are two potential reasons to explain why there was no significant movement in Lawson Test scores, pre- to post- course. First, the frequency of PSTs' experiences with science varied. The number of college level science courses taken by each student prior to this study are listed in Table 10. No measureable ties between the number of former college level science courses and students' Lawson test scores pre- or post- course were found. In fact, Student A, who scored the highest on the pre-course test, took only one college level science course prior to participating in this study. Student C, whose initial Lawson Test score ranked her as one in the top three, and Student I, whose initial score ranked her in the lower half of the class, had both taken three college level courses prior. Student C's scores were unchanged while Student I's post-course score showed the greatest increase (+2). There is no way to determine if work in a particular discipline or type of course afforded more opportunities to gain skills in scientific reasoning.

Table 10. *Number of College Course Taken Prior & Lawson Test Pre- & Post- Course Scores*

Student	Number of former college science courses	Pre-Course Score (10 Possible Points)	Post-Course Score (10 Possible Points)
A	1	9	9
G	1	6	7
E	2	9	8
B	2	8	8
D	2	7	8
K	2	6	6
M	2	6	4
H	2	5	7
L	2	5	5
C	3	8	8
F	3	6	7
I	3	5	7
J	3	5	6
N	Unknown	/	4

Key	
Score Change	**Color**
Increase	
Decrease	
No Change	

The number of courses taken prior may tell us about how much time the PSTs spent learning science. However, the way science was presented and the frequency with which they learned and/or used scientific reasoning, if at all, cannot be measured. Each of these factors may influence their performance on the scientific reasoning skills assessment (Lederman, et al., 2002).

The second, and more probable, reason there is no significant movement is because the scientific reasoning skills the Lawson Test assesses (i.e. conservation, proportional thinking, identification and control of variables, probabilistic thinking, and deductive reasoning (Carmel & Yezierski, 2013; Coletta & Phillips, 2009)) are not closely aligned with the scientific practices established by the NGSS (i.e. 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, and obtaining, evaluating, and communicating information) which were the primary focus of the methods implemented in this course.

While the Lawson Test does not indicate statistically significant changes in PSTs' scientific reasoning skills, other more nuanced examinations of tasks within which students engaged in class and analysis of what PSTs learned through coursework do illustrate growth in science-related skills, more specifically, in science and engineering practices.

Learning Science Content

Each week of the course addressed science concepts that aligned with elementary level disciplinary core ideas and performance expectations in the Next Generation Science Standards (NGSS). PSTs were, therefore, expected to engage with and learn content related to the standards they would address as teachers of elementary school science such as matter and its functions, weather and climate, and the growth and development of organisms. An analysis of the three main data sources from PSTs' course assignments (i.e. weekly checkpoints, quizzes, and focus group interviews) sought to answer the research question: *What do PSTs learn about science content in a co-taught science methods course aimed at combining the teaching of science content with the teaching/modeling of inquiry-based instruction?* Though I can confidently say formative assessments like the quizzes administered and class discussions conducted throughout the class to gauge students' learning showed they were progressing in their understanding of science, the data does not provide enough evidence to discern what they learned in terms of core ideas across disciplines.

To begin my examination of what PSTs learned in terms of disciplinary core ideas (DCI) I compared my lesson plans (i.e. lesson objectives, essential questions, and anchor charts) with what PSTs said they learned in terms of science in weekly checkpoints. An analysis across weekly checkpoints showed PSTs mainly communicated what they learned about science by restating the agreed upon definitions of science terms and key concepts that closely mirrored information listed on class anchor charts. In each class, these charts were used to record what PSTs learned from their class work. In this way, anchor charts evidenced co-constructed knowledge. Often implemented as closure to an investigation, anchor charts were used to succinctly summarize the conceptual learning that took place in class. Figure 7 shows an example of an anchor chart and samples of statements pulled from PSTs' weekly checkpoints in which they answered the question: *What did you learn in terms of science?*

Figure 7. *Class Co-constructed Anchor Charts & PSTs' Weekly Checkpoint Responses*

Class Co-Constructed Anchor Chart	**PSTs' Weekly Checkpoint Responses to the question: *What did you learn in terms of science?***
<u>What We Learned About Matter</u> • matter is made up of tiny pieces called particles • particles can move • particles spread out • there is space between particles • air is made up of particles	• *I learned that air is made up of something and that something is particles.* • *This week, I learned that air is not just "nothing"; it is made up of particles too.* • *We learned that air is made up of particles.* • *I also learned that there is space between particles.* • *I learned that liquid particles have space between them.* • *Lastly, I learned that matter- takes up space, is always moving (they spread out), is composed of many particles, can't always be seen (like air).* • *We learned several properties of matter. We learned that matter is made up of tiny particles. We also learned that matter is always moving, and since it is always moving, matter spreads out across space.* • *I learned that air is made up of something. That something is matter, which is made up of tiny particles, takes up space, and moves.* • *I learned that matter is made up of tiny pieces, also known as particles.*

The key concepts recorded addressed the content planned by instructors but the statements represented the words PSTs used to describe their understanding in class. Therefore, it is not surprising PSTs applied them when writing about new knowledge and understanding of science in reflective assignments. These assignments required PSTs to be able to use work conducted in class to explain how they arrived at the key concepts; the class average for the 8 weekly checkpoints was 91%, suggesting they were able to do this effectively. However, because students typically used phrases taken directly from the anchor charts it is difficult to discern whether they truly learned the science concepts they wrote about or were just able to connect what we did in class to the key concepts.

Likewise, quizzes and focus group interviews provided some evidence to suggest PSTs learned key concepts but not enough to make bigger assertions about what they learned. The class quiz average was 9/10 points. This suggests students were able to explain their understanding of the core concepts assessed, yet, because only three quizzes were administered throughout the course, each focused on one core idea in science, they provide limited data. I can say, for example, that PSTs were able to explain how the density of an object affects whether it sinks or floats, but I cannot make assertions about the depth of their understanding or determine whether their understanding would transfer to scenarios other than the one presented on the quiz.

Focus group interviews served as the data source geared toward assessing PSTs' science content knowledge after the class was completed. When asked what they learned in terms of science, however, PSTs responded by describing the *learning processes* they experienced and engaged in, not the *science content* they learned. This made what they actually learned in terms of core science ideas unclear. What *is* clear from this analysis is PSTs were able to explain how we arrived at key science concepts from evidence gathered by conducting science investigations in class. They were also able to cite several examples of how the learning processes they experienced helped them develop skills and pedagogies for teaching science.

Scientific Processes Mediate Students' Learning: Investigating Like Scientists

Research suggests in order to teach science competently and confidently, elementary school teachers must be knowledgeable in both content and pedagogy. This study aimed to teach both through an experiential approach where PSTs, played dual roles as students and future teachers of science. Possibly because this course was designed to merge the teaching and learning of content and pedagogy, when asked what they learned in terms of science content in focus group interviews PSTs conflated the two. They tended to describe the processes, science practices, and inquiry methods that helped them to learn the content, rather than identifying specific science topics or disciplinary core ideas (DCI) they learned. In this way, experiences with inquiry and the reflective discourse that followed were cited most often as examples of what students learned from this course.

In what follows, I use the students' voices to identify how scientific processes and practices helped them learn about both science as students and pedagogy as future teachers of science. I begin by establishing two ways PSTs described they learned the key concepts in science: physical investigations and scientific modeling. I then examine how PSTs applied what they learned in terms of pedagogy to their thinking about and planning for elementary science instruction.

Physical investigations. The discipline addressed in the course in most depth was physics. This may be because I partnered with an expert in physics to co-teach the course; however, research suggests this discipline is the one which most elementary school teachers feel least competent teaching and, therefore, might need the most evidence and experience with to understand. When addressing concepts in physics, we often conducted investigations in which we demonstrated or facilitated exploration of hands-on materials to find evidence to disprove or support hypotheses that answered scientific questions about core concepts. Through these scientific investigations we modeled how scientists systematically disprove hypotheses using evidence as they work toward potential answers to questions and/or solutions to problems.

Providing physical evidence seemed to help PSTs understand the core concepts more deeply and concretely than they had prior. For example, during the class in which we explored whether items floated or sunk in water, we conducted a scientific experiment in which PSTs tested items in water. Thirteen of the 14 PSTs cited this experiment in their weekly checkpoints as evidence of learning. Cameron described this experiment.

> We asked the question: *Do heavy things sink and light things float in water?* We tried to answer by finding the mass of different items with a triple beam scale then placing them in the water. We set up a chart of the name of the item, mass, and if they float or not. We gathered our information and we realized that the clear sticks that [the professor] gave us had debunked our question. We ended up focusing more on the clear sticks and tried to figure out why the heavier one floated and the lighter one sunk. We compared the sticks and learned that the sticks are made out of the same material but one is slightly bigger than the other. Knowing our prior knowledge that matter is made up of tiny particles/pieces, we were able to relate that the particles could be less compact in one tube. The compactness of particles in a given space was called density. We were also able to confirm this idea of density by finding the density of water and also dropping certain type of blocks that vary in density in order to see that highly dense blocks sunk and less dense blocks floated.

The lesson began by observing two cans of soda, Coke and Diet Coke, being placed in a tub of water. The slightly heavier one, the Coke, sunk while the other floated. This observation sparked the question: *Do heavy things sink and light things float in water?* As Cameron explains, PSTs then engaged in an investigation in which they tested items for sinking and floating, recorded their data, and drew conclusions from their analysis. Jen also explained this experiment in her weekly checkpoint.

> When testing four different pipes that looked very similar to one another we noticed simply finding the mass of an object was not a way to determine if it would float or not. Of the four pipes, two were a little bigger than the other two but they all had a similar mass. When put in the water, the ones that were a tiny bit bigger floated and the smaller ones did not. We discussed that the density is found by multiplying volume and mass together. When calculating the densities for these pipes we discovered that the pipes that sank were denser, the particles are more close together.

My co-teacher and I deliberately placed the pipes Jen referred to in the pile of materials students were required to test. Because all of the pipes weighed approximately the same and some floated while others sunk, the volume, or the amount of space taken up by the pipes had to be considered. In this way, they provided clear evidence that would disprove the hypothesis: heavy things sink. Jen narrowed her analysis of the experiment to these materials but, like Cameron, she was able to use the scientific experiment conducted and the evidence gathered from it to explain her understanding of density.

Though the curriculum addressed physical, earth and space, and life sciences, however, the first five weeks of the course were solely focused on lessons in physical science. In reviewing focus group interviews, I found physical science investigations, were cited most frequently in response to questions related to what PSTs' learned in terms of science content. The lesson on Newton's Laws was cited most often as evidence of learning. Though no one explicitly stated the laws in focus group interviews, PSTs consistently used them as examples to support what they learned from the course. Karin, for example, felt this was a defining moment in which she realized she was capable of doing science. In reflecting on this experience she said,

> That really hit me with the roller blade thing. The purpose of that was Newton's First Law…Ann is pushing [the professor] on the roller blades and we're all just observing, ya know. And then we went into the classroom and we recorded our observations and…at the end of it he was like, "Wow! Great! You guys are so smart. Newton's First Law." And we were, like, "Wow we just discovered it!"

Bree also cited this experiment when talking about what she learned in the course saying:

> Well, one concept that I really, really learned was Newton's Laws and I think why I really got it is because we didn't even know that we were going to explore Newton's Laws. We just experienced what Newton's Laws were without actually knowing what it was. So we came to the conclusions ourselves before it had a definition or a topic to it. So, I think the exploration really helped us.

Beginning with their own observations helped Karin and Bree's explain the science phenomena using investigative evidence. In Maria's focus group interview, she also emphasized how influential learning Newton's Laws through inquiry was in making her and her classmates feel like scientists.

> They didn't tell us we were gonna learn the three laws of Newton. We did an experiment where we actively engaged in the experiment…We learned that doing it that way makes the student, first of all, really understand the concepts without giving them a definition

> that they're not gonna understand. We learned that this is all effective because the student gets to really feel like they learned it on their own and not that someone gave them the information…they also feel proud of themselves that they came up with this conclusion that a famous scientist came up with doing his experiments. So I thought it was a cool way of learning that. Like, I never learned about Newton's Laws that way.

Though not stated explicitly in focus group comments, PSTs were able to explicitly state the agreed upon key concepts (i.e. Newton's Laws) we arrived at as a class from the investigations conducted in their weekly checkpoints. Ann's weekly checkpoint served as a good example of this.

> When the force on an object is in the same direction as the motion of the object, the object will speed up. Conversely, when the force on an object is in the opposite direction as the motion of the object, the object will slow down. Lastly, when there is no [unbalanced] force in either direction on an object, the object will remain at constant speed. I learned this when [the professor] was on roller skates. When a student pushed him the same way that he was skating, he sped up. When a student applied force to him in the opposite direction than where he was skating, he slowed down. When no force was applied, he remained at a constant speed.

Investigating the laws of motion afforded students opportunities to talk about their shared observations from scientific experiments as evidence and discuss the conclusions that could be drawn from them. Scientific investigations provided concrete evidence to support abstract physics concepts. These experiments were described more explicitly and with more detail than experiments in other disciplines.

Scientific modeling. Scientific models can take many forms such as force diagrams, 3D models using manipulatives, kinesthetic models, and pictorial models (i.e. food chains and life cycles). Scientists use these models to predict and explain scientific phenomena and as the means by which to demonstrate how understanding of a concept has evolved and/or changed (Schwarz et al., 2009). Therefore PSTs were taught to develop, analyze, and critique models. At some point in either course assignments or focus group interviews, all 14 of the PSTs mentioned scientific modeling as evidence of learning.

Scientific modeling was a pedagogical practice explicitly taught and practiced in this course. It was used to model science concepts, assess PSTs' understanding of them, and their ability to create models that could be used to teach science to elementary school students. There was a variety of scientific models created and studied throughout the course (i.e. force diagrams, particle models, kinesthetic models, 3D models, food chains, life cycles, etc.), however, three types stood out in PSTs' course work and focus group interviews: 1) force diagrams, 2) 3D models with manipulatives, and 3) kinesthetic models.

Force diagrams. Simply put, force diagrams illustrate the applied forces, movements, and resulting reactions in a given scenario. These forces are not always easily seen, therefore, diagraming them allows the learner to visualize what is happening in an investigation. Several students wrote about force diagrams as scientific models in Week 5's checkpoint through which they reflected on what they learned about forces and motion. Jen wrote about an experiment designed to teach students to think about how an object's weight affects the forces acting on it and vice versa. In this experiment she volunteered to hold a tennis ball in one hand and a medicine ball in the other so she could feel and report to her peers on the difference in upward force required to hold up each ball. In her checkpoint Jen said:

> I knew the tennis ball took less force to hold up compared to the medicine ball because the strain on my arm was less. After I did this and the class observed it, we needed a way to write it that could be universal and understood by everyone. To represent the ball we just used a circle, and to represent the force we drew lines coming from the ball to show the direction of force on the object. So for this activity there were two circles both with arrows coming directly out of the top, the circle representing the medicine ball had a larger arrow that showed the extra force used to hold it up.

Jodi expanded on this experiment's scientific model as she included multiple forces (i.e. the student's hand pushing upward and the earth pulling downward (gravity)) acting on the balls and described how they were represented. She said:

> After seeing this same experiment with a larger ball, we discovered that the student's hand and the earth were both exerting a force on the ball. We decided that the best way to represent this on paper was to draw a circle with an arrow pointing up and another arrow pointing down. The up arrow represented the force that his hand exerts on the ball, and the down arrow represented the force that the earth exerts on the ball.

In her description Jodi also alluded to the fact that we engaged in discussion about how to best represent what we understood about the investigation conducted in class. Because there are multiple ways to model a science concept, it was important to talk to PSTs about how to *best* represent what they understood. This required some trial and error, but as Jodi's description shows, once PSTs were confident in developing and deciphering force diagrams they were able to use them to analyze evidence gathered from three different experiments. Also in this weekly checkpoint, Cameron explained how the class used force diagrams to record three motion experiments to draw some exciting conclusions.

> As a class, we came up with 3 different diagrams based on the force applied to Chris in the different 3 trials. The first one showed that Chris had no continuous force on him as he was going down the hallway but still had the force of the Earth and ground on him. This showed an equal balance of forces. Otherwise, Chris would've been flying or been pressed further into the ground. But, he was still moving because he was pushed once. The equal lengths between the pouches showed a constant speed for Chris. The second diagram showed Chris having a force being continuously applied in the same direction as he went down the hallway, along with the force of the earth and ground applied to him. The increasing lengths of the pouches showed that Chris was increasing speed. The last diagram shows Chris having a force applied to him in the opposite direction as his motion. From what we saw, Chris slowed down in the direction was trying to go. From analyzing our force diagrams, motion of Chris, and the type of motion, we were able to conclude and develop Newton's First Law of Motion.

Jen highlighted these diagrams in her weekly checkpoint as well writing:

> We first made a diagram for the first scenario [with the professor on roller blades] which looked very similar to the ones from before with the two balls. Since when he passed us we did not see any force pushing him forward this was not added to this diagram. We then made a diagram for the second scenario which added a third arrow to the left side representing Ann's forcing pushing. Then the third scenario had a third arrow as well but this time it was to the right to represent the force of Julianne pushing him backwards. Everything we put together in this week's lesson, mostly from what we saw in the hallway roller blade experiment, can be summed up in one sentence. When force is going the same was as an object it speeds up and when force is going in the opposite direction

of the motion it will slow down. After learning all of this information and putting in all together we realized that what we discovered about this motion was the same as Newton's Law of Motion.

As Jen, Jodi, and Cameron's comments indicate, PSTs were able to formulate conclusions about science concepts from the development and analysis of scientific models.

3D modeling. Although there was only one 3D model developed in this course, the frequency with which it was mentioned in focus group interviews and post-course reflections suggested this experience stood out to students. In this earth science investigation, PSTs explored how the configuration of the Earth, moon, and sun create the phases of the moon seen from Earth. This model was used as an example of how perplexing it can be to construct an explanation for a scientific phenomenon. Initially, this experience was very frustrating for PSTs, however, because preserving through the challenge to create the model resulted in a scientific discovery, PSTs cited this investigation as one from which they began to understand and appreciate how scientists conduct this work.

In this investigation, my co-teacher and I began by distributing a handout with pictures of the phases of the moon over the course of 28 days to each student. We instructed PSTs to observe the phases and to record their observations as we both circulated, questioning and prompting them to consider different aspects of the pictures. After they shared some observations with the class, they were prompted to think of possible explanations for their observations. Several PSTs said they thought they understood concepts related to the phases of the moon until they were asked to explain their thinking to a peer. Common misconceptions, like the shadow of the Earth on the moon creates the phases, were shared by the students.

We then provided each group with the materials needed to create 3D models that would allow them to test their explanations. Groups of four and five students were required to manipulate two Styrofoam balls, representing the Earth and moon, around a lit lamp, representing the sun, to show how the Earth views the moon in phases. Students worked collaboratively for about twenty minutes and all members of the groups were engaged in different ways: moving one of the balls, moving their bodies in relation to the balls in an effort to see the phases on the ball representing the moon, directing each other, and studying the handout with the pictures. Since they agreed on the misconception, they were confident they understood the concept correctly and, therefore, experienced frustration in failed attempts at trying to support their initial explanation with manipulatives.

Bree prompted her group to join Lydia and Cameron's group and they worked together to see if they could figure out the configuration. The nine of them were so focused and determined they shooed us away when we told them to take a break.

A number of students expressed concern during this investigation. Lydia spoke passionately about her frustration with this experiment.

> It was a lot of trying to deal with personal frustration. Like with the sun and the moon and sitting there and being frustrated. Do you lift it? Do you turn it? Do you tilt it? Do you move it this way? Because you know how it is when you're watching the moon in the night sky but to sit there and try to explain it for yourself becomes frustrating and it's taking up a lot of time and you just want them to tell you and they're like, "We're not telling you, you need to figure it out."

Cameron, who was in Lydia's group for this investigation, also expressed feelings of frustration.

> We spent the whole ten minute break trying to figure out why the moon, or how the seasons came about. I don't know, like, it took forever. We sat there with our materials and we were just spinning it around for like ten whole minutes. It was hard I think because it was such a bigger picture than we couldn't really get. And probably because we used to learn in elementary school we were just learning about memorization about that stuff so that's probably why it was a lot harder.

Many asked us to "just tell" them how the Earth, moon, and sun were "supposed to" be configured.

All of the investigation groups, however, did successfully complete their 3D models. Following their work with the 3D models, we asked the groups to draw a 2D representation of their 3D models on their team boards. We then told them to hold up their models and explained that we were going to prompt them to ask each other questions and to critique each other's models. My co-teacher and I laughed at how smoothly the lesson went even amidst their frustration with the trial and error process. The classroom felt alive with students enthusiastically asking each other critical questions and explaining their thinking and investigation processes, in detail, to one another.

In focus group interviews, Leah described how the challenge of figuring out how things worked and being pushed work through the model to understand the concepts deeply made her a more confident future teacher of science.

> Something like that [how the Earth moves] we always just were just taught and took for granted. Like okay, we thought that the sun moved around the earth but now we know that the earth moves around the sun and we were never able to explain it. It was just what we were taught. But now we're able to get up in front of our students and we might not

> be able to explain exactly why it does that but we can at least give them concrete examples and we…know what we're talking about.

Kinesthetic models. Although scientific models like force diagrams and 3D models with manipulatives helped PSTs to discover core ideas in science, the models they cited most often as helpful to their learning were those in which they played physical roles in demonstrating. I refer to these as *kinesthetic models* because they required PSTs to get out of their seats and move their bodies to represent the scientific phenomena they were investigating. When explaining what they learned in terms of science in their weekly checkpoints, PSTs cited four examples of kinesthetic models as the means that helped them gain understandings of the science concepts.

The first kinesthetic modeling took place in the second class meeting. Students explored the cause of the sound heard when a balloon pops. To better understand this, we first needed to consider what causes a balloon to expand. We modeled this by asking some students to act like air particles on the inside of the balloon and others to act like particles on the outside of the balloon. Erin described this experience in her weekly checkpoint.

> When the class made a "human balloon," I also learned that more stuff (air/particles) is pushing outward than is more stuff on the outside being pushed in towards the balloon, thus causing it to inflate. A deflated balloon has air particles moving around and bouncing into each other inside of it, but no more air is being added, thus causing it to remain deflated.

Ann also cited this example using our discussion during this demonstration.

> If you have ten people pushing on the inside of a balloon and one person pushing on the outside of the balloon, who will win the battle? The people on the inside of the balloon, causing the balloon to expand.

The "human balloon" was used to deepen students understanding of how air particles behave which is central to the DCI in *Matter and Its Interactions* in the NGSS.

Another example of when we asked students to act as particles of matter was in the class in which we developed a definition of density in science. First, I facilitated the modeling of high and low population density by instructing the class to stand very closely together in a corner of the room and then spread out throughout the room. We related high population density and people in close proximity to one another to high density in science where particles of matter are closely packed. Jen expanded on this in her weekly checkpoint.

> To reinforce this idea, we all stood up and acted as human particles. When we all stood close together we modeled a dense object, the "particle" in the middle said she felt squished, like she couldn't breathe. Then we all spread out to represent the larger objects with a smaller density. In this model we all had plenty of space to breath and more around.

It seems modeling this way helped PSTs, like Jen, to view the concept from a different perspective, in this case, one in which she was able to "feel" like the particles.

Upon analysis of my lesson plans, I found that two of the four kinesthetic demonstrations PSTs cited as helpful to their learning came as remediation lessons. After reviewing PSTs' weekly checkpoints, my co-teacher and I discovered they had not mastered some of the concepts addressed. We therefore incorporated kinesthetic demonstrations to provide different perspectives from which to view key science concepts. For example, in Week 6, students circulated through learning stations in which they gathered information (i.e. number of hours of daylight in Alaska and Antarctica throughout the year, pictures taken in June and January in Australia and the USA, temperatures in cities in the northern and southern hemispheres and along the equator, etc.) that provided evidence to suggest why we experience seasons around the world. No one station provided enough evidence to allow PSTs to arrive at the accepted understanding. They had to analyze evidence across the stations to be able to conclude the Earth is tilted on an axis and it is this in relation to direct sunlight that results in how seasons are experienced on Earth. This posed a cognitive challenge to PSTs and many left the lesson without being able to fully articulate their understanding.

In the following class meeting, I decided to kinesthetically model the Earth's motion around the sun to help them "see" this phenomenon. PSTs sat in the middle of the room so they could view the Earth from the sun's perspective. Using a globe to show the angle of the Earth, I walked around the classroom mirroring the way in which the Earth revolves around the sun. The intent of this model was to give PSTs a new angle from which to view the scientific phenomenon. Several students cited this demonstration as the moment at which they began to understand this concept. In her weekly checkpoint, Erin said:

> Some of us were still confused, so Amy took the globe and stood at various areas of the room, with the center of the room representing the Sun. She showed us that no matter where in the room (in the revolution around the Sun) she moved, the tilt was consistent, but different parts of the world were receiving the direct sunlight at different points in the revolution. Again, this demonstrated why we experience seasons.

Bree cited this demonstration as well writing:

> What really helped us understand this concept was when Professor Lewis held the globe and moved around the classroom with it. Since the Earth is always on the same tilt, sometimes the northern hemisphere is pointing at the sun or sometimes the northern

hemisphere is pointing away from the sun. It just depends on the location of its revolution around the sun.

Erin picked up on the fact that not everyone understood the concept from the information gathered in the stations. Both she and Bree identified this kinesthetic modeling as the method that cleared up confusion. As such, scientific modeling served as a means to help students visualize what could not easily be shown through scientific investigations or thinking experiments, where students are asked visualize without manipulatives.

Scientific Processes Mediate Students' Learning: Teaching through Inquiry

I believe that science in the elementary school should be taught in a way that allows students to form investigations before being told what they should learn and a way that students' knowledge are constantly being informally assessed through intense critical thinking questions. My philosophy on teaching science is that students will learn best when given the opportunity to conduct experiments or view models that promote the idea of investigative techniques and once students think they have drawn a good conclusion, it is the teacher's job to push them further until the best possible answer or conclusion is formed.

In the comments above Ann explained how her experiences in class shaped her science teaching philosophy. In each class meeting, PSTs were asked to think about how they would apply what they experienced to their future teaching. All 14 PSTs were able to draw from their experiences as students of science to consider future pedagogies as teachers of science. Because most reported having experienced traditional science instruction in which textbooks and cookbook experiments mediated students' learning, being taught using an inquiry-based approach was new. However, focus group comments and post-course reflections suggest most would structure their future instruction in ways that mirror the pedagogies they experienced in the course, using an inquiry-based approach. Assignments like lesson and unit plans offered opportunities to examine how these and other PSTs would approach planning to teach science as a result of taking the course.

Planning inquiry-based lessons. In order to evaluate PSTs' abilities to incorporate the pedagogy they were experiencing and learning into practice, they were required to design a unit of study in which they composed several lesson plans. The assignment was designed to assess PSTs' ability to compose lesson objectives that focused on merging content with science practices and behaviors associated with inquiry. To prepare PSTs for this work, we modeled objectives that planned for students to "discover," "uncover," or "collaboratively investigate" a science concept. We encouraged PSTs to use the NGSS to design their objectives and lesson procedures so that the performance tasks in the NGSS were targeted. We also emphasized the importance of the alignment between the lesson objectives, assessments, and procedures and encouraged them to use an inquiry-based approach.

Initially, PSTs struggled to apply what they experienced as students to practice through planning. An email exchange between my co-teacher and I captured how we felt and what we initially attributed to being the cause of their poor performances on this first assessment of pedagogy in practice. After reviewing my group's work I emailed:

> So, I've started looking at their lesson plans and I'm bummed. The first few I've seen aren't great. They are not making the connection between the objective and the activities. I guess that's normal at this stage since we are getting them in the fall semester. I'm being pretty hard on them but providing lots of feedback.

My co-teacher responded:

> I agree, they aren't so great. I have found that their objectives are very vague, and like you said, there is no connection between the activities and the objectives. I am doing the same thing you are, giving a lot of feedback. I really think it has to do with it being the fall, not the spring. Hopefully we will see some growth on the second plan.

In comparing the lessons overall, we agreed several also missed points like composing measureable objectives that included science practices. Some composed objectives that focused on low level understanding of science content only. Karin's first lesson plan objectives were written as follows: 1) *Students will be able to identify which organisms (fish) are supported in freshwater and saltwater.* 2) *Students will be able to identify the two different types of water that exist on earth: freshwater and saltwater.* 3) *Students will be able to identify which types of bodies of water are found in freshwater and saltwater.* All of these objectives required students to simply identify (memorize) science facts without developing an understanding of the differences between fresh and salt water or how the characteristics of each affected the animal and plant life that live within them. These objectives imply the lesson would follow a traditional approach to instruction.

In contrast to how they were being taught science, some lessons developed by the PSTs began with activities through which the teachers *told* students about the content before allowing them to investigate it. For example, Lydia composed a lesson on the life cycle of a butterfly for 3rd graders. Her objective stated: *Students will be able to construct the life cycle of a butterfly*. She began the lesson by bringing the students to the carpet. "And with an anchor chart the students will respond to the question: What characteristics make up a living thing? (ex. born, breath, grow, eat, sleep, move, have cells)." She then planned to show students the cover of *The Very Hungry Caterpillar* by Eric Carle. "Students will be asked what they think will happen based in what they see on the cover of the book. The book will be read while stopping to ask questions." Although the lesson objective might suggest students would be able to construct the life cycle through inquiry, her lesson procedures were teacher-directed and did not offer opportunities for the students to explore the concept. Lydia's approach to planning the lesson suggested students would simply be able to identify the stages of the life cycle as they would be told those stages through the book reading. The lesson plans they submitted mid-way through the semester, therefore, showed many were not prepared to teach content using science practices and inquiry, or that they were simply unsure of how to transfer their experiences and what they thought about science instruction to practice.

My co-teacher and I provided explicit feedback on these lesson plans in hopes students would resubmit their work with improvements. In Lydia's case, she was asked to consider how she could redesign the lesson so that the 3rd graders could begin with observations that would allow them to develop questions about the caterpillar and how it lives and grows. She was also advised to evaluate whether the text was an appropriate choice for the grade level.

To address the low level objectives, in Week 10 of the course I spent some time in class discussing the importance of challenging students' thinking by setting higher-level objectives. I used some of the lesson objectives from the PSTs' lessons as examples to improve upon. I also highlighted examples of lesson plans that successfully demonstrated the inquiry process and challenged students' scientific thinking. In Maria's lesson, for example, she planned to have students circulate through centers in which they would collaboratively observe the characteristics of animals found in different habitats to consider how those characteristics are connected to their survival. Her lesson procedures went as follows:

Students will work in groups of 3 and go around the classroom where pictures of 8 different types of animals will be on display. Students will have 3 minutes for each picture to make and write observations on their worksheets. They will also think about reasons why the animal has specific characteristics. They will be instructed to also look at the environment that surrounds the animal. As students work, I will go around listening and prompting questions.

- Why do you think the animal needs that characteristic? (claws, teeth, color etc.)
- Can the animal survive without it?
- Where is the animal? Do you think that the animal has certain characteristics because of its environment? (fur because is cold)
- What if the animals live somewhere else, do you think it would still need those characteristics?

After completing the activity students will go back to their seats. As a class, students will share their observations and conclusions.

This lesson addressed foundational understanding of the 3rd grade life science NGSS performance expectations that state student should be able to:

- Use evidence to construct an explanation for how the variations in characteristics among individuals of the same species may provide advantages in surviving, finding mates, and reproducing.
- Construct an argument with evidence that in a particular habitat some organisms can survive well, some survive less well, and some cannot survive at all.

Her lesson procedures required the students to engage in science practices like analyzing and interpreting data, constructing explanations, and obtaining, evaluating, and communicating information. Maria created a lesson in which she showed her students something and allowed them to discover the science behind what they observed through questioning and discourse on science content.

Unlike Maria, several PSTs struggled to plan an inquiry-based lesson on the first try. Discussing ways to improve objectives and redesign lessons prompted several PSTs to resubmit their first lesson. PSTs who chose to resubmit their lessons made vast improvements in composing lesson objectives and procedures that mirrored the inquiry processes we experienced in class, in particular. Josie, for example, used my feedback to strengthen her objectives. Her original objectives and the objective she composed with feedback can be seen in Figure 8.

Figure 8. *Objectives Following Instructor Feedback*

Original objectives:

- Students will be able to understand matter and its properties.
- This will include which materials are best intended for a certain purpose and why based on their properties.

Improved objective following feedback from instructors:

- Students will be able to determine the three types of matter and their properties including which materials are best intended for a certain purpose and why based on their properties.

The first of her original objectives suggested students' "understanding" would be assessed. Because "understanding" is not a behavior that can be measured, she was prompted to consider *how* she planned to assess their understanding. With feedback from instructors, Josie was able to create a measureable objective in which students were assessed by their ability to determine the three types of matter and cite their properties as evidence to identify which were best for an intended purpose.

This individualized instruction was often helpful in PSTs learning process as they said the feedback aided them in making specific improvements to their work. In focus groups and post-course reflections, PSTs reported being able to focus more on learning the content and pedagogy than earning grades because they were permitted to resubmit their work once they had reviewed and addressed instructors' feedback. Jodi described feedback as being beneficial in learning about how to apply pedagogy to practice during lesson demonstrations. In her focus group interview, she explained,

> I feel like the lesson plan we had to present in class was really helpful because it wasn't like just present your lesson plan, they like, after the first like thirty seconds of us presenting they stopped us and were like hold on, what do you think you should be asking right now. That was really helpful….They were sitting where we would be sitting and as we would go into the next thought or the next thing they would stop us and be like this is a better way to approach this or this would be a better question to stop and ask. I think that was really helpful to have to teach a real lesson and get feedback as you are doing it.

Using feedback from instructors, PSTs learned how to adjust instruction in the moment. PSTs, like Jodi, saw this practice as helpful in that she was able to understand how instructors thought about practice. However, inconsistencies in their work suggests the limited time spent in one science methods course might not be enough for all to gain the PCK and support needed to teach science using inquiry effectively.

Summary. In this course, PSTs took on the dual roles of students and future teachers of science. As science students they progressed in their use and practice of science-related skills required of elementary school science teachers. They were able to identify two specific methods for conducting science that helped them to learn these concepts: scientific investigations and scientific modeling. In some way, all PSTs attributed their learning to the scientific processes through which they acquired science-related skills and pedagogies for teaching science.

One semester-long course of learning science through inquiry, however, was not enough for all PSTs to be able to plan instruction using an inquiry-based approach. Some had difficulty designing lesson plans that applied what they experienced and what they were taught as best practice.

How Three Students' Individual Experiences and Perceptions of Science Contributed to What They Learned about Science and How to Teach It

Case studies can be used to "illustrate the complexities" of a given situation or context showing that "not one, but many, factors contributed to it" (Merriam, 1998, p.30). In this study, descriptive portraits of three preservice teachers (PSTs) in my science methods course were used to examine what they learned from the course and the factors that may have contributed to their learning. In what follows, I first describe each student as a learner of science. I then describe what each student learned in the course using themes that emerged from examination of each PST's coursework.

Bree: A Logical, Mathematical View of Science

Bree always arrived a few minutes before class began full of frenetic energy. She came to class from the gym wearing casual athletic clothing with her long dark hair in a ponytail. When she sat for class, however, she was focused - not one to be distracted by her cell phone or laptop. She attended every class meeting with notebook, pen, and planner ready and, unless otherwise advised, she sat in the same, front right corner seat for each class. Bree engaged in class discussions and investigations fully choosing to take diligent notes by hand and often asking instructors to repeat their questions so they could be recorded in her notebook. In my researcher journal, I noted that at the end of each class her eyes shifted from the anchor charts to her notebook checking whether she had logged all of the key points listed about the science content and pedagogical practices recorded from class activities and discussions.

From her class performance an observer might describe Bree as a focused and conscientious student. Often, however, my co-teacher and I received messages like, “Sorry, sorry that it is 3 minutes late!!” or “I am so sorry, but this is late yet again. Even though they [the assignments] have been late quite a bit, I promise to always have them in by 12:30AM!” from Bree around midnight the day assignments were due. Bree struggled to keep up with coursework demands. She explained she turned them in at the last minute, or minutes after they were due, because she kept critically thinking about how to present what she learned in class on paper in the days that followed each class. Even after much consideration, Bree said that when she turned them in she felt unsure and that the assignments felt unfinished.

The self-doubt about whether she had been thorough enough in her explanations often played a role in Bree’s class performance. Though Bree’s Lawson Test results put her at the top of the class in scientific reasoning and she consistently earned full, or nearly full credit, for her course assignments, she seemed worried about not knowing enough science content to teach the subject confidently. She often asked questions that made me feel like she was worried she would fail her students by not being competent in the subject or knowing the “right” answers to their questions.

Bree’s experiences with science in public school shed some light on why she may have felt pressured to get the science “right”. In her pre-course reflection, Bree explained that she dreaded middle and high school science as she found it stressful:

> Even though I did well in [high school] biology, chemistry, and physics, they definitely were not classes that I would call fun. These classes required a lot of studying and a lot of

> work and concentration. The activities were not that fun either. I found them to be more stressful than exciting because we had to do write-ups after the observations. I was always afraid I was doing the lab experiments incorrectly because sometimes they were a bit confusing, and my confusion could have prevented me from fully understanding my observations.

In contrast, Bree's experiences in elementary science were more experiential. She depicted it as, "When you got to leave the classroom…go outside and explore the trees or the grass. It was a time where you were allowed to get a little dirty." However, in middle school Bree began to view science as a subject that required memorization of facts and accuracy in performance. This may be one reason why Bree sought to gather and record as much information as she could about science and teaching science.

Bree often exhibited discomfort with her lack of content knowledge. It was not only that she wanted to learn the concepts in depth but that she wanted to acquire a plethora of details about the topics we were addressing. One way she attempted to quench her desire for information, therefore, was through her *Thorough Depictions of Science*. She often included an overabundance of details about the science content, long and comprehensive retellings of what happened in class, and multiple questions through which she asked for more information. Second, because Bree was fearful she wasn't a strong science student, she relied on her strength in math as a lens through which to view the subject. Using this lens she developed a mathematical view of science which she used to both navigate science as a student and to plan future science instruction. In the end, despite Bree's efforts to diligently learn every scientific detail, I review evidence that suggests self-doubts about her competence in science may have affected her perception of how well prepared she was for teaching it in the future.

Thorough depictions of science. Each week, students were required to submit a weekly checkpoint to communicate what scientific concepts and processes they learned and about how to teach science from the work conducted in class. Bree's checkpoints stood out because they were often more thorough than her peers in several ways. First, her depictions of each class meeting were very detailed; she included comprehensive descriptions of the experiments and activities using a sequential (i.e. first, then, next) approach. In addition to these play-by-play retellings, Bree included multiple science core ideas from the experiments and activities. She also clearly explained the connection between what was done in class and what she learned from it. Extraneous information like how the professors transitioned from one activity to the next and the kinds of questions they asked were also used to create a comprehensive view of her learning experiences. Lastly, though the weekly checkpoint assignment required students to pose two questions to engage the student and teachers in feedback loops, Bree often posed several questions at the end of her weekly checkpoints. This suggests that she not only concerned herself with composing thorough explanations of what took place in class and what she learned from it, but that she was also exhaustive in her efforts to learn as much as she could about multiple aspects of each topic.

Consider the response from Bree's first weekly checkpoint when compared with the weekly checkpoints composed by Jane and Cameron shown in Figure #9. All three answered the question: *What did you learn in terms of science content and how did you learn it?*

Figure 9. *A Comparison of Students' Work.*

Bree's Weekly Checkpoint	Jane's Weekly Checkpoint	Cameron's Weekly Checkpoint
This week we learned about motion and force. The objective of the lesson was to teach	In terms of learning science content, I learned the different types of motions. The three different types were constant	In class, we learned that if there is no force acting on an object or if there are equal forces, there is no change in

students about Newton's first law of motion. At the end of the lesson, we came to the conclusion that an object at rest (in motion) stays at rest (in motion) until an outside force acts upon it. We did many things during the class to help us come to this conclusion. First, [the professor] held two different balls, and then gave one student the balls and asked her what the difference between them was. She said that one ball was much heavier than the other. [The professor] then asked us why one ball might feel heavier than the other. This is because the balls want to go down to the earth. This brought us to the discussion of what might be causing stuff to go to the earth. Some students said that earth might be a magnet or that maybe the air (like water) wants to push things down. We disproved both of these thoughts. Not everything is magnetic, like humans, but humans still fall to the earth. The air around the balls does not cause the balls to go down because we saw a video of a bell jar, and how sucking air out does not change the object's level inside (I forgot what object that was). By disproving our observations, and	speed, speeding up, and slowing down. To learn this content we were able look at the motion of a roller coaster by looking at a photo of people on the peak of a roller coaster. By imagining what would happen with personal experience, we were able to discover when the speed was faster, slower, or constant during that particular time. In the second part of the lesson, I learned that force is an interaction between two objects. When there is no force acting on an object, there are no changes in the motion, when force is exerted in the same direction, the object speeds up, and when the force is exerted in the opposite direction, the object slows down. I learned this by being able to watch [the professor] use his rollerblades while [the student] was able to push him from the back. There were three different ways that he was being pushed, and each one represented the different forces that we were able to learn about.	the object's motion. If the force is exerted in the same direction of an object, the motion of the object speeds up. If the force is exerted in the opposite direction of an object, the motion of the object slows down. We learned Newton's First Law of Motion on our own. We learned this by running an experiment with [the professor] on rollerblades. We performed 3 different trials and within each trial, he dropped a pouch to mark every second passed. The first one, [the professor] was pushed once by Josie and the pouches were dropped in equal length. For the second trial, [the professor] was continuously pushed by Josie and the pouches were dropped in unequal lengths. The length between each pouch were increasing. For the last trial, [the professor] did was not pushed, but as we went to the end of the track, Josie's arm pushed [the professor] back to the other direction. Pouches were not dropped but he slowed down and then eventually, was pushed to move the opposite direction. After our observation, we created 3 different force diagrams, which was modeled earlier in class. As a class, we came up with 3 different diagrams based on the force applied to [the professor] in the different 3 trials. The first one showed that [the professor] had no continuous

receiving some scaffolding from the teachers, we came to the conclusion that earth must be the thing that was causing the balls to go down. We learned that earth was an object that caused things to go down. We then observed that when [the professor] was holding the ball, it was not going down. We saw that it was because his hand prevented the ball from falling. When the student held both balls, she stated that one hand had to strain more than the other to keep them leveled. We then drew a diagram on the board. We drew the ball, and then drew an arrow pointing up to show the force our hand is putting on the ball. Then, we drew another arrow that was pointing down to represent the earth's force pushing down on the ball. These lines had to be of equal length because force going down on the ball matched the force going up. This is an interaction between the hand, the ball, and the earth. We were then told that we created a force diagram. Next, we did an activity of us observing [the professor] on roller blades. There were three motions. One motion was a student pushing on [the professor] once, and then

force on him as he was going down the hallway but still had the force of the Earth and ground on him. This showed an equal balance of forces. Otherwise, [the professor] would've been flying or been pressed further into the ground. But, he was still moving because he was pushed once. The equal lengths between the pouches showed a constant speed for [the professor]. The second diagram showed [the professor] having a force being continuously applied in the same direction as he went down the hallway, along with the force of the earth and ground applied to him. The increasing lengths of the pouches showed that [the professor] was increasing speed. The last diagram shows [the professor] having a force applied to him in the opposite direction as his motion. From what we saw, [the professor] slowed down in the direction was trying to go. From analyzing our force diagrams, motion of [the professor], and the type of motion, we were able to conclude and develop Newton's First Law of Motion.

him rolling down the hallway. During the motion, [the professor] threw down markers each second. The markers were of equal length for this motion, so it told us that he must have been going at the same constant speed. The second motion consisted of a student pushing on [the professor] continuously. Again, [the professor] threw down markers each second. During this motion, the markers' distance between each other increased. This showed us that the force on [the professor] continuously caused his speed to increase. The last motion was [the professor] rolling, and then being stopped by a student. When [the professor] rolled into the student, [the professor]'s speed slowed down, and then he stopped. This showed us that a force that was acting on [the professor] in an opposite manner caused his speed to slow down. After this activity, we went back into the classroom and analyzed the scenario we just witnessed. We talked in our group, and then drew force diagrams to represent [the professor]'s motion. We made three key observations. First, when [the professor] as in motion with no force		

being pushed on him continuously, [the professor] remained at a constant speed. Second, when [the professor] had a continuous force being placed on him, his speed started to increase. Lastly, when [the professor] had a force act on him in an opposite manner, his speed slowed down. We saw that when a force was going the same direction as the motion, the speed of the object increased. We also saw that when a force was going the opposite direction of the motion of the object, the object slowed down. At the end of the class, we were told that our definitions were exactly what Newton's first law was about, and that we came to this genius motion law by observation!		

Jane began her weekly checkpoint by listing the main points from the lesson. She said, "I learned the different types of motions. The three different types were constant speed, speeding up, and slowing down." She then gave general descriptions of the activities done in class:

> We were able look at the motion of a roller coaster by looking at a photo of people on the peak of a roller coaster. By imagining what would happen with personal experience, we were able to discover when the speed was faster, slower, or constant during that particular time.

She listed what she learned and which activities, in general, helped her to learn the concepts, but she does not make explicit connections between the two. She included both the work conducted in the thinking experiments (i.e. roller coaster where students have to use prior experience to imagine the motion) and the scientific investigations (i.e. professor on roller blades demonstrates Newton's Laws of Motion) but described them in the form of summaries without any specifics.

Cameron's checkpoint was more detailed. Unlike Jane who began with a general summary, Cameron began by stating Newton's Laws specifically. She then connected the Laws with the experiments conducted in class that helped her and her peers to discover them. She explained:

> We learned Newton's First Law of Motion on our own. We learned this by running an experiment with [the professor] on rollerblades. We performed 3 different trials and within each trial, he dropped a pouch to mark every second passed. The first one, [the professor] was pushed once by Josie and the pouches were dropped in equal length.

Cameron went on to describe the second and third rounds of this investigation that resulted in students' data analysis and subsequent identification of Newton's Laws of Motion. She also explained that students were asked to create scientific models, in the form of force diagrams, to show their understanding of the Laws in relation to the experiments.

> The last diagram shows [the professor] having a force applied to him in the opposite direction as his motion. From what we saw, [the professor] slowed down in the direction was trying to go. From analyzing our force diagrams, motion of [the professor], and the type of motion, we were able to conclude and develop Newton's First Law of Motion.

In this way, she made connections between the central disciplinary core ideas (DCI), the experiments she experienced to learn the DCI, and the ways in which students communicated their understanding to their peers and teachers.

Like Cameron, Bree made clear, explicit connections between what we did in class and what was learned from the experiments and activities. Both Cameron and Bree included information about the diagrams students were required to draw to communicate their understandings. Bree's work, however, was more comprehensive as it contained details about how the lesson began using simple experiments and discussions about what pulls objects to the Earth and how the professors helped the class navigate concepts like *gravity* and *force*. Bree wrote:

> This brought us to the discussion of what might be causing stuff to go to the earth. Some students said that earth might be a magnet or that maybe the air (like water) wants to push things down. We disproved both of these thoughts. Not everything is magnetic, like humans, but humans still fall to the earth. The air around the balls does not cause the balls to go down because we saw a video of a bell jar, and how sucking air out does not change the object's level inside (I forgot what object that was). By disproving our observations, and receiving some scaffolding from the teachers, we came to the conclusion that earth must be the thing that was causing the balls to go down. We learned that earth was an object that caused things to go down.

She summarized the dialogue between the teachers and students to illustrate their analysis of observations and claims about science. She even included the hypotheses other students suggested. For example, Bree first mentioned ideas posed by students like magnets or air being responsible for pulling objects to the earth. She then explained the thinking that went into disproving these hypotheses using evidence gathered in class from experiments or students' prior knowledge. Disproving these hypotheses was an important part of the inquiry process, however, these were details Bree's peers chose not to include.

Similarly, Bree's second weekly checkpoint provided comprehensive descriptions of what we did in class and the claims we established from information gathered in the investigations on matter. She explained the core idea that *air is made up of something* and then used two different investigations conducted in class to provide the evidence to support this hypothesis.

> We also learned that air was something, meaning that it was made up of tiny particles. We were taught this by two ways. We saw an empty cup being submerged face down into a container of water. Since the water did not go into the cup, it demonstrated that air had to be something or else the water should have filled into the "empty" glass jar. The other activity we did to help us learn why air had to be something was thinking about a balloon. We had to think critically about why a balloon expanded when air was pushed into it. When a balloon is deflated, we learned that the activity of the air particles on the outside is equivalent to the activity of the air particles on the inside of the balloon. When a lot of air is forced into a balloon, the balloon starts to expand. This is because the amount of particles on the outside of the balloon is no longer equivalent to the amount of particles on the inside. The particles inside of the balloon start to bounce against the walls of the balloon and against each other. The particles have nowhere else to go except against the walls of the balloon.

She explained "since water did not go into the cup" there is evidence to support that air is made up of something. Likewise, Bree said when air is blown into the balloon, "the balloon expands" supporting the hypothesis that air is something as it causes a change in the shape of the balloon. Consistently throughout the course, Bree composed weekly checkpoints, like these, that contained thorough depictions of the learning processes and evidence-claim connections showing she both understood the science content and the importance of the inquiry process.

While Bree's work suggests she was able to thoroughly explain her conceptual understanding of the science conducted in class, her fear of being wrong or not knowing the content well enough, however, continually troubled her. Concerns shared in her pre-course reflection and questions posed weekly by Bree suggested she was grappling with the fear of failing to know enough about the science content. Evidence of this fear could often be found in the questions she posed in her weekly checkpoints. Figure 10 contains excerpts that include questions posed by Bree.

Figure 10. *Examples of Bree's Weekly Checkpoint Questions*

Week	**Weekly Checkpoint Excerpts**
#1	*One question that I have is the one that I stated in class. What is noise? I did take neuropsychology two years ago, but I still cannot tell you what noise is. I was then thinking about what if a student asked me that question when I am teaching science. I obviously do not know the answer, so how do I answer little Bobby's question? Should teachers tell their students that they do not know the answer, but they will get back to them once they find out? I guess that would be the best thing. Students have the tendency to think that teachers know everything, but perhaps that makes teachers intimidating to some students. If students know that teachers can get an answer wrong too, then maybe the students would be more willing to participate in discussion because they are not afraid of failure.*
#2	*I was wondering if it still would work if you used sand instead of salt. Salt can dissolve. So that could have meant the water dissolved the salt very quickly and that is why it went to the bottom. Sand does not dissolve, so I was wondering if the water still would have went to the bottom of the tube (I forgot the proper name of that tube). I also want to know what happens to the chemical vapor once it makes it into the air. I remember the water cycle we learned in science class where the water in the ocean went into the air, and then the clouds, and then back down into rain. I was wondering if the chemical vapor ever goes "down."*
#3	*One question that I still have is why did the Diet Soda not float? Is it because the artificial sweetener in the soda made the density less than 1? Also, since Diet Soda does not float, does that mean it is extremely unhealthy?*
#4	*I was wondering if you could tell me why we know something is in motion. I get that we knew the ball was in motion because we had to move our head and telescope to keep the ball in view. How would [the professor] know the ball was in motion when he was viewing it from his perspective (the telescope not moving to keep it in view)? Do we know the ball is in motion because at least one group of people or things has to move to keep the object in view?*

Bree's questions suggest she was seeking to increase her science content knowledge in two ways: depth and detail. For example, questions posed in weeks 1 and 4 showed she was critically considering all she would have to know to master the topic in order to be able to teach it to others. In addition to capturing concerns about not being able to answer students' questions, the excerpt from her first weekly checkpoint showed she wanted to acquire a more in-depth understanding of the concepts of sound and motion.

Questions posed in weekly checkpoints 2 and 3 evidenced her need to acquire additional details related to the topics we addressed in class. Though the investigation in week 2 asked PSTs to hypothesize what would happen to the level of the water (100ml) when 10ml of salt was added to it, Bree wanted to know what would happen if sand was used instead of salt. Likewise, in the lesson on sinking and floating in which we tested a can of Coke and Diet Coke in a tub of water, Bree wanted to know more about why the artificial sweetener, that allowed the Diet Coke to float, was less dense than the sugar, that caused the Coke to sink. Both sets of questions showed she wondered about extensions of the topics. The fact that she posed the questions suggested she was being thorough in her efforts to gather as many details as possible about the phenomena we studied.

Viewing science through numbers. Bree was one of nine elementary education students in the class who were seeking middle school certification in math. Every assignment type that Bree handed in to class, contained evidence that suggested Bree viewed science through a mathematical lens. When her peers used definitions and wordy explanations to communicate their understanding of science, Bree used numbers, measurements, and proportional relationships to express how she viewed the concepts behind the experiments conducted in class. The analogies between math and science in Bree's work suggest she used her understanding of math to think through and communicate her understanding of science concepts.

For example, in week #4's lesson on the dynamics of motion, PSTs were given battery-powered toy cars that moved at two different speeds (one fast and one slow) and asked to develop a method for answering the question: *How can you determine if the cars are speeding up, slowing down, or moving at a constant speed?* There were several ways to design this investigation and PSTs were put in groups and asked to find their own way to answer the question. In her weekly checkpoint, Bree used measurements of the distances her team marked to explain how they gathered data about the cars' speeds.

> We did some trial and error, but we decided to throw down a packet at the 0 meter mark, at the 1 meter mark, and then at the two meter mark. Then, we started the cars right away at the 0 meter mark and timed how long it took for the car to go a meter. We did several trials, but the seconds between the 0 meter to the 1 meter and the 1 meter to the 2 meter mark were not consistent. After making this observation, our professor reminded us that a car doesn't go from 0 to a specific speed right away; the car needs some time for it to actually get up to speed. With this knowledge, we started the car a little away from the 0 meter mark, and then timed the length of the 1 meter and the length of the second meter. On average, our times for these two-meter lengths were pretty similar; they were really only off by point something of a second. We did this experiment multiple times because we wanted to get reliable data. That is why I said on average the times were similar. After several trials, we came to the conclusion that the speed of the two cars was, indeed, constant.

As can be seen in this description, Bree's notation of exact measurements (i.e. 1 meter, 1 meter, 2 meter marks) and mention of the importance of reliable data suggests she views the work conducted by her group through a statistical perspective considering multiple variables that contribute to the outcome.

Bree's coursework consistently suggested that when we conducted multiple experiments, those that involved numbers stood out to her as best examples of the disciplinary core ideas she learned. In week 11's class, students learned about the cross-cutting concept, energy, by engaging in multiple experiments and activities designed to expose them to a variety of perspectives through which to view the topic. We experimented with harnessing energy using solar panels and transferring energy using children's toys. In reflecting on this lesson, Bree focused on the work we did calculating the input/output of calories through numbers and percentages.

> Our body also does physical activity. That means it also needs more food so it can have the ability to do stuff, like play sports or study. We then learned about the calories in food, and then we learned about the body burning those calories through exercise. A lot of this was not new to me because I am all about losing weight. I know so much about calories in and calories out. In order to lose weight, one's diet is much more important than one's exercise habits. Unfortunately, someone's diet is 80% of the role of weight loss. It takes much longer to burn 100 calories than to consume 1000!

In this activity, students were prompted to guess the number of calories consumed from eating sample food items (i.e. apple, banana, Panera breakfast sandwich, Starbucks coffee drink) and burned in a variety of physical activities (i.e. biking, yoga, running, gardening). Bree was excited and engaged in this activity citing her Fitness Pal phone app as the source of her estimations. Other students wrote about this activity in their checkpoints but none used specific examples with numbers to make connections between math and science.

Bree's response to an unannounced quiz also illustrates how she utilized her strengths in math to navigate the science concepts covered in class and to communicate her understanding of them. In a quiz on sinking and floating, PSTs were given the following scenario:

> "*You place a solid plastic PVC cylinder into a bucket of water. It floats. What would happen if you cut the PVC cylinder in half? Use your understanding of sinking and floating in water and density to explain your response.*"

While her peers relied on the definition of density or other examples of sinking and floating to explain their understanding of this scenario, Bree responded to this item by calculating the densities of the cylinders of different sizes and comparing them to the density of water.

> If you cut the plastic PVC stick in half, it would still float in the water. This is because the ratio of mass over volume would be the same: less than 1 g/ml. Let's say the original stick's density was D=12g/36ml. This density is 1/3 g/ml. Now you cut the stick in half. The new density is 6g/18ml. The density is still 1/3 g/ml! Any density less than 1 will float.

Assignments, like the weekly checkpoints and quizzes, were designed to challenge PSTs to articulate their understanding of science. The aim of this work was to increase PSTs' abilities to confidently talk about and transfer their conceptual understanding of science. It seems Bree utilized her confidence in math to overcome what seemed to be a lack of confidence in science.

Teaching science. A lot has been written about how a lack of content knowledge, false perceptions of science as a static or unpredictable, or negative prior experiences with the subject, result in most elementary school teachers having low self-efficacy in their abilities to learn and teach science (Avery & Myers, 2012; Lewis, et al, 2014). Bree seemed to lack confidence in her abilities as a science student and, therefore, worked to acquire in-depth and detailed science content knowledge and to utilize her strength in math to navigate the course. In addition to her efforts to thoroughly and comprehensively cover the science content, I discovered evidence to suggest Bree doubted her abilities to assess what students might know or be able to do and how to move them along in their understanding, as well as whether she would be able to teach science through inquiry.

Contrary to research on self-efficacy and reform-oriented instruction which suggests that low self-efficacy results in didactic instructional practices (Avery & Myers, 2012; Lewis, et al, 2014), I found Bree's lack of self-efficacy in science content knowledge, seemingly, did not deter her from *planning* to teach science through inquiry. She used her own experiences as a student in the course to evaluate how science should be taught. For example, in the checkpoint she submitted after our class experimented with objects in water to determine what caused them to sink or float, Bree wrote, "So when a student actually understands why a formula works, it allows that student to use the concepts in many different contexts and provides a deeper understanding." Likewise, in her focus group interview, she cited her experiences as a student to suggest teaching strategies that work best in science instruction.

> One teaching strategy that I really liked was having the students explore a concept…I feel that this is a great strategy because the students are coming up with explanations by themselves. It makes it much easier for the students to learn something when they construct the ideas themselves.

Similarly, in her final reflection paper Bree referred to the process of discovering science as an overarching concept she would take away from the course.

> Also, I will make sure my students are active participants in their own learning. I do not want to spoon-feed my students the science content. I want to make sure that my students construct their own ideas. That is why I have to make sure my students process and absorb all of the information they are receiving. Science is all about discovering not about memorizing.

These comments suggest Bree learned from her own experience that teachers should challenge students' thinking and understanding through science exploration.

In the lessons she developed in the course, Bree demonstrated an ability to plan instruction that would advance students' thinking and understanding through inquiry. Many of the activities she planned in her unit included processes and practices that encouraged student exploration and would lead to the discovery of concepts in science. Lesson objectives in her unit plan, for example, targeted students' use of science practices to engage with content. Three objectives from one lesson in her unit were written as follows:

1) Students will be able to describe Earth's geosphere using qualitative (words) and quantitative (numbers) data.
2) Students will be able to interpret data to assess the state of moisture in the geosphere.
3) Students will be able to explain why the geosphere is an important part of the water cycle.

These objectives suggest Bree would teach her students to be able to view the water on Earth qualitatively in that, for example, it helps sustain the lives of plants and animals, and quantitatively in percentages that would allow them to compare the amount of fresh and salt water on the planet. She also planned for students to use the data gathered from their research and experimentation to interpret the status of water in the geosphere. Her third objective indicates she would teach and expect her students to be able to use their calculations to make assertions about the concept of water on Earth. These objectives are well aligned with science and engineering practices that suggest students should be able to analyze and interpret data and use mathematics and computational thinking.

Other examples of Bree's efforts to plan inquiry-based lessons could be found in her lesson procedures. For example, in one lesson in this unit, she planned for students to develop their own tool to measure precipitation stating:

> In this lesson, students will be learning how to measure precipitation. Students will be designing their own tool that could measure how much rain there is. Then, students will test out their tool by a simulation. This lesson teaches students about how rain is measured. Also, students learn about the importance of measuring precipitation.

Not only did Bree plan this activity to build foundational experiences for understanding the NGSS Earth's Systems standard that states: *Describe and graph the amounts and percentages of water and fresh water in various reservoirs to provide evidence about the distribution of water on Earth*, but the activity required students to utilize several science and engineering practices (i.e. planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, obtaining, evaluating, and communicating information) to engage with the science concept. This lesson was included in a unit in which Bree's students would conduct multiple authentic experiments like this that would contribute to their understanding of the DCI.

A more detailed example of how Bree would scaffold students' learning in the inquiry process could be seen in her lesson play. Scripts containing student-teacher lesson dialogue, called lesson plays, were used to assess PSTs' knowledge of possible students' responses and how they thought about promoting students' scientific thinking and their content knowledge and understanding through questioning and scaffolding. The lesson plays, therefore, suggest how PSTs would talk to students about science. Consistent with an inquiry-based approach, in Bree's lesson play, the teacher taught students about the amount of fresh water available for human consumption through the analysis of percentages of water on Earth.

> Teacher: Ocean water makes up 97% of the water on this Earth! And the other 2% of water is frozen in ice caps! (Student 2), you were correct! Even though there is water that is underground, it still only makes up 1% of the total water on Earth.
> **Students gasp in awe**
>
> ***Student 3***: Are you kidding me? So there is only 1% of water available to drink and use?
>
> ***Student 4***: Does that mean that one day we will run out of water to drink? How much is 1% of all of our water, anyways? Can running the shower for 24/7 get rid of all that water?
>
> ***Teacher:*** Good question! We will figure this out. I want you guys to fill up your beakers with 100mL of water. This 100mL is going to represent all of the water on this Earth. Now, I want you and your table to take out 1% of that water, and put it in another beaker. What do you think we are trying to do?
>
> ***Student 5:*** We are trying to see what 1% of something looks like. Since we know that there is 100% of water in our first beaker, the second beaker is going to represent how much fresh water there is on this Earth.
>
> ***Teacher:*** Very good (Student 5)! Okay class, start!
>
> **Students work with their table to figure out what 1% of the Earth's water looks like. They must use their mathematical skills in order to figure out what 1% of 100mL is**
>
> ***Teacher***: Okay class. Who wants to tell me how they went about getting their 1% of water?
> **Half of the class raises their hands**
>
> ***Teacher:*** (Student 1) please come up to the front of the class and tell us what your table did.
>
> ***Student 1***: Sure thing! My table and I first had to figure out what 1% of 100mL is. We did this by making a proportion. We set 100% over 100mL equal to 1% over X (100%/100mL=1%/X). The X represents how many mL there are in one percent of

> 100mL. We then cross-multiplied. This gave us (100%)(X)=(100mL)(1%). We then divided each side by 100%. The percentages cross each other out, so you end up with 1mL. So that is the answer we got. We poured out 1mL of water since 1mL of water is 1% of 100mL.

This script suggests three things about Bree's approach to teaching science. First, the analysis of data indicates Bree would help her students to use evidence to construct arguments about scientific phenomena. Second, the analogy made between the water in the beaker and the water on Earth shows she would use scientific models to help students see abstract science concepts in concrete ways. Third, Bree's uses math as a vehicle for teaching science. Here she demonstrated her ability to facilitate data analysis and the development and analysis of scientific models. Moreover, this lesson play showed she researched and planned 5th grade math standards to determine how she could teach the science concept using grade level math.

Data collected from Bree's weekly checkpoints, unit plan, and course reflection suggest she understood the value of the inquiry process and was capable of planning science instruction through inquiry-based lessons, and some through curriculum integration. However, there is not enough evidence to suggest she would be able to overcome her concerns about her lack of content knowledge and the necessity of doing science "correctly" to teach this way. In fact, Bree's focus group interview comments stood out in that her perspective on her preparedness for teaching science was different from her peers. While other PSTs said they felt prepared to teach science, Bree continued to offer concerns about not being able to do what they had experienced in class with her future students.

> Well, the only problem is they were very creative when they were teaching us these activities and stuff but I can only teach it with these topics that we learned in class. Let's say we did something else, a different topic that we had to teach for the curriculum, I

> would not be creative enough to do those activities. So, I could only teach science these fun ways if it was the topics. So if I had to do force in school then I would do these activities but I found that during the unit plan I just wasn't creative enough to think of my own model or whatnot.

Summary. Bree approached the learning of science content using her strengths in math and by being thorough in her efforts to acquire as much content knowledge as possible. She performed well on assessments of science content and her course work consistently provided evidence she understood the core ideas, and could support her scientific claims with evidence. Her unit plan suggests she is capable of planning instruction through an inquiry-based approach and her lesson play suggest she would utilize her strength and comfort in math to help students develop concreate understandings of abstract concepts in science. However, a summative comment in her focus group interview, questions posed in her weekly checkpoints, and exchanges with instructors regarding her uncertainty about students' capabilities in science suggest that unless she was taught every DCI in the NGSS Bree might feel under-prepared for teaching science through an inquiry-based approach.

Erin: Making Connections to Science

From the beginning of the semester the friendship between Erin and Jodi stood out to me. Unless instructed otherwise, they sat together in every class. Both were quiet in whole group discussions but were willing participants in small group and partner investigations. Therefore, I often found myself standing close to their group during investigations as I learned most about them as learners in these activities.

It was in these moments, working collaboratively with her peers, that Erin stood out as a leader. Always smiling and cheerful, she exuded a positivity that made her approachable.

Covertly, Erin played a key role in the learning process. Though not forceful or obtrusive, she often directed the work conducted by her group by casually prompting them to try something a little differently or posing questions that changed the direction of the investigation. In this way, Erin was the catalyst for creative thinking that led her group toward scientific discoveries. Erin was seemingly very aware of the importance of connections to peers in conducting science as this was a pervasive theme in her course assignments, class participation, and focus group interview comments.

Another connection prevalent in Erin's coursework was finding ways to integrate literacy and science. As one of the nine students seeking a middle school certification in English/Language Arts, Erin often saw ways science could be connected to lessons in literacy. Other themes I discovered in Erin's work could be traced back to her memories of elementary school science. She described her experiences as an elementary school science student as, overall, positive. In her pre-course reflection, Erin labeled them as *meaningful* because they "fostered creativity, integrated other subjects, and embraced the individual needs and abilities of each student." She appreciated the hands-on approach to the subject and the fact that it afforded opportunities to learn from experience. In her words:

> The experiences that I found the most memorable and impactful were the ones that required hands-on participation and active involvement. My earliest recollection of a hands-on activity is from first grade, where we had to learn about and then carry out the incubation and hatching of duck eggs. We continued with a similar concept in second grade, where we got to learn about and witness the process of butterfly maturation, starting with the eggs, the cocooning process, and finally their emergence. In third grade, we took on a pretty extensive rainforest report and wall mural, which is one of my

> favorite elementary school memories. And lastly, a lesson about buoyancy, density, and displacement in fifth grade required us to create small boats that would float—and that we would eventually race. These experiences, which most significantly influenced my feelings and attitudes toward learning science, were all hands-on activities that were done in conjunction with textbook learning.

In the work Erin described, she and her peers had multiple opportunities to explore the phenomena they were learning about in science in life outside of school. In analyzing Erin's course work and comments she made in her focus group interview, I found she often emphasized the need for the teacher to make explicit connections between the students' lives outside of school and the science content being addressed in school. It seemed making the science content relevant and relatable was important to Erin as a learner and teacher of science.

In examining Erin's analysis and reflection of both past experiences and experiences in the methods course there was one overarching theme: *making connections to science.* As a student, Erin highlighted the connections she made to science in two ways: making connections to science with peers and making connections to science with students' lives. As a future teacher, Erin used these connections and her strength in literacy to plan her future teaching practices. In what follows, I use her course assignments, my researcher's journal, and her focus group comments to examine how her emphasis on these three types of connections shaped her learning experience and how she viewed the teaching of science.

Making connections to science with peers. Vygotsky believed that social interaction creates powerful opportunities for learning as it facilitates those interacting to consider different perspectives or ways of thinking about a topic (Hus & Aberšek, 2011; Palincsar, 1998). The activity that takes place externally with peers is later reconstructed internally as learners reshape their schema to accommodate the addition of new information gained from their collaborative work (Vygotsky, 1978). In science class, in particular, collaborative work requires learners to communicate their ideas and prior knowledge, consider evidence from investigations, and collaboratively reshape their understandings of science concepts. Therefore, the course was designed to facilitate peer collaboration and co-constructed learning experiences.

The importance of conducting science collaboratively was a pervasive theme in Erin's course work. Throughout her assignments and coursework Erin often used words like *collaborative* and *cooperative* to describe the interactions she had with her peers in class. In addition to being a social person, approachable and kind to her peers, Erin saw the academic value in working with others to better understand the science content and to grow one's thinking as a scientist. In weekly checkpoint #1 Erin wrote,

> Group work and collaboration is also essential in a science classroom. Some tasks are just too substantial to undertake independently. My group had to find the surface area of the classroom and everyone had an assigned role. Multiple people did the actual measurements, one person calculated them, and another recorded them.

In the example she described how the task could not be completed without the help of all members of the group.

Similarly, in her weekly checkpoint after the class had explored Newton's Laws, PSTs were required to design a scenario in which one object's motion could be observed from three different perspectives: speeding up, slowing down, and moving at a constant speed. Erin credited the collaboration with her peers for her deeper understanding of the concept.

> We also had to collaboratively come up with and draw a scenario with one object in which there are 3 observers, each seeing the object as either having a constant speed,

> speeding up, or slowing down. Not only did this activity get us thinking about the different types of motion, but it also had us think critically and analyze the relationship between the 3 types of motion.

In addition to using terms like *collaborative* and *cooperative* when explaining the learning process, Erin nearly always used pronouns such as *us* and *we* that suggested multiple students were involved. Her depictions of how she learned consistently reflected her belief that this work could not be done alone.

The course was designed to facilitate peer collaboration to mimic the work conducted by scientists in the field (NGSS, 2013) as well as to reap the benefits of learning through social interaction (Lewis, et al., 2014). When asked about how the course design aided her in learning science in her focus group, Erin highlighted how the connections she made to her peers also helped her to overcome uncertainties she felt about learning science.

> There was also always group work, like, you got to work with your table or draw models with your table which would kind of ease the stress a little bit because I know at the beginning of the semester a lot of us were like, 'Ugh. Science is not my forte. I'm scared to like... I don't wanna do this on my own,' sort of thing. Knowing that you could talk to your group about concepts and rely on each other, ask someone to clarify something, and that was part of every single activity that we did. You could work with your group.

Moreover, in this reflection Erin illustrated three ways groups worked together: 1) to design and draw models, 2) to rely on each other to reason through and discuss science concepts, and 3) to use each other as resources for clarification and support. This reflects Vygotsky's assertion that "what children can do with the help of others might be in some sense even more indicative of their mental development than what they can do alone" (Vygotsky, 1978, p. 85). The work conducted with more capable peers lies in the zone of proximal development where learners develop strategies that move them closer to independent problem solving, or their actual development level (Vygotsky, 1978). In this checkpoint Erin acknowledged the initial lack of confidence in her content knowledge and explained how the support of her peers eased her apprehension and helped her to learn.

Making connections to science through students' lives. In her final reflection Erin wrote, "I saw that science is literally everywhere and part of everything. It is important that the content we teach children is meaningful and that they can transfer this knowledge to other areas of their lives." Here she expressed how engaging with science as a student transferred to her awareness of the science present in her everyday life outside of school. In several ways, Erin emphasized the importance of connecting science to students' lives outside of the classroom to make science relevant. The research base also suggests connections between the science content and students' prior knowledge of, experiences with, and assumptions about it must be acknowledged, expressed, and checked in order to make science relevant. Learners must consider what they think they know and understand about the phenomenon they experience, compare their ideas with those of others, and test them against evidence gathered from scientific exploration and investigation (Zembal-Saul, 2008). The deeper understandings that result foster stronger awareness of and new connections with the science behind everyday phenomena.

Evidence to suggest Erin benefited, as a student of science, from science-to-self connections could be found throughout her coursework. For example, in week 11's lesson we investigated energy resources and students explored and discussed multiple resources (i.e. news report on fracking, a peer reviewed study on the effects of fracking, data on the economics of renewable energy and fossil fuels, websites made by groups for and against fracking, a map that marks fracking locations in the United States, and the United States Geological Survey's website noting the locations, frequencies, and intensities of recent earthquakes) with their peers. They were then asked to take a critical stance on the subject of fracking. In her final reflection, Erin revealed how this experience contributed to her appreciation for how making science relevant could help students discover their roles in, and the impact they could have on the science community. She wrote:

> For example, this lesson on the transfer of energy allowed us to begin thinking about where we get our energy from (fossil fuels). Then this led to a discussion about other things such as environmental issues, how limited our supply of fossil fuels is, and in what ways can we replenish our fossil fuels and how this can be done. It is important to show students all the concrete ways in which they contribute to the scientific community.

Here Erin indicates that making science relevant not only taught her about the content but helped her to understand how what they were learning was meaningful to and important in their lives outside of school. Her comments suggest that with the use of authentic examples from *real life*, she began to see and critically consider the science in her real life.

Erin highlighted the importance of making science relevant in several weekly checkpoints. As can be seen in Figure 11, she sometimes provided science-to-self connections as evidence of how she learned and understood science content and other times reflected on how she viewed relevancy to content from a teacher's perspective.

Figure 11. *Examples of Erin's Weekly Checkpoint Responses*

Week	Weekly Checkpoint Excerpts
#2	*There are various graduated cylinder pictures with varying amounts of liquid in them, step by step calculations, the 'need to know' behind concepts, as well as relevant examples. It helped me broaden my understanding of volume as well as learning how to present material in meaningful and relevant ways….* *I also learned that it is super helpful to use real life examples when explaining complex content. Some science concepts are too complicated to understand, and students respond better when teachers present knowledge to them in ways that are relevant to their lives.*
#3	*I also learned that teachers need to create a "need to know" for students because that is their motivation to move onto the next task. This was demonstrated in almost every activity we did. The order of the lesson was the inverse of traditional lessons. We measured things or carried out activities before we were given strict definitions or formulas. The investigations were done first so that we could understand the reason for doing those things.*
#4	*There are various graduated cylinder pictures with varying amounts of liquid in them, step by step calculations, the 'need to know' behind concepts, as well as relevant examples. It helped me broaden my understanding of volume as well as learning how to present material in meaningful and relevant ways.*
#8	*When we are able to use toys to explain a scientific concept, we see how it is applicable to real life, how it is relevant, and how science can easily be fun and engaging….I learned that it is important and quite easy to make relevant and relatable connections. We used toys that I'm sure we have all played with as children in order to examine how energy is transferred. Amy also used the movie The Incredibles to explain how the son, Dash, whose superpower was the ability to run at extremely fast speeds, needed a suit that could withstand heat (from the friction from his high-speed running).*

Erin made two science-to-self connections in week #8's checkpoint. She wrote about connections to pop culture, in the form of movies and toys, as experiences that helped her to understand the applicability of the physics concept, friction, and the cross cutting concept, energy. She also cited this example in her focus group comments from a teacher's perspective saying:

> You could really pull from things that are close to home for kids and relate it to science. I feel like that was one of the big takeaways. Science is everywhere and you could find resources in simple things.

Erin's experience reflects research that asserts connecting content to pop culture topics both familiarizes it and peaks students' interests (Hagood, Alvermann, & Heron-Hruby, 2010).

In weekly checkpoints #2, #3, and #4 Erin aligns students' "need to know," the purpose of the work conducted in science, to relevant connections to their lives outside of school. In all three examples, she asserts understanding why they were conducting the investigations was influential in motivating her to want to learn. Moreover, she suggests learning about how and why complex science is connected to life outside of school could make learning it easier, more engaging, and more fun.

Overall, Erin's coursework demonstrated her appreciation for learning science as she discovered ways that science was relevant to her life and those of her peers. In her final reflection she explained she now understood the value of developing personal connections to science, realizing science wasn't just for school.

> This course has made it evident that students need a personal connection to the material, whether that's through engaging them emotionally or connecting the new information with previously acquired knowledge. Without that, students may not only disengage and quickly forget, but they may also lose the motivation to try…. Well, so then kids feel like this is meaningful. I mean, it's not like I'm just learning this because it's cool it has something to do with their lives. Like, even comparing it to my own science experience, I just read the textbook and that's how you got the information. But this they're doing things and using things that you see at home so it means something to them. It's not just science for school.

Reflections composed in Erin's coursework and shared in focus group comments consistently centered on creating a learning environment that allowed students to view science in relevant and meaningful ways.

Planning to make connections to science. Consistent with work that suggested peer collaboration and relevant science-to-self connections aided her in learning in science, course assignments that assessed Erin's pedagogical content knowledge (PCK) suggested she valued collaboration and making science relevant to students' lives in her approach to teaching. When describing her pedagogical view for teaching science, she cited several ways in which the science content could be connected to students' individual lives: first-hand exploration, building on previous knowledge and experiences, and accommodating students' individual learning styles. She also highlighted how science could be connected to other subjects like her passion - literacy. In her final reflection she wrote:

> In order for students to build these skills and understandings so that they become applicable to their own lives, they must be involved in firsthand exploration and investigation where inquiry skills are nurtured (inquiry-based). Instruction must be built directly on their previous knowledge and conceptual framework (learning progression), and an array of instructional modes should be used to accommodate diverse learning styles. Students should be given opportunities to interact and share their ideas with their peers, and other subject areas should be infused with science.

Erin's view shows she valued the individual student's perspective and believed teachers should seeks ways to make the content relatable and relevant to them all.

In her 2nd grade unit plan on Ecosystems, Erin chose to include multiple opportunities for students to work collaboratively. In each lesson in this unit, she planned for students to work in small groups to share ideas, analyze, and investigate science. Likewise, she used materials that focused on topics that were directly relevant to the students' local environment.

In her first lesson, Erin planned for students to go outside, into the school yard, and record ten observations. Upon their return to class, her students would share their observations with their group and record them on post-its, omitting duplicates. These ideas would later be sorted and classified into living and nonliving things based on students' observations of their characteristics. This simple lesson involved collaborative discussions and work among students about the science that could be found in their own school yard.

Later in the unit, once students' had established an understanding of the differences between living and nonliving things, Erin planned for students to answer the essential question, "*What happens to dead plants and animals?*" In the lesson's procedures, she planned to elicit ideas from the students individually; then, to have students work in groups to investigate their ideas. In her lesson summary Erin wrote:

> Prepare a re-closeable plastic bag with materials that were "once living." Ideas of items to place in the bag are cut fruit, grass clippings, and moist bread. Including dead insects that can be found around the classroom will help students think about what happens to dead animals as well as dead plants….I will show students the bag and then pass the bag around for each student to observe more carefully. I will explain to the students that they should not open the bag. Question to ask: What do you think will happen to the items in this bag? I will allow students to share their ideas. Question to ask: Do you think all of the items in the bag will rot? Explain your answer.
>
> Next, I will tell students they will design an experiment to determine what happens to animals and plants when they die. Ask students to think about what causes rotting and have them record their predictions in their science notebooks. Students will determine the one item that they would like to test to determine if it causes rotting. For effect of

temperature: Place a piece of fruit or vegetable in two bags. Seal both bags. Place one bag in the refrigerator. Place the second bag in an area that stays at room temperature. For effect of air: Immediately place one piece of fruit or vegetable into a re-closeable plastic bag. Expose a second piece of the same fruit or vegetable to the air for an extended period of time, and then place it in a re-closeable plastic bag. Seal both bags and leave in a warm place. For effect of water: Completely dehydrate one piece of fruit and place in a closeable plastic bag. Place a second piece of fruit that is not dehydrated in a re-closeable plastic bag. Seal both bags and leave in a warm place.

Return to the bags a few days later and have students record the difference in their science notebooks.

In this lesson summary, students were prompted to collaboratively investigate factors that contribute to the decomposing and rotting processes of plants and animals. Students first shared their ideas about these processes and then investigated them using objects that could be found in their backyards. Erin's plan utilized peer collaboration as the means by which students would investigate science and to share and process their ideas.

Additionally, Erin's methods are consistent with an inquiry-based approach. The lesson procedures use science practices in that students are asking questions by considering different variables involved in the decomposing and rotting processes of plants and animals and then planning and carrying out investigations to test those variables. The unit plan, therefore, suggests that in addition to promoting collaboration and making relevant connections to content Erin would promote the use of science practices through an inquiry-based approach.

Evidence from this unit also suggested that through her English/Language Arts content lens, Erin saw science instruction as an opportunity to teach and practice literacy skills. Because elementary school teachers spend nearly five times more instructional time on literacy than science (Trygstad, et al., 2013), one might assume that science instructional time would be spent focused on science only. However, Erin saw science as a vehicle to teach literacy. Specifically, the lesson play used to assess how PSTs would talk to students about science showed Erin might choose to focus on students' development and understanding of science content through critical analysis of vocabulary. In her lesson play on the food chain, Erin posed questions that prompted students to develop understandings of the scientific terms used to classify types of plants and animals in the chain.

> *Teacher*: That's right! But what is so important about plants? Does anyone remember what plants have to do that make them so special?
>
> *Heather*: Plants are special because they have to make their own food. Animals go out and eat other plants or animals for food, but plants have to do all the work themselves and make their own food.
>
> *Teacher*: Very good! Do you remember the special word that we use to describe things that make their own food?
>
> *Heather*: Producers! Plants are producers because they produce, or make, their own food.
>
> *Teacher*: Excellent! Do you think it would be helpful if Kevin wrote underneath his drawing of grass the word "producer"?
>
> *Class*: Yes!
>
> *Teacher*: I think so too. So Heather told us that plants are producers. But she also said something else very interesting. She said that the other animals in the food chain have to go out and find other plants and animals to eat for food. What do we call animals that eat other animals and plants for energy?
>
> *Bryan*: We call them consumers. It's kind of like when you go shopping. You don't make the clothes at the store but you buy them so you can wear them. Same thing for a frog. He doesn't make the grasshoppers but he goes hunting for them and eats them.
>
> *Teacher*: That's a great way to think of it. Should we label on our food chains which animals are consumers?

Instead of presenting the vocabulary words simply as definitions to be memorized, the teacher in the play helped the students understand important vocabulary in a meaningful context. In this case, she used a scientific model to talk to students about why plants, who produce their own food, are called *producers*, as well as how producers fit into the bigger food chain. Her script was focused simultaneously on developing students' understanding of the scientific model in the form of a food chain and on promoting knowledge of the vocabulary words and their meanings. In this way, Erin emphasized literacy skills through the use of scientific terminology.

Erin consistently identified opportunities to teach science through literacy. In her final reflection of the course she explained how she utilized her literacy skills throughout the course to reason through and explain her thinking and understanding of science concepts.

> This course exposed me to the fact that the use of literacy skills while learning science content extended and expanded my scientific reasoning. By having to draw and label models and write out explanations and responses, I was able to clarify my ideas, make claims, present arguments, and record and present findings. We drew upon our real life experiences…to make hypotheses. Having to describe and write [our understanding] was very simple and a very efficient way to integrate literacy into the science lesson because we were already thinking about it and trying to reason it in our heads. It gave us the opportunity to make our thoughts verbal and it prompted us to think critically, using experiences from the real world to help us.

During this course, Erin was seeking an endorsement in literacy instruction. It appears as though her interest in, affinity for, or comfort with this subject mediated her view of science instruction in the elementary school. She thoughtfully connected strategies for teaching literacy with the teaching of science. Her reflections suggest she might seek ways to teach science through literacy but not necessarily that she would replace literacy instruction with science.

Summary. Connections to science motivated Erin as both a student and future teacher of science. Collaborating with peers, understanding how the science related to her life, and being able to utilize her strengths in literacy seemed to make the course content more accessible and less intimidating. Coursework that assessed Erin's future practice suggested she would utilize these science-to-self connections to teach her future elementary school students science.

Maria: How a Scientist Learns to Teach Science

> *"We have observed that some teachers don't focus a lot on science in the elementary grades and argue that math and literature are more important or maybe they do want to teach more science but doesn't know how to make more time for it…teachers struggle with the increasing external demands on the school curriculum, the integration of language arts with science can enhance both subject areas. You can teach science by using a book about a science concept during literacy and that will meet objectives in both science and literacy and at the same time provide a different way of learning about science to students."*

From the beginning to the end of the course, Maria was an advocate for high quality science instruction. She came into the course with strong views about the importance of science instruction in the elementary school and about the lack of science instructional time in today's elementary school classrooms. As the excerpt above from her final reflection shows, she aptly attributed one of the reasons for little science time in school to the emphases placed on literacy and math. In class, she also acknowledged that a discomfort or low self-efficacy in science contributed to elementary school teachers' hesitancy to teach the subject. As such, she often offered ideas about how to address teaching science in ways that would directly overcome these challenges. In the focus group interview she and Bree had an exchange that captured the differences in how they viewed their preparation for teaching science and evidenced Maria's efforts to ease her peer's concerns.

> Interviewer: So how do you feel about implementing these methods in your own classroom when you're a teacher?
>
> Bree: Well. The only problem is they were very creative when they were teaching us these activities and stuff but I can only teach it with these topics that we learned in class. Let's say we did something else, a different topic that we had to teach for the curriculum I would not be creative enough to do those activities. So, I could only teach science these fun ways if it was the topics. So if I had to do force in school then I would do these activities but I found that during the unit plan I just wasn't creative enough to think of my own model or whatnot.
>
> Maria: But you were at least trying. I think that if we didn't have this class I think that whatever information the school gave us that's how we would present it. But now we're gonna think, okay how do I come up with this. Whether you come up with an effective way or not at least you're thinking that way…our professors are not gonna have time to teach us everything, every topic. So I guess they really brought in, I guess, a thinking cap for us. At least we're thinking about it….The purpose is to go out and look for it.

Maria saw opportunities in the creative work conducted by teachers of science and she worked to get her peers to see the value in thinking about planning and teaching as an innovative process.

In class, it was clear Maria was not afraid to take academic risks in an effort to learn and to help her peers to learn. She was often the first to raise her hand to answer questions about both content and pedagogy. When conducting experiments she frequently offered ideas explaining the science behind our investigations even if she wasn't sure she was on the "right track." From the first day on, she stood out as a confident student of science describing how she felt about her future role as a science teacher optimistically as, "Excited, smart, and creative."

Maria's preference for the subject may be, in part, due to the hands-on nature of the work conducted in science. As a young student, Maria was an English Language Learner. Thus, science afforded her opportunities to learn content by *doing*. Though her coursework sometimes presented grammatical and structural errors challenges involving language seemingly did not negatively affect her confidence in the content or detract from her ability to learn and grow as a student and future teacher of science. She was able to explain her understanding of science well both in class and through her course assignments. Overall, Maria seemed to be the most confident student of science in the course.

Maria's comfort with and affinity for science was not surprising given she was the only PST in the cohort seeking science certification. In examining her case, I discovered confidence in her content knowledge allowed her to focus most of her efforts on learning about the methods for teaching science. In what follows, I first establish how her self-efficacy for science shaped her course experiences. I then explore the ways in which Maria described the value of and benefits of learning through inquiry. Lastly, I explore Maria's ability to merge content and pedagogy to plan lessons in science that approach instruction through inquiry.

Self-efficacy in content knowledge. Maria's middle school science experiences were very positive and she credited them as the inspiration for choosing to earn a certification in the subject. In her words:

> I personally have always enjoyed science, but my best experiences come from my years in middle school, which is why I have chosen to teach science in middle school. When I think back on my education in science, I realize that I actually do not remember much from elementary, except learning about plants and getting to grow my own. Perhaps is

> because my teachers focused mostly in math and English, or because they didn't make science memorable.

Maria acknowledged her prior experiences contributed to current feelings about science and her future role as a science teacher. In her focus group interview, Maria expanded on this view by explaining how prior knowledge and experiences created barriers for others in learning the content.

> I think another barrier along with what they are saying is kind of ourselves… Because it's really hard to take out what a person previously learned in their life and say, "Oh, ya know, you were wrong about that."

Given that Maria was consistently open to learning the content, whether she knew it previously or not, I do not believe Maria viewed herself as one of the students who created barriers for herself in learning science. Instead, I think she was implicitly referring to the obstacles she observed as she witnessed her peers engaging with the content. In the interview, Maria went on to further explain the only challenge PSTs faced in learning the content was in the reconstruction of their prior knowledge. The disequilibrium Maria explains is the kind of work Vygotsky suggests results in cognitive growth (Hus & Aberšek, 2011; Palincsar, 1998; Vygotsky, 1978). In science, teachers create opportunities where students question old understandings and compare them with new understandings based on evidence. Learners later internalize these new understandings, reconstructing and growing their schema (Vygotsky, 1978). It seems Maria viewed this disequilibrium as a barrier to learning if students were not willing to re-learn the content they assumed they already knew.

Reflecting Maria's comfort with and understanding of the nature of science as an evolving subject, she was able to articulate her understanding of the science concisely using terminology modeled in class. Her weekly checkpoints were, by far, much shorter than those of her peers as she succinctly explained the concepts she learned and how she learned them. For example, when describing the investigation of motion to discover Newton's Laws, Maria wrote:

> When Chris was pushed once, he continue skating without a change in his speed. We know this because, he was dropping bean sacks every second to show how far he had traveled. We observe that all sacks were spaced out equally, meaning that he was going in a constant speed. His speed didn't change because there was no force, other than the force of earth and the floor, acting on him. Then, Chris was constantly being pushed while skating, the student who was pushing him was also going in the same direction. Again, he dropped a sack to mark the distance he had travel per second. It clearly showed that Chris was going faster the further he continued to skate. This happened because there was a force pushing him in the same direction that he was skating making him go faster.

None of the information in this checkpoint is superfluous. Each sentence is necessary to communicate a clear understanding of the science concept. Whereas Bree tended to use a lot of words to explain her understanding, possibly because she wasn't sure what, exactly, she was "supposed to" have learned, Maria often accurately and concisely explained her understanding of science in a to-the-point manner. This might suggest she was confident in the conclusions drawn about the content and how we arrived at them.

Similarly, when reporting what she learned about sinking and floating, she succinctly explained the purpose of the lesson, the definition she learned through her experience, and how she and her peers went about exploring the concept.

> I learned that what causes objects to float is density not how heavy an object is. Density is how compact particles are in a given space. We learned this by conducting an

> experiment, where we watched several objects float or not float in a bucket of water. Materials included; coke, diet coke, tennis balls, shell, marble, fork, foam, PVC, metal tube, and pine cone. At first we thought that weight caused an object to float. But looking at our data we noticed that some objects that weight a lot did float. Specially two PVC that weight the same but had different heights. The longer PVC did float while the shorter one didn't. The mass was distributed evenly in the longer PVC and very compacted on the shorter PVC causing it to sink.

With a complex subject like science, it is difficult to capture conceptual understandings in a concise way. When teaching young students, however, it is preferable the teacher is able to summarize the main concept succinctly so students are not overwhelmed with lots of distracting details. Maria's approach to writing about what she learned and how she learned it made her understanding clear as core ideas were not clouded with extraneous details.

Making sense of science through inquiry. As a student of science, Maria consistently expressed how much she enjoyed and benefited from being able to discover science for herself. Evidence of this could be found in her course assignments, focus group comments, and notes about class performance in my researcher's journal. Maria was often the first to raise her hand when PSTs were asked what they thought about the investigations we conducted in class and, as such, her ideas were starting points for exploration into possible hypotheses we later investigated. Her behaviors suggested she was eager to be a part of the inquiry process and was not afraid to be "wrong." In her third weekly checkpoint Maria explained how she viewed the discovery process from a pedagogical perspective and gave evidence to support it from her experiences as a student in the course.

> I learned that a good and effective way of introducing a concept is by using an activity first to let students investigate on their own first, before telling them what the lesson is about. For example, in class, before telling us that we were going to learn about volume and density, Chris and Amy provided several experiments that allowed us to pose questions and think further about what we were learning. It was after we had made our own conclusions that Chris actually defined volume and density. This lets students discover things on their own and also understand a concept more because they think about it first before given the answer.

Maria acknowledged the sense of accomplishment she felt from discovering the content with her peers instead of being told what to think by teachers. Her reflective comments in weekly checkpoints and in her focus group interview comments focused similarly on the inquiry processes and the benefits of discovering and making meaning of science. For example in discussing her pedagogy in the focus group interview, Maria said:

> Just the mention of Newton's laws of motion sound very scary and hard. Students will not be as interested to learn about it if you were to just say, "Class today we are going to learn about Newton's laws of motion." But if you were to go and say, "Today you are going to see me skate while one of you push me down the hall," the students will definitely be more excited and eager to participate. Letting them make their own observations and then leading them and scaffolding them to notice certain patterns to come up with their own conclusion allows them engage in critical thinking and helps them become students who can make their own conclusions while understanding exactly why certain things happen. Just telling them what Newton's laws of motion are takes away the opportunity to let them investigate on their own. Also, at the end when you

> finally do introduce the concept of Newton's law, students will feel very smart and proud that they came up with the same conclusion that a famous scientist did.

As this comment shows, Maria appreciated that students might have preconceived ideas about what science is, potentially viewing it as a set of complex ideas and lots of facts. She understood this might make the subject intimidating for some. Instead of making science content simpler, however, she felt pushing students to learn the content themselves both helped them to learn it more deeply and to have more confidence in knowing they could. Many of her reflective comments in weekly checkpoints aligned with this point of view. Even in the first checkpoint Maria noted how scaffolding students' thinking instead of telling them what to think helped her to understand how to teach science through an inquiry-based approach. She said:

> One thing that I learned about teaching science is to push students to think more about their ideas. Not only to think of an idea but to be able to explain what they mean instead of just using complicated science term without even knowing what it means. I noticed that both professors always pushed us more; always asked us why and how, and always told us it was ok when we couldn't remember the correct scientific words as long as it made sense to us.

She consistently advocated for practices she had experienced that focused on depth of understanding through inquiry-based experiences. Embedded in her descriptions of the work she found beneficial are science and engineering practices such as analyzing and interpreting data and obtaining, evaluating, and communicating information.

Similarly, in her 6th weekly checkpoint, Maria explained how practice with developing and evaluating scientific models could be used to help students navigate abstract concepts, like phases of the moon, they might otherwise struggle to understand.

> I learned that using and choosing a visual 2D model to explain the moon's phases it's really difficult. An image may seem very good but many can give inaccurate information that students will consume as factual. For example, in class we looked at several moon phases images, many demonstrate a new moon as an eclipse. I learned that we, as teachers, have to be very careful with the models and images we choose to show in our classrooms. If we can't find anything better, then we must let students know what inaccuracies are present.

In this class meeting we examined several 2D models of moon phases and evaluated what students might think if they viewed them without input from their peers or the teacher. We discussed how each could be used effectively if teachers asked questions that promoted critical analysis of how the model fit with what they understood about this scientific phenomenon. Maria's statement about letting "students know what inaccuracies are present" showed she understood the teacher must act as a knowledgeable other in helping students to understand how to read and critically evaluate scientific models for accuracy.

Maria's weekly checkpoints and course reflections often focused on learning and practicing science-related skills and inquiry-based methods for teaching science and helping students to make meaning of science. Her class and course work suggest she is an advocate, specifically, for the use of questioning and scientific modeling in inquiry-based instruction to help students make sense of science. It may be that Maria's comfort with the content allowed her to devote more attention to the pedagogical practices modeled in class and how she could adapt them to her own practices.

Merging content and pedagogy through practice. Coursework such as lesson plans, lesson plays, and unit plans were designed to assess PSTs' ability to apply their understanding of both to practice. All three of these assignments submitted by Maria demonstrated evidence to suggest she was proficient in her knowledge and understanding of both science content and pedagogy.

In Maria's 3rd grade unit on Biological Evolution, she planned lessons that would facilitate the development of students' conceptual understanding related to the following big ideas:

- The world is made of different types of environments.
- In a particular environment, some animals survive well, some survive less well, and some cannot survive.
- Sometimes specific characteristics of an organism help it survive and reproduce.
- Change in an environment affects organism living there.
- Fossils provide evidence about the types of organisms that lived long ago.
- Cause and effect is used to explain change.

Each big idea contributes to students' ability to complete performance expectations in the NGSS 3rd grade NGSS which state: *Analyze and interpret data from fossils to provide evidence of the organisms and the environments in which they lived long ago; Use evidence to construct an explanation for how the variations in characteristics among individuals of the same species may provide advantages in surviving, finding mates, and reproducing; Construct an argument with evidence that in a particular habitat some organisms can survive well, some survive less well, and some cannot survive at all.*

In every lesson for this unit, Maria planned an investigation in which her students would explore some aspect of these big ideas. In the 2nd lesson of the unit, Maria planned to have students in groups of 3, circulate around the room visiting pictures of animals in their natural environment, making, discussing, and recording their observations. Following the collection of observations, she planned to ask students questions like:

- Why do you think the animal need that characteristic? (Claws, teeth, color etc.)
- Can the animal survive without it?
- Where is the animal? Do you think that the animal has certain characteristics because of its environment? (e.g. fur because is cold)
- What if the animal lives somewhere else, do you think it still need those characteristics?

These questions were designed to get students to be able to "explain how specific animal characteristics and adaptations help the animal survive by making observations and collaborating in groups" and to begin to "make connections, through their observations, analyzing how the environment influences animals' acquisition of certain characteristics and the development of adaptations." In this way, her planned questions were aligned with the big ideas in the unit as these concepts are foundational to understanding biological evolution. They also align well with inquiry-based methods for instruction where students' use their observations to develop, test, and construct ideas about science.

In the 4th lesson in her unit, Maria's objective states: *Students will be able to explain how variations of beaks on birds help them survive in an environment by conducting an experiment where they use items as models of the bird's beaks*. To accomplish this she planned for students, in groups, to cycle through stations in which they would explore how the shape and size of the bird's beak determines what kinds of foods are accessible to it.

> Today we will focus on the different types of beaks birds have. Students will pretend to be three types of birds, each with different types of beaks by using everyday objects; hummingbird, robin, and an evening grosbeak. The teacher will show pictures of the

> birds, so that students can see how their beaks look. The class will be divided in three; the hummingbirds will have a pipette as a beak, the robin will have forceps as beaks, and the grosbeaks will have clothespins. Each students will have cups as their stomach. The classroom will have four stations: bugs (plastic bugs on a table), worms (thick yarn on a container with soil), flower with nectar (small cups with water), and nuts (small marbles on a shallow container). Students will have 1 minute on each station to try to feed themselves. Afterwards students will discuss what they were able to eat and what they couldn't eat; how did their beak help them get their food? How did it not? Exit-slip: What will happen if your bird leaves in an environment where there is only food that their beaks can't grab?

In lessons prior to this one in the unit, Maria planned for students to investigate different environments to learn about the availability of resources and examine their characteristics to begin to make connections between the two. The observations students would make at each station in this lesson sought to help children develop an understanding of how physical characteristics of animals affect their ability to survive in different environments in a more specific manner. Students would, thereafter, be able to critically evaluate the characteristics they observe to make connections between them and the animals' chances of survival. Later, Maria planned to build on these connections to facilitate students' understanding of animal adaptations.

Maria's lesson play for this unit showed how she perceived students would engage with this concept, the kinds of questions she would pose to help them progress in their understanding of it, and how she would move them along in their understanding of the overarching concepts.

> Teacher: Ok, I see what you are saying. Can you explain what you mean by "the green bugs adapted to their environment?"

Student: That the bugs were able to change so that they can camouflage with the plants. So that the birds don't eat them

Teacher: So the birds can only eat the brown bugs because they can be seen?

Students: Yes

Teacher: If the bugs adapt to their environment by changing so that they can camouflage, does that mean that some brown bugs are changing into green bugs?

Student: No, the brown bugs are getting eaten.

Teacher: Oh, so the green bugs survive but not the brown bugs.

Students: Yes

Teacher: So, did any of the bugs change?

Student: I don't think so...No because the brown bugs got eaten.

Teacher: So, then what happen. Think about the activities we had in class. What happen after animals survive in their environment?

Student: They have offspring! Those are the ones that adapt to the environment!

Teacher: Do you mean they change in order to camouflage?

Student: uhm..?

Teacher: Let me ask you this, when the bugs have offspring, what color are they?

Student: Green

Teacher: All of them?

Student: No, a few are going to be brown.

Teacher: Ok, and are they the ones that change?

Students: Noo, they get eaten too!

Teacher: How about the green bugs?

Student: They don't get eaten and they keep having offspring, and then it happens again and again, like the simulation we had in class.

> Teacher: Yes, it is like that, so now imagine this process happened several times, we will have a lot of bugs right? What color will they be?

One of the questions the teacher in Maria's script asks, "Can you explain what you mean by 'the green bugs adapted to their environment?'" serves as evidence to suggest Maria would mine for the students' understanding of the concept in order to address misconceptions and/or allow the student to guide next steps in the lesson. This student/teacher exchange provides evidence to suggest Maria appreciated that students may struggle to deeply understand the concept, adaptation, and that she was able to utilize methods modeled in class to plan her instructional approach.

Instead of simply telling the students what to think, Maria used questions to scaffold students' thinking and the scientific model to help students assess and communicate their understanding. The teacher in the script redirected the conversation shifting the focus from animal's camouflaging to survive, which does not seem to help the students understand, to the inherited traits of offspring, which helps the students arrive at a beginning understanding of animal adaptation. Maria's script demonstrates her ability to analyze the questioning techniques and mediation tools she experienced as a student and apply them to her own teaching practices. Her lesson play also evidences her efforts in structuring classroom dialogue to allow the students to co-construct science for themselves.

Maria's coursework, participation in class, and reflections on her experiences consistently demonstrated confidence in her abilities to learn and teach science. Her ability to incorporate what she learned in class about teaching science into her lessons and lesson play suggest she will be able to utilize the scientific practices and processes modeled to teach elementary school science content.

Summary. Because of her confidence in the subject matter, Maria considered herself a scientist from the beginning of the semester. She was not afraid to take academic risks and this risk taking allowed her to continue to grow her understanding of the science content. Maria understood how research-based best practices such as inquiry-based instruction, questioning, and scientific modeling could be used to teach young students science. Several assignments submitted by Maria, such as her lesson plans, lesson plays, and unit plan, suggested she was able to merge her science content knowledge and PCK to plan instruction that mirrors the methods used to design and teach this course.

Conclusion

If elementary school students are to understand science as it is valued and practiced in the field they need teachers who possess a command of science content knowledge, and an understanding of the skills and pedagogies for teaching and learning science. Moreover, future elementary school teachers need to be able to transform their knowledge of science in ways that effectively enables students to experience and practice the doing of science. This study sought to examine what PSTs learned about science content and skills and pedagogies for teaching them in one science methods course.

To achieve this purpose, I examined student learning of the whole class in three ways: in terms of science content, science reasoning skills, and pedagogy for teaching elementary school science. Then I examined student learning through three case studies that examined more deeply how individual students experienced the course as well as to identify commonalities in their experiences. Through these analyses I discovered challenges in assessing students' content knowledge and scientific reasoning skills. However, evidence of students' experiences with and learning from conducting science as students through inquiry-based instruction suggest the scientific processes that mediated their learning benefitted them as both students and future teachers. Case study analyses further shed light on how the course was experienced differently by each student, what aspects of the curriculum and course design worked for them, and which could be improved upon to better address the needs of more students.

In the following chapter I discuss these findings in relation to current literature and next steps I might take as a teacher educator and researcher of science education and teacher preparation.

CHAPTER 6: DISCUSSION & IMPLICATIONS

In the last six months, scientists at NASA discovered 1,284 new planets ("NASA's Largest Collection of Planets," 2016), environmental biologists identified mutualistic relationships in salt marshes that suggest a potential resilience to climate change (Dybas & Orlando, 2016) and engineers developed a method for locating clogged sewer drains using acoustical waves (Bates, 2016). Countless advances are made in the natural and designed worlds of science every day. No textbook can teach what we need to know and understand in order to engage with the work conducted in the field of science, nor maintain the pace of scientific discoveries in the 21st century. Teachers hold the key to facilitating the kind of thinking and doing necessary to develop learners who are literate in this ever-changing field. In order to prepare our nation's children to participate in a global scientific community, teachers need to be well equipped with science content and pedagogical content knowledge (PCK).

This study documents a course designed to teach preservice elementary school teachers about science content and science-related skills and practices through inquiry-based instruction. It was also designed to provide opportunities to learn about, and analyze, pedagogical practices for teaching science to young learners. In this chapter, I examine the findings of this study in relation to the research literature and my original research questions. I then explore what the findings of this study suggest for improving the design of this specific class and the preparation of elementary teachers to teach science. To provide some context for the findings, I begin with a summary of the research design. This is followed by an examination of the four key findings and their implications for practice. I conclude by proposing future research and actions I will take as a teacher educator to improve this science methods course as a result of this study.

Research Design

I began with a problem of practice that highlighted current inadequacies in preparing elementary school teachers to teach science. I posited that if elementary school teachers are to be able to teach science effectively, they must be knowledgeable in both science content and pedagogical practices that align with the work conducted by scientists in the field and that, therefore, teacher preparation courses must address both (Akerson, et al, 2014; Baumgartner, 2010; Davis & Synder, 2012; Gess-Newsome, 2002). In researching the state of teacher preparation in science instruction, I found most PSTs are unprepared, either lacking in content knowledge across disciplines or in an understanding of how to teach science so that students develop practices and beliefs that mirror the nature of science (Baumgartner, 2010; Bodzin & Beerer, 2003; Bulunuz & Jarrett, 2009). My research questions sought to examine what PSTs learned in a science methods course aimed at addressing these deficiencies by teaching across science disciplines and modeling and teaching inquiry-based instruction. I employed a constructivist lens to ground the research in methods for accomplishing this work.

Participants were the 14 preservice teachers in my methods course, whose comfort with and experiences in science varied. These participants were also seeking varied subject concentrations. Data collection began in September of 2015, concluding with focus group interviews in December 2015. The Lawson Test, a measure of learners' understanding of conservation, proportional thinking, identification and control of variables, probabilistic thinking, and deductive reasoning (Carmel & Yezierski, 2013; Coletta & Phillips, 2009), was used to measure students' scientific reasoning skills prior to and at the end of the course. Qualitative data was collected in the form of course assignments, my researcher's reflective journal, and through focus group interviews to examine what students learned from the course and to elicit students' views of the curriculum, course design, and co-teaching model. In order to both broadly and deeply examine their learning, I employed two methods: an examination of the learning and perceptions of the whole class and of the learning and experiences of three nested case study participants.

As the purpose of this study was to examine PSTs' preparedness for teaching science in the elementary school, the research questions that guided this study were as follows:

1. What do PSTs learn about science content in a co-taught science methods course aimed at combining the teaching of science content with the teaching/modeling of inquiry-based instruction?
2. What do PSTs learn about pedagogy in a co-taught science methods course aimed at combining the teaching of science content with the teaching/modeling of inquiry-based instruction?
3. What are PSTs' experiences and evaluations of the co-taught science methods course aimed at combining the teaching of science content with the teaching/modeling of inquiry-based instruction?

Using these questions, data analysis took place in three phases: 1) whole class case, 2) nested cases, and 3) cross-case analysis. I explored not only what students learned from the course but how they explained what they learned through their course experiences. A review of students' course assignments and perceptions shared in focus group interviews indicated students learned most from experiencing inquiry-based instruction as students of science. In what follows, I provide a findings and implications.

Findings & Implications

Data analysis led to 5 key findings that helped address my research questions. I begin by looking at the first two research questions that focus on what PSTs learned in terms of content and PCK. Because the practices PSTs suggest were beneficial to their learning were used to model methods for teaching elementary school science, I suggest that teacher educators "*Practice What You Teach"* in science methods courses like this one.

Lastly, I present 3 findings in connection with the third research question that explored PSTs' evaluations of the curriculum, course design, and co-teaching model. First, I use my analysis of the nested case studies to posit two findings: 1) PSTs' prior knowledge in and experiences with science contribute to how they view themselves as scientists and how they think about teaching science, and 2) PSTs may use their strengths in one subject matter as a lens through which to view science and/or the teaching of science. Third, I find that although PSTs learned both science and engineering practices and pedagogies for teaching science through their experiences in this course, one semester-long course is not enough to obtain the depth of understanding needed to comprehensively address the vast science content in and pedagogies necessary for teaching elementary school science. I suggest three methods for increasing PSTs' work with authentic elementary school classroom contexts.

Assessment of Science Content: What did PSTs learn about science?

During the course, my co-teacher and I used in-class activities and discussions, weekly checkpoints, and quizzes to assess PST's science content knowledge. As I attempted to more critically assess what PSTs' learned in terms of science for this study, I discovered much of the core ideas they cited in weekly checkpoints as science content knowledge were taken, in some cases – verbatim, from anchor charts co-constructed in class. Likewise, when asked what they learned in terms of science in focus group interviews, PSTs described *learning experiences*, not *science concepts*. They talked about learning the definition of density by testing if items sunk or floated and described the roller blading investigation as the method used to teach Newton's Laws but they never explicitly stated the science concepts behind these learning experiences. It was difficult to discern, therefore, what they learned in terms of science that will last past the formative assessments administered during the course. Similarly, the Lawson Test used to assess PSTs' scientific reasoning skills prior to and at the end of the course did not capture the gains I observed and students' reported having developed by doing science in class. I found this measure to be ineffective in assessing their growth.

These findings illustrate the challenge teachers face in assessing students' science content knowledge in classroom. Because science is such a dynamic field of study, no one assessment can capture the knowledge and skills needed to fully understand and engage with it. However, PSTs often reported having learned about science through scientific modeling. Having to communicate how they understood the science we were investigating using models required them to engage in metacognition. Often created collaboratively, PSTs also had to be able to communicate what they thought to their peers and to be able to debate and discuss complex science with them. These scientific models also served as the formative assessments instructors used to assess PSTs' understanding in class and guide instructional practices.

To date, the research base on scientific modeling is limited to middle school grades and above (Kenyon, et al., 2011). However, PSTs' reported scientific modeling as a means by which they were able to effectively work through understandings science. This suggests teacher educators use scientific models to engage PSTs in learning about science as well as potential tools to assess PSTs' learning. In addition, further research should be conducted on scientific modeling as a method for assessing the science content knowledge of elementary school students.

Since conducting this study, my co-teacher and I have taught the science methods course once more using a parallel co-teaching model. In my course, I incorporated scientific models in three additional ways. First, on the second quiz of the course I prompted PSTs to create a 2D model of the configuration of the Earth, moon, and sun in creating the moon phases, instead of simply asking them to explain it in words. Second, I used four of the models created by PSTs on the quiz to teach them how to evaluate scientific models as evidence of learning. Third, I collected scientific models created by students and presented them in class for critical analysis. Discussions about these scientific models centered on challenges associated with assessing students' science content knowledge and how models could be used as tools to both teach and assess learning. In the future I intend to continue to utilize scientific models in these ways. I also aim to conduct additional research about how scientific models could be used as evidence of learning, both in teacher preparation courses and in elementary school classrooms.

Practice What You Teach: What did PSTs learn about PCK?

The interactive co-teaching approach was implemented to address issues associated with courses that focus primarily on content *or* pedagogies for teaching science. PSTs reported that the co-teaching model was, in small part, responsible for improving their learning in science content and in PCK. However, their evaluations of the course suggest the course design, curriculum, and practices used to teach them science content were more influential in progressing their understanding of science, science and engineering skills, and pedagogies than the co-teaching approach, itself.

No other studies to date have documented an interactive co-teaching model with a physics expert and expert in elementary methods of instruction to plan and implement an elementary science methods course. This approach could be used as a model for addressing the historically dichotomous approach to teaching science and pedagogy to future teachers. However, because the course has been taught independently by both instructors using the same course design and curriculum since this study was conducted, additional research needs to be conducted to determine whether collaborative planning and parallel co-teaching might achieve similar outcomes. Findings from this study, however, do suggest the collaboratively designed course and curriculum could be used as a model for teaching pedagogy to address multiple science disciplines. It was the balanced emphasis on content knowledge, pedagogical content knowledge, and elementary methods of instruction that benefitted PSTs. Working openly and collaboratively with my co-teacher resulted in a continual evolution of the course and methods for addressing all three areas of expertise. For example, when I felt we were focusing too much on advanced understandings of science content I would highlight how to transfer their knowledge and understanding to elementary students. My co-teacher and I thoughtfully considered how we could utilize the expertise of the other to create a well-rounded learning experience for our PSTs. Therefore, if science methods courses aim to provide students with these three areas of knowledge and skills, science content, PCK, and elementary instructional methods, a balanced curriculum and course design should be a priority.

Instead of teaching PSTs *about* learning and teaching science through inquiry, PSTs in this course experienced science through inquiry-based instruction as students. In focus group interviews, weekly checkpoints, and class discussions they highlighted these experiences as having aided them as students and teachers of science. As students they discussed initially feeling frustrated in having to answer tough questions but later experiencing pride as they designed and posed complex questions to each other while conducting science. PSTs also shared experiences in which they had to overcome challenges in trying to discover the science behind phenomena they had never before thought critically about. During class investigations, they were able to explain their understanding of the science concepts by analyzing the outcomes of their investigations. Though they did not explicitly state the disciplinary core ideas they learned during focus group interviews, PSTs celebrated what they felt they learned about science through the inquiry processes. Their analysis of the course design and curriculum suggests that in order to learn science content, PSTs need to experience it as students.

In keeping with research findings linked to PSTs experiences with reflective discourse about practice (Akerson, et al, 2014; Bodzin & Beerer, 2003; Gess-Newsome, 2012), discussions in this course encouraged participants to think about how the way they were being taught affected what they learned and how they viewed themselves as learners . Experiencing the benefits of using scientific models and questions that moved them forward in their thinking about science content gave PSTs ideas for implementing these strategies in their own practice as teachers. Pulling apart the investigations and activities conducted in class helped PSTs consider the roles of the students and the teacher and the outcomes of the instructional practices. Through this work, PSTs saw how the way they were being taught framed what they learned and how they viewed science, in general.

Findings from this study, therefore, suggest this and other science methods courses should teach PSTs science content through pedagogies for teaching elementary school science and purposefully facilitate reflective discourse about practice. Both the course design and curriculum should be intentionally planned to provide opportunities to conduct this work.

Past vs. Present Experiences & Self-Efficacy in Science: What were PSTs' experiences and evaluations of the curriculum and course design?

Evidence from all three cases suggests past experiences with science contributed to how each PST viewed herself as a scientist and, thereby, framed how she experienced and what she gained from this science methods course. This finding echoes the research base that finds prior experiences with science, positive or negative, shape elementary school teachers' instructional practice (Anderson & Clark, 2012; Avery & Meyer, 2012; Parker, 2004). If PSTs prior experiences fostered positive self-identities as science students, they might be better able to use a science methods course to learn pedagogies for teaching science; while, if their prior experiences fostered negative feelings associated with themselves as students of science, more of their work was focused on becoming comfortable with the content.

Examples of this can be found in all three cases. Although Bree reported positive experiences with science as an elementary school student, science instruction in her middle and high school years, which emphasized memorization and accuracy of performance, taught her there was a right and wrong way to do science. Bree's concern for accuracy and uncertainty regarding whether traditional or inquiry-based instruction was best was a common theme in her course work and class performance. Erin also had positive experiences as an elementary school student of science. In reflecting on her experiences as an elementary student she highlighted the collaborative nature of the experiments she conducted with her peers. Throughout the course, Erin commonly credited the collaboration with peers as influential in her learning process. Maria entered the course as a confident student of science. Her past experiences with the subject were generally positive and she credited them with motivating her to acquire a certification in the subject. Her reflective coursework and the comments she made in her focus group interview suggest her comfort with the science content allowed her to hone in on the pedagogical practices being modeled and discussed in class.

These findings suggest teacher educators need to be aware of their PSTs' past experiences with science and to address them explicitly. The pre-reflection assignment illuminated some of PSTs' past experiences. However, surveys about the nature of science and PSTs' self-efficacy as students and future teachers might be beneficial in providing additional information regarding how they view science as a subject and their capabilities in conducting and teaching science. This information could be used to differentiate instructional supports and practices for PSTs within the science methods course as both students and future teachers of science.

Content Lenses: What were PSTs' experiences and evaluations of the curriculum and course design?

The 5-year teacher preparation program at the university's graduate school of education where this study was conducted requires students seeking elementary certification to also choose a subject matter concentration for middle school instruction. Bree was seeking a math certification, Erin, a certification in English, and Maria was the only PST in the cohort seeking a certification in science. In examining their coursework, I found that each PST viewed the science content and practices experienced in the course through a different *content lens*. Their content lenses aligned with how they communicated their understanding of the science content, composed student-teacher dialogue, and/or viewed science, as a subject, in elementary school.

The use of their subject matter concentration as a learning mode in science suggests even with careful curriculum planning and fidelity to course implementation, PSTs will experience the course differently. All three nested case study participants entered the course with specific experiences in science that provided insight into how they felt about science, themselves as students of science, and aspects of science instruction they attributed to their learning (e.g.

hands-on experiences, collaboration, discovery learning). Evidence of the effects of those experiences were found both in course assignments collected throughout the semester and in focus group interviews conducted at the semester's end. This finding suggests that what students' viewed as important to learning upon entering the course did not change as a result of the course. It also suggests that teacher educators might, therefore, consider how to link other areas of elementary school content and curriculum in teaching PSTs how to think about and teach elementary school science.

Literacy integration, for example, was explicitly modeled in the course as specific children's literature was used to show PSTs how they might address science content through literacy instruction, and vice versa. As the content lenses of the three nested case study participants seemingly shaped how they viewed science as learners and future teachers, the integration of other areas of the elementary school curriculum should be explicit. One ways to encourage this integration might be to incorporate standards of subjects such as math and social studies when designing investigations to teach science content. Teacher educators and PSTs might also collaboratively critique sample lessons that model curriculum integration and/or consider ways in which lesson lacking integration could be enhanced through this approach.

Furthermore, this data set suggests that PSTs in methods courses would benefit from instruction that was differentiated to better address their needs as learners. Like elementary school classroom teachers, teacher educators work with diverse student populations whose areas of strength and need differ based on prior knowledge, experience, learning preferences, culture, readiness, etc. Often unacknowledged in higher education, these factors contribute to *what* and *how* students learn.

In order to help all students successfully learn the science content and PCK for teaching elementary school, teacher educators must get to know how their students learn and what content, methods of instruction, and assessment tools would help them to learn. For example, students like Bree, who used her strength in math to navigate the science content, might benefit from investigations in which science and math were purposefully integrated. Likewise, Erin, and others with affinities toward literacy instruction, may have felt more confident teaching science if literacy and science integration was modeled more often and discussed in more depth. Teacher educators promote the use of differentiated instruction to meet the needs of K-12th grade students but the findings from Bree, Erin, and Maria's cases suggest that student teachers would also benefit from this approach to learning and teaching.

More on Science: What were PSTs' experiences and evaluations of the curriculum and course design?

Modeling my practices after pedagogies I once used as a classroom teacher allowed me to link authentic elementary school instruction to this course. However, an area of the curriculum and course design that was lacking was opportunities for PSTs to experience and/or observe science instruction using an inquiry-based approach in practice, in real classrooms and schools. Because school days are often focused on high stakes tested subjects, namely literacy and math (Trygstad, et al., 2013), PSTs were often unable to observe science instruction in their 1 day practicum placement in the field making the link between the university classroom and the field site challenging. Although PSTs read about and professors shared stories about authentic examples of inquiry in practice, Bree for example reported feeling unprepared to teach science at the end of the course citing, primarily, a lack of authentic examples and knowledge of what elementary school students would, or would not, be able to do as the cause of her discontent.

This finding reflects the teacher education research base that asserts PSTs benefit from learning and experiences in contextual settings similar to that within which they will teach (Bodzin & Beerer, 2003; Etkina, 2010; Gess-Newsome, 2002).

These findings suggest teacher educators should seek out methods for bridging the perennial gap between theory and authentic practice. Videos, case studies, or clinical experiences in the field should be inserted into the course design to provide PSTs with additional opportunities to experience inquiry with elementary school students in practice. Teacher educators should seek to develop networks of practicing elementary school teachers who teach using methods that could be used to both support their work in the classroom and to provide PSTs' with authentic examples from the field. The Graduate School of Education at the university in which this study was conducted maintains partnerships with local school districts. In the future, I intend to collaborate with liaisons, who serve as bridge-builders between the university and partnership schools, to foster opportunities for shared growth in science instruction in teacher preparation coursework, and in teacher educators' and practicing teachers' professional work.

Limitations & Significance

Several potential problems in the design of this study need to be considered. First, I acknowledge that I was not able to conduct in-depth observations of students' learning while I was simultaneously teaching the course. However, assignments specifically post-course reflection papers and focus group interviews provided in-depth explanations of student learning and the instructional methods used in class. Moreover, in my researcher's journal, I was able to create more comprehensive descriptions of the students' varied learning experiences.

Secondly, participants in this study could not be controlled for previous science learning. Although demographic information was collected regarding what classes students took in the past, there was no way to examine what they learned in those courses and whether the science they learned addressed the content necessary for teaching elementary school science. There was also no way to determine the level of learning they achieved in those courses. Instead, weekly checkpoints and quizzes were used to diagnostically and formatively assess and examine students' learning throughout the course.

Lastly, as I was simultaneously the researcher and teacher in this study, there is inevitable personal bias about the success of the course. It is then possible that this bias may have impacted my interpretations of the data. I have tried to minimize potential bias with the use of self-reflexivity, triangulation, and peer review. Moreover, to avoid the influence a teacher-student relationship would have on the students' responses to the focus group interview questions, an external researcher conducted the focus group interviews.

Despite these limitations, this study aimed to fill a gap in the research base on preparing elementary school science teachers. The use of a co-teaching model in a course aimed at merging the teaching of science content with inquiry-based methods of instruction is a new strategy to address the dichotomy that separates teaching science with teaching methods of instruction in teacher preparation programs. I hope that the findings from this study will provide an example of this particular approach to preparing elementary teachers for science instruction. Future studies should extend this research to determine the applicability of this curriculum and course design to other science methods courses in this and other universities in which PSTs are required to take one semester- long science methods course for elementary school certification. This approach would provide a basis for comparison and would help to test consistencies in the learning acquired from this course. Additional research should also explore how a co-teaching model could be used in other methods course to merge diverse areas of expertise in both content and pedagogies for teaching at the elementary school level, and/or for curriculum planning and course design. As college level methods courses often focus narrowly on either content or practice, this model for teaching presents a method for addressing both areas, necessary in facilitating PSTs' self-efficacy in teaching specific content, in one course.

The data collected through this study provided insight into the experiences of individual student's learning in preparation to teach elementary school science. Insights into the contextual characteristics of students' experiences can be used to inform the design of future elementary school science methods coursework. Additional research should examine how integrating science with other elementary school subject areas could be used to increase PSTs' efficacy in learning and teaching science. While analyzing nested case study documents for this study, I noticed that PSTs' ways of thinking, talking, and writing about science were aligned with their chosen subject matter certifications. I could not find any studies that examined, or even noted, how PSTs' preferences for or comfort in other subjects could be used to increase their science content knowledge or self-efficacy as scientists or teachers of science. Further research into how subjects such as literacy and math (subject areas preferred by most in this university's graduate school) could be used to teach science might shed light on methods for teaching science to PSTs and elementary school students of science.

Lastly, as research suggests most important to teachers' abilities to teach science is their level of content knowledge, PCK, and self-efficacy for teaching science, further research on PSTs' self-efficacy for teaching science before and after taking this course must be explored. The Lawson Test was ineffective as the quantitative measure for assessing PSTs' growth in this course. The Science Teacher Efficacy Belief Instrument (STEBI), used in other studies to measure PSTs' self-efficacy for teaching science (Knaggs & Sonergeld, 2015), could instead be used to examine PSTs' self-efficacy prior to and following their participation in this and other science methods courses.

Conclusion

With current global pressures for students to learn the STEM (Science, Technology, Engineering, and Mathematics) subjects in meaningful ways and the release of the *Next Generation Science Standards*, science education is finally getting the national attention it deserves. Teachers are expected to teach children to "think like scientists" and engage with science in ways that allow them to take the lead in creating questions and exploring scientific methods to answer those questions. Yet, as a teacher educator, I see that our PSTs are not prepared to do this work; they are not getting what they need from our teacher preparation programs to be confident teachers of science. Though I am confident PSTs' experiences in our course increased their content knowledge in physics and exposed them to inquiry-based methods of science instruction they can potentially use in the future, this one-semester course did not offer enough time to cover life science or earth and space science with much depth. Nor did it provide enough opportunities to explore a variety of types of investigations and ways of conducting science with young students that would help PSTs to be able to facilitate inquiry-based instruction in different school settings and contexts.

Despite the limitations of this study, I am thrilled about what PSTs say they did learn from their experiences as students of inquiry. I have already begun the process of improving the curriculum to incorporate more experiences with earth and space, and life science and designing assessment measures to better determine what PSTs really learn in terms of science. I am also working with my colleagues to find ways to connect work in this course to PSTs' clinical practice in the field. One day, maybe, as a result of methods courses that intentionally merge the learning and teaching of science content and PCK, children will be taught by elementary school teachers with competencies that enable them to become curious, ambitious, and confident young scientists.

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Appendix

Appendix A

Rutgers, The State University of New Jersey
05:300:461:02 Science in the Elementary School
Fall 2015
Mondays 9:50-12:50 p.m.
GSE-25A

Instructor: Amy Lewis Chris Bloom	amy.lewis@gse.rutgers.edu
Phone Number: (908)763-7160 (732) 672-9432	10 Seminary Pl.
Office Hours: by appointment	
Mode of Instruction: ___ Lecture _X_ Seminar ___ Hybrid ___ Online ___ Other	Permission required: __ No _x_Yes Directions about where to get permission numbers: from the instructor

Rutgers University welcomes students with disabilities into all of the University's educational programs. In order to receive consideration for reasonable accommodations, a student with a disability must contact the appropriate disability services office at the campus where you are officially enrolled, participate in an intake interview, and provide documentations: https://ods.rutgers.edu/students/documentation-guidelines. If the documentation supports your request for reasonable accommodations, your campus's disability services office will provide you with a Letter of Accommodations. Please share this letter with your instructors and discuss the accommodations with them as early in your courses as possible. To begin this process, please complete the Registration form on the ODS web site at: https://ods.rutgers.edu/students/registration-form.

Course Description

New Jersey Professional Standards for Teachers 2014[1]

1. Standard One: Learner Development. The teacher understands how learners grow and develop, recognizing that patterns of learning and development vary individually within and across the cognitive, linguistic, social, emotional, and physical areas, and designs and implements developmentally appropriate and challenging learning experiences.

i. Performances:

(1) The teacher regularly assesses individual and group performance in order to design and modify instruction to meet learners' needs in each area of development

(cognitive, linguistic, social, emotional, and physical) and scaffolds the next level of development;

ii. Essential Knowledge:

(1) The teacher understands how learning occurs--how learners construct knowledge, acquire skills, and develop disciplined thinking processes--and knows how to use instructional strategies that promote student learning;

2. Standard Two: Learning Differences. The teacher uses understanding of individual differences and diverse cultures and communities to ensure inclusive learning environments that enable each learner to meet high standards.

i. Performances:

(3) The teacher designs instruction to build on learners' prior knowledge and experiences, allowing learners to accelerate as they demonstrate their understandings

ii. Essential Knowledge:

(2) The teacher understands and identifies differences in approaches to learning and performance and knows how to design instruction that uses each learner's strengths to promote growth;

(5) The teacher understands that learners bring assets for learning based on their individual experiences, abilities, talents, prior learning, and peer and social group interactions, as well as language, culture, family, and community values

iii. Critical Dispositions:

(1) The teacher believes that all learners can achieve at high levels and persists in helping each learner reach his or her full potential;

(3) The teacher makes learners feel valued and helps them learn to value each other;

3. Standard Three: Learning Environments. The teacher works with others to create environments that support individual and collaborative learning, and that encourage positive social interaction, active engagement in learning, and self-motivation.

i. Performances:

(3) The teacher collaborates with learners and colleagues to develop shared values and expectations for respectful interactions, rigorous academic discussions, and individual and group responsibility for quality work

(4) The teacher manages the learning environment to actively and equitably engage learners by organizing, allocating, and coordinating the resources of time, space, and learners' attention;

ii. Essential Knowledge:

(2) The teacher knows how to help learners work productively and cooperatively with each other to achieve learning goals;

(3) The teacher knows how to collaborate with learners to establish and monitor elements of a safe and productive learning environment including norms, expectations, routines, and organizational structures;

iii. Critical Dispositions:

(2) The teacher values the role of learners in promoting each other's learning and recognizes the importance of peer relationships in establishing a climate of learning;

(3) The teacher is committed to supporting learners as they participate in decision-making, engage in exploration and invention, work collaboratively and independently, and engage in purposeful learning; and

(4) The teacher seeks to foster respectful communication among all members of the learning community

Council for the Accreditation of Education Professionals (2013)[2]

Standard 1: Candidate Knowledge, Skills, and Dispositions

1.1 Content Knowledge and Pedagogical Knowledge

1.2 Instructional Practice

- Learning Experiences

Course Catalog Description:

This course presents science as an integrated body of knowledge using investigative and inquiry techniques. Thematic or problem-based approach to science teaching. Impact on the elementary school of new developments in science and new refinements in the teaching of science; emphasis on content, method, material, and general curricular implications.

Other description of course purposes, context, methods, etc.:

The goals of the course include the following:

- As future teachers, students will be introduced to hands-on experiences that encourage them to teach science topics that are appropriate for elementary level students, and can be modified for diverse learners.
- Together as a class, we will consider ways that selected topics in the physical, life and earth systems sciences can be presented to students at the pre-school through elementary level. We will also consider how these topics influence everyday life.
- Students will be introduced to, and have the opportunity to use, pedagogical techniques that foster inquiry approaches to science teaching.
- Students will become familiar with the National Science Standards including the Next Generation Science Standards (NGSS) with emphasis on science practices and content, and consider how fields such as literacy, language arts and mathematics can be integrated into science lessons and/or units.
- Together as a class, we will consider ways to enhance elementary student learning outcomes using research based approaches.

Class materials each student needs to have/buy/bring to class:

- Additional readings (will be available on the course website, save a copy on your computer or print)
- Next Generation Science Standards (save a copy on your computer)
- New Jersey Core Science Standards (save a copy on your computer)

Grading and Activities

Your course grade will be based on several different items. This syllabus offers an outline of the items, however it is not set in stone and adjustments may be made throughout the semester in order to meet our needs. You will be informed of any changes either in class or by email.
Hard work, attendance to all classes, completion of all the assignments, participation in class activities/discussions and resubmission of the assignments are all factors considered for the attribution of the final grade for this course. To obtain full credit for any academic task, each student must show signs of dedication to extending his/her scientific knowledge as well as constant academic effort aimed toward improvement and individual scientific knowledge and skills development. The more work you dedicate to the course, the more you will get out of it. Below is an outline of class activities. The goals of this course are to learn and practice techniques for teaching and transition from student to teacher and each assignment is designed to help you meet these goals. **Therefore, each assignment can be improved by submitting the assignment again, and I encourage you to do so**. After you submit each assignment, it will be scored, and feedback may be provided (depending on assignment). Once the assignment is returned to you, you may then work to improve it. All resubmissions are due before the next class after the work is returned

Activities points	
Weekly checkpoints	15
Weekly Quizzes	10
Lesson Plays (2 times throughout the semester)	20 (10 points each)
Lesson Plan	10
Unit Plan with assessment	15
Teaching and teaching preparation	10
Pre-reflection and final reflection	15
Science Surveys	5
Total	**100**

The grade breakdown is as follows:

A – 90 - 100
B+ - 85 - 90
B – 80 - 85
C+ - 75 - 80
C – 70 - 75
D – 65-60

Description of Activities

Participation in class discussions:
Class work will be primarily group work. You will work to explore and learn various components of science that is often taught at the elementary and middle school level. At the same time you will learn how students construct similar concepts. We will also discuss the readings that you will do at home.

Try not to miss any class meetings because it will be difficult (almost impossible) to learn the material on your own. You are welcome to express an opinions you have and ask questions regarding the materials but make sure this is done in a respectful and professional manner. You are expected to show up, contribute to discussions, use technology for classwork, and stay off you cell phone while in the classroom. If you need to miss class for any reason, please email me as soon as possible. Unsatisfactory participation and **any** unexcused absences will negatively affect your course grade.

Weekly homework assignment:
Each week you will complete a homework assignment related to one of the topics we discussed in class. Most weeks, you will be responsible for complete a part of a lesson plan related to the content covered. Each week, the homework is due on **Wednesday** by midnight. It should be **uploaded to Google Classroom**. Once we receive it, we will provide feedback and upload it back to your Dropbox. You may be asked to do revisions. Revisions are due by the next class.

Quizzes:
At the beginning of each class, you will take a short quiz. Each quiz will address one or more standards and be related to science content. You will receive the your scored quiz by Wednesday. It is your responsibility to make any corrections to the quiz and resubmit it by the next class. If you have any questions regarding your quiz, we can talk about it during office hours.

When resubmitting an assignment, you must do three things:

1) Identify the difficulty you had
2) Provide a new answer
3) Explain why this answer is correct

Lesson Plays:
Two times throughout the semester, you will be asked to write a lesson play for a prompt given in class. This assignment is designed to get you to consider the dialogue through which you will engage students in thinking about and practicing science and to consider how your students' thinking will be expressed and guided through interactions with peers and with the teacher. Full directions for this assignment will be given in class.

Lesson plans and teaching:
You will compose two lesson plans of elementary school length (approximately 30 minutes) for this course. The first lesson plan will be submitted for review and feedback. The second lesson will be graded and delivered in class. You will create a lesson plan, teach the lesson, and then revise the lesson plan after receiving feedback from your classmates and the instructor. The final lesson plan will be in the GSE format (with some modifications) and will be posted on the course website so that your classmates can use it. Both will be present in the Unit Plan.

Unit Plan:
You will be required to create a unit plan with a final assessment (rubric, test, or performance task). You will include as many lessons as are necessary to comprehensively teach the concepts within the unit (including revised Lesson Plans). More information will be provided in class.

Pre-reflection and final paper:
At the beginning of the course, you will be asked to write a reflection (approximately 2-3 double spaced pages) on your experiences with learning science. Upon completion of the last class, you will write a final reflection in which you will describe your philosophy of teaching science, and how your philosophy has changed throughout the semester. This paper should be approximately 4-5 double spaced pages in length.

<u>Check your e-mail & Google Classroom regularly</u>. I will use Google Classroom to make class announcements and e-mail to contact you individually. You will need to pay attention to these announcements/emails in a timely fashion. If you do not usually use your Rutgers e-mail account, be sure that you have set it to forward to the account that you do check.

Week	**Teaching Science Pedagogical Topic**	**Science Content Topic/Guiding Questions**	**Readings** (Readings are aligned with the week's content and should be read prior to class.)
1	Course Introduction The Nature of Science & The Goals of Science Education The Structure of Scientific Knowledge	***Doing* Science** Content-related: How can scientific models be used to understand students' thinking? Pedagogical: How can teaching practices facilitate opportunities for students to think like scientists?	Syllabus
		Physical Science	
2	Standards Learning Progressions	**Matter** Content-related: How can evidence be used to construct ideas?	Michaels, et al. *Ready, Set, Science!* Chapter 1

	CHOOSE UNIT TOPIC	Pedagogical: How teachers help students reason through scientific problems? What are learning progressions?	Cummins, *Reading About Real Scientists* Miele, *Using Draw-a -Scientist Test for Inquiry and Evaluation* *Teachers' Attitudes About Science* article *NGSS K-2, 3-5 Storylines*
3	Inquiry-based Science Teaching	**Motion** Content-related: What can be learned from the development and testing of different investigation designs? Pedagogical: How can teachers merge science content with science practices?	Colburn, *An Inquiry Primer* Michaels, et al. *Ready, Set, Science!* Chapter 4 Lott & Wallin, *Modeling the States of Matter in a 1st Grade Classroom* Danielson, *Framework for Teaching: Domain 2a&b*
4	Goal Setting Objective & Assessment Alignment	**Dynamics** Content-related: How can observing and measuring patterns of phenomena help to predict future occurrences? Pedagogical: How do questions facilitate learning? How do teachers assess during learning?	Marshall, *In Step with the New Science Standards* Roseman & Koppal, *Aligned or Not?* Danielson, *Framework for Teaching: Domain 1a-e*
5	Unit Planning & Question Types/Techniques	**Dynamics 2** Content-related: What is force? Pedagogical: How do questions facilitate learning? How do teachers assess during learning?	Wiggins & McTighe, *Understanding by Design Framework* Hus & Aberšek, *Questioning as a Mediation Tool* Danielson, *Framework for Teaching: Domain 3b*
		Earth Science	
6	Lesson Plans: Evaluating Modifying Pre-made Plans	**Light/Night and Day** Content-related: How can 3D models be used to investigate scientific phenomena that cannot be explored through experimentation?	Windschitl, *Why We Can't Talk to One Another About Science Education Reform* Michaels, et al. *Ready, Set, Science!* Chapter 6

		Pedagogical: How can content and practice be integrated through goal setting? How does creating models influence students' thinking?	
7	Evaluation & Assessment	**Phases of the moon** Content-related: How can 3D & 2D models be used to investigate scientific phenomena that cannot be explored through experimentation? Pedagogical: How can student generated questions guide instruction?	Johnson, Uline, & Perez, *The Quest for Mastery* Danielson, *Framework for Teaching: Domain 1f & 3d* **Lesson Play 1 Due**
8	Assessment Design	**Seasons** Content-related: How can the examination of evidence help students to understand science? Pedagogical: How can you differentiate instruction for a diverse student population?	Michaels, et al. *Ready, Set, Science!* Chapter 2 Plummer, Davis, & Brazier, *Linking Science & Literacy*
		Life Science	
9	FOSS Kits	**Seeds** Content-related: How can observations plants and animals be used to classify/organize them? Pedagogical: How can you make prepackaged science programs more inquiry-based?	Bryce, *Meeting the Reading Challenges of Science Textbooks in the Primary Grades* **Lesson Plan 1 Due**
10	Teaching Diverse Learners	**Genetics and Heredity** Content-related: What can observations and analysis of animals' observable traits tell about the relationships among animals and their environments? Pedagogical: What should science teachers consider when choosing resources to support students' learning?	Kohn, *The Case Against Grades*

11	Reflection & Metacognition: Self-Reflection and Student to Teacher Reflection	**Energy** Content-related: What kinds of resources/evidence should scientists use to examine how scientific phenomena? Pedagogical: In what ways can cross-cutting concepts be revisited in different disciplines?	Danielson, *Framework for Teaching: Domain 4* **Lesson Play 2 Due**
12	Authentic Instruction and Assessment	**Engineering** Content-related: How can knowledge and understanding of scientific phenomena be used to solve authentic science- and engineering-based problems? Pedagogical: How can students practice authentic application of science content, practices, and engineering skills?	
13	Teacher Evaluation	**Teaching Day 1**	AchieveNJ: NJ Department of Education http://www.nj.gov/education/AchieveNJ/ **Lesson Plan 2 Due one week after teaching**
14	Teacher Evaluation	**Teaching Day 2**	**Lesson Plan 2 Due one week after teaching**
15			**Unit Plan Due**

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Academic integrity is essential to the success of the educational enterprise and breaches of academic integrity constitute serious offenses against the academic community. Every member of that community bears a responsibility for ensuring that the highest standards of academic integrity are upheld. Only through a genuine partnership among students, faculty, staff, and administrators will the University be able to maintain the necessary commitment to academic integrity.

The University administration is responsible for making academic integrity an institutional priority and for providing students and faculty with effective educational programs and support services to help them fully understand and address issues of academic integrity. The administration is also responsible for working with other members of the academic community to establish equitable and effective procedures to deal with violations of academic integrity.

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Any involvement with cheating, the fabrication or invention of information used in academic exercise, plagiarism, facilitating academic dishonesty, or denying others access to information or material may result in disciplinary action being taken at either the college or university level. Breaches of academic integrity can result in serious consequences ranging from reprimand to expulsion.

http://senate.rutgers.edu/FinalInterimAcademicIntegrityPolicy.pdf

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Appendix B **The Lawson Test of Scientific Reasoning**

1. Suppose you are given two clay balls of equal size and shape. The two clay balls also weigh the same. One ball is flattened into a pancake-shaped piece. *Which of these statements is correct?*

   a. The pancake-shaped piece weighs more than the ball
   b. The two pieces still weigh the same
   c. The ball weighs more than the pancake-shaped piece

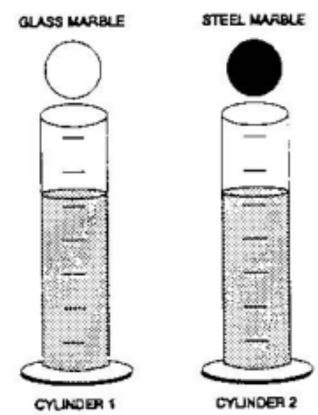
2. *because*

   a. the flattened piece covers a larger area.
   b. the ball pushes down more on one spot.
   c. when something is flattened it loses weight.
   d. clay has not been added or taken away.
   e. when something is flattened it gains weight.

3. To the right are drawings of two cylinders filled to the same level with water. The cylinders are identical in size and shape.

   Also shown at the right are two marbles, one glass and one steel. The marbles are the same size but the steel one is much heavier than the glass one.

   When the glass marble is put into Cylinder 1 it sinks to the bottom and the water level rises to the 6th mark. *If we put the steel marble into Cylinder 2, the water will rise*

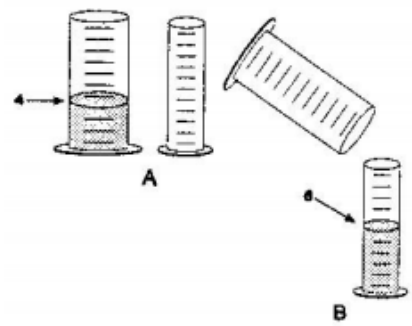


   a. to the same level as it did in Cylinder 1
   b. to a higher level than it did in Cylinder 1
   c. to a lower level than it did in Cylinder 1

4. *because*

   a. the steel marble will sink faster.
   b. the marbles are made of different materials.
   c. the steel marble is heavier than the glass marble.
   d. the glass marble creates less pressure.
   e. the marbles are the same size.

5. To the right are drawings of a wide and a narrow cylinder. The cylinders have equally spaced marks on them. Water is poured into the wide cylinder up to the 4th mark (see A). This water rises to the 6th mark when poured into the narrow cylinder (see B).



Both cylinders are emptied (not shown) and water is poured into the wide cylinder up to the 6th mark. *How high would this water rise if it were poured into the empty narrow cylinder?*

a. to about 8
b. to about 9
c. to about 10
d. to about 12
e. none of these answers is correct

6. *because*

a. the answer can not be determined with the information given.
b. it went up 2 more before, so it will go up 2 more again.
c. it goes up 3 in the narrow for every 2 in the wide.
d. the second cylinder is narrower.
e. one must actually pour the water and observe to find out.

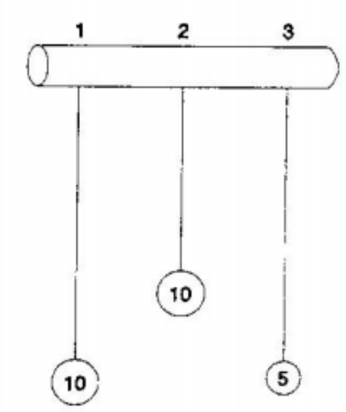
7. Water is now poured into the narrow cylinder (described in Item 5 above) up to the 11th mark. *How high would this water rise if it were poured into the empty wide cylinder?*

a. to about 7 1/2
b. to about 9
c. to about 8
d. to about 7 1/3
e. none of these answers is correct

8. *because*

a. the ratios must stay the same.
b. one must actually pour the water and observe to find out.
c. the answer can not be determined with the information given.
d. it was 2 less before so it will be 2 less again.
e. you subtract 2 from the wide for every 3 from the narrow.

9. At the right are drawings of three strings hanging from a bar. The three strings have metal weights attached to their ends. String 1 and String 3 are the same length. String 2 is shorter. A 10 unit weight is attached to the end of String 1. A 10 unit weight is also attached to the end of String 2. A 5 unit weight is attached to the end of String 3. The strings (and attached weights) can be swung back and forth and the time it takes to make a swing can be timed.



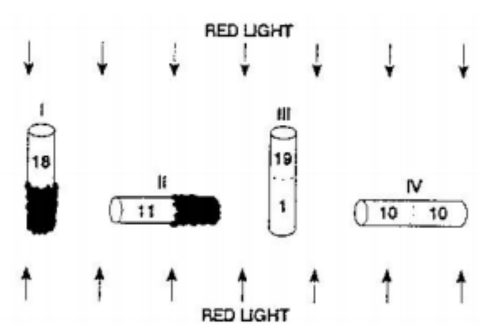
Suppose you want to find out whether the length of the string has an effect on the time it takes to swing back and forth. *Which strings would you use to find out?*

a. only one string
b. all three strings
c. 2 and 3
d. 1 and 3
e. 1 and 2

10. *because*

a. you must use the longest strings.
b. you must compare strings with both light and heavy weights.
c. only the lengths differ.
d. to make all possible comparisons.
e. the weights differ.

11. Twenty fruit flies are placed in each of four glass tubes. The tubes are sealed. Tubes I and II are partially covered with black paper; Tubes III and IV are not covered. The tubes are placed as shown. Then they are exposed to red light for five minutes. The number of flies in the uncovered part of each tube is shown in the drawing.



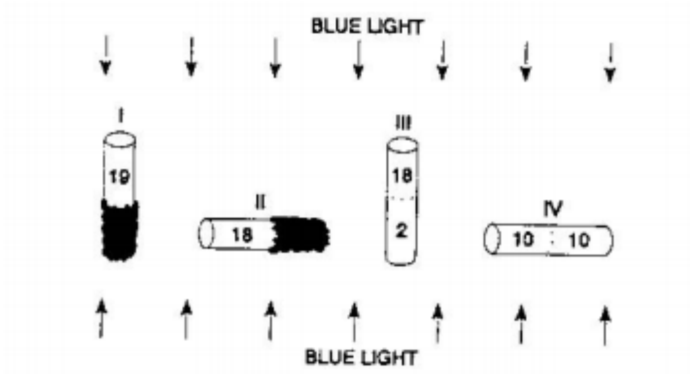
This experiment shows that flies respond to (respond means move to or away from):

a. red light but not gravity
b. gravity but not red light
c. both red light and gravity
d. neither red light nor gravity

12. *because*

a. most flies are in the upper end of Tube III but spread about evenly in Tube II.
b. most flies did not go to the bottom of Tubes I and III.
c. the flies need light to see and must fly against gravity.
d. the majority of flies are in the upper ends and in the lighted ends of the tubes.
e. some flies are in both ends of each tube.

13. In a second experiment, a different kind of fly and blue light was used. The results are shown in the drawing.



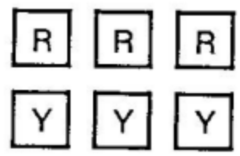
These data show that these flies respond to (respond means move to or away from):

a. blue light but not gravity
b. gravity but not blue light
c. both blue light and gravity
d. neither blue light nor gravity

14. *because*

a. some flies are in both ends of each tube.
b. the flies need light to see and must fly against gravity.
c. the flies are spread about evenly in Tube IV and in the upper end of Tube III.
d. most flies are in the lighted end of Tube II but do not go down in Tubes I and III.
e. most flies are in the upper end of Tube I and the lighted end of Tube II.

15. Six square pieces of wood are put into a cloth bag and mixed about. The six pieces are identical in size and shape, however, three pieces are red and three are yellow. Suppose someone reaches into the bag (without looking) and pulls out one piece. *What are the chances that the piece is red?*

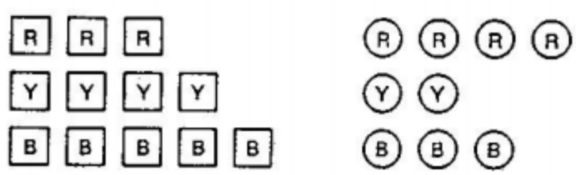


a. 1 chance out of 6
b. 1 chance out of 3
c. 1 chance out of 2
d. 1 chance out of 1
e. cannot be determined

16. *because*

a. 3 out of 6 pieces are red.
b. there is no way to tell which piece will be picked.
c. only 1 piece of the 6 in the bag is picked.
d. all 6 pieces are identical in size and shape.
e. only 1 red piece can be picked out of the 3 red pieces.

17. Three red square pieces of wood, four yellow square pieces, and five blue square pieces are put into a cloth bag. Four red round pieces, two yellow round pieces, and three blue round pieces are also put into the bag. All the pieces are then mixed about. Suppose someone reaches into the bag (without looking and without feeling for a particular shape piece) and pulls out one piece.



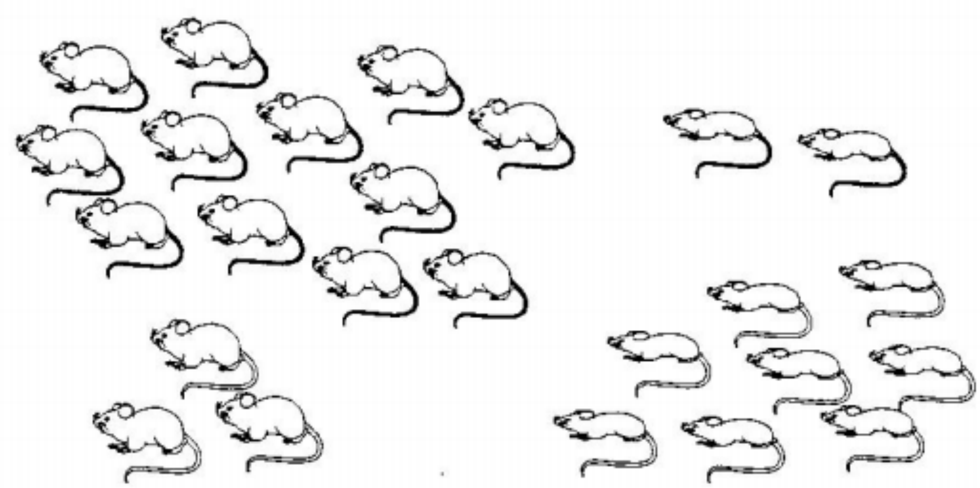
What are the chances that the piece is a red round or blue round piece?

a. cannot be determined
b. 1 chance out of 3
c. 1 chance out of 21
d. 15 chances out of 21
e. 1 chance out of 2

18. *because*

a. 1 of the 2 shapes is round.
b. 15 of the 21 pieces are red or blue.
c. there is no way to tell which piece will be picked.
d. only 1 of the 21 pieces is picked out of the bag.
e. 1 of every 3 pieces is a red or blue round piece.

19. Farmer Brown was observing the mice that live in his field. He discovered that all of them were either fat or thin. Also, all of them had either black tails or white tails. This made him wonder if there might be a link between the size of the mice and the color of their tails. So he captured all of the mice in one part of his field and observed them. Below are the mice that he captured.



Do you think there is a link between the size of the mice and the color of their tails?

a. appears to be a link
b. appears not to be a link
c. cannot make a reasonable guess

20. *because*

a. there are some of each kind of mouse.
b. there may be a genetic link between mouse size and tail color.
c. there were not enough mice captured.
d. most of the fat mice have black tails while most of the thin mice have white tails.
e. as the mice grew fatter, their tails became darker.

Appendix C

CONSENT FORM

Title of the Study: Preparing Preservice Elementary Teachers to Teach Science

Principal Investigator: Amy Lewis (phone: (908) 763-7160, email: amy.lewis@gse.rutgers.edu)

DESCRIPTION OF THE RESEARCH

You are invited to participate in a research study about preservice teachers' experiences in a co-taught elementary science methods course. The purpose of the research study is to learn about students' perceptions of a co-taught methods course aimed at merging the teaching of science and elementary teaching methods. We are interested in learning about what you learn and what aspects of the curriculum and instructional methods you feel help you to learn. You have been asked to participate because you are a future elementary school science teacher.

Throughout the class, I will observe your interaction with your peers, take notes, and reflect on the activities and their outcomes in a journal. I will collect copies of documents including weekly checkpoints, quizzes, and course reflections. I will also consider the results of the Lawson Test of Scientific Reasoning administered at the beginning and end of the semester. Lastly, I will ask that you participate in an audiotaped focus group interview with a small group of your peers.

WHAT WILL MY PARTICIPATION INVOLVE?

If you decide to participate in this research I will ask that you permit me to use some of your coursework as part of my data collection. Specifically, your pre- and post- course Lawson Test results, weekly checkpoints, quizzes, and reflections will be used to better understand what you learn through this course.

In addition, I will ask you to participate in an audio-recorded focus group interview with a small group of your classmates. The focus group interview will be conducted by a doctoral student from the GSE and take place after the semester is over. It will take approximately one hour to complete.

ARE THERE ANY RISKS TO ME?

There is no risk to you as a participant in this study. All data collected will be secured on a password-protected computer file and pseudonyms will be used to protect anonymity. I will not share any identified data with anyone.

HOW WILL MY CONFIDENTIALITY BE PROTECTED?

This research is confidential. Confidential means that the research records will include some information about you and this information will be stored in such a manner that some linkage between your identity and the response in the research exists. Some of the information collected about you includes your gender and college major. Please note that we will keep this information confidential by limiting individual's access to the research data and keeping it in a secure location on a password-protected computer.

The research team and the Institutional Review Board at Rutgers University are the only parties that will be allowed to see the data, except as may be required by law. If a report of this study is published, or the results are presented at a professional conference, only group results will be stated. All study data will be kept for three years. While there may be publications as a result of this study, your name will not be used. If you participate in this study, I would like to be able to quote you directly without using your name. If you agree to allow me to quote you in publications, please initial the statement at the bottom of this form.

RISKS & BENEFITS
There are no foreseeable risks to participation in this study. In addition, you may receive no direct benefit from taking part in this study.

WHOM SHOULD I CONTACT IF I HAVE QUESTIONS?
If you have any questions about the study or study procedures, you may contact the principal investigator Amy Lewis at 2503 Pinhorn Dr. Bridgewater, NJ 08807, amy.lewis@gse.rutgers.edu, or at (908)763-7160. You can also contact my faculty advisor Dr. Sharon Ryan at 10 Seminary Pl. New Brunswick, NJ 08901, sharon.ryan@gse.rutgers.edu, (848)932-8080.

If you have any questions about your rights as a research subject, please contact an IRB Administrator at the Rutgers University, Arts and Sciences IRB:

Institutional Review Board
Rutgers University, the State University of New Jersey
Liberty Plaza / Suite 3200
335 George Street, 3rd Floor
New Brunswick, NJ 08901
Phone: 732-235-9806
Email: humansubjects@orsp.rutgers.edu

Your participation is completely voluntary. If you begin participation and change your mind you may end your participation at any time without penalty.

Your signature indicates that you have read this consent form, had an opportunity to ask any questions about your participation in this research and voluntarily consent to participate. You will receive a copy of this form for your records.

Name of Participant (please print): ____________________________________

__________ I agree to participate in this research study ___________ Initial

__________ I give my permission to be quoted directly in publications without using my name. ___________ Initial

__________ I give my permission to be observed regularly throughout semester. __________ Initial

__________ I give my permission to be audio-recorded during the focus group interview.

__________ Initial

Participant's Signature: ___________________________________ Date: __________

Principal Investigator Signature:______________________________Date_________

Audio/Visual Addendum to Consent Form

You have already agreed to participate in a research study entitled: *Preparing Preservice Elementary Teachers to Teach Science* conducted by Amy Lewis. We are asking for your permission to allow us to audiotape as part of that research study. You do not have to agree to be recorded in order to participate in the main part of the study.

The recording(s) will be used for analysis of the research team.

The recording(s) will include your names as you will introduce yourself on the recording to the facilitator. If you say anything that you believe at a later point may be hurtful and/or damage your reputation, then you can ask the interviewer to rewind the recording and record over such information OR you can ask that certain text be removed from the dataset/transcripts.

The recording(s) will be stored on a password-protected computer. The recordings will be kept for three years.

Your signature on this form grants the investigator named above permission to record you as described above during participation in the above-referenced study. The investigator will not use the recording(s) for any other reason than that/those stated in the consent form without your written permission.

Subject (Print) ____

Subject Signature ____________________________ Date ______________________

Principal Investigator Signature _____________________ Date __________________

Appendix D

Focus Group Guide

Welcome. Hello and welcome. My name is….. and I will be the facilitator of this focus group. Thank you for agreeing to participate in our focus group study aimed at gaining insight from your experiences as students in the *Science in the Elementary School* course. We will begin by asking you to share some of your general experiences in the course and lead to more specific questions regarding aspects of the content you learned and of the curriculum and instructional practices in the course.

In case you don't know, a focus group is one way of getting people together to discuss their perceptions, thoughts and feelings about a particular issue—in this case, the *Science in the Elementary School* course. By eliciting your views on this topic, we hope to draw conclusions about what experiences you found to be helpful to you in learning about science and how to teach science to elementary school students. We also hope we can get recommendations from you as to how the course could be improved.

Before we get started let me go over some ground rules so that everyone gets the chance to speak. As students and future educators, your opinions are very important to our topic. There are no right or wrong answers or opinions. Though you have all taken the same course, you might feel differently about your experiences or have perceived them in different ways. Please feel comfortable sharing how your experience is different or the same as someone else in the group. As much as possible, we would like you to provide examples to illustrate your answers. We need to tape-record today's focus group session so we can accurately document and convey your ideas for the purpose of this study.

Today our focus group has two foci. The first set of questions will focus on your *Science Content Knowledge and Pedagogical Content Knowledge for Teaching Science.* The second set of questions will focus on *Course Design and Instruction.* We have a list of questions (provide them with a copy) we are going to follow. We are going to go through these questions one at a time and as we are a group rather than in a one-on-one situation, we ask that one person speak at a time. Each time you answer a question, please state your name so we can identify the speakers by voice on the tape recorder. Please don't speak when someone else is speaking. Raise your hand and I will call on you at the appropriate point in the conversation. If you don't want to answer a question that's fine

So let's start with introductions. Please state your name for the tape recorder. Okay let's begin with what you have learned about science and the teaching of science to elementary school children

Content & Pedagogy for Teaching Elementary School Science

One of the goals of *Science in the Elementary School* is to combine the teaching and learning of science content with practices that model how to teach science to elementary school students. So, we'll start with what you learned with regard to science content and how you learned it.

Content

1. If you were describing this class to a student at another university what would you say about the class?

   Probes:

   - What did you learn in the class?
   - What would you say you did in the class?
   - What about the class stuck out to you?

2. Give me an example of a time when you feel like you really got a science concept in class.

   Probes:

- Describe for me what you were doing.
- What were the teachers doing?
- What were your classmates doing?

3. Which science discipline - life science, physical science, or earth science - concepts do you feel you learned the most about?

   Probes:

   - Why do you think you learned the most about that area of science?
   - Did you have a strong understanding of that area of science before taking the course?
   - Was there an area of science you wished you learned more about?

4. What were some of the barriers you experienced learning science content?

   Probes:

   - Give an example of how the course addressed the barriers.

Pedagogy

This course was also focused on teaching you about how to teach science to elementary school students so next we'll discuss what you learned about the practices and thinking involved in teaching what you learned to your future students.

5. Give me an example of a time when you really felt as though you learned something about the pedagogy for teaching science to elementary school students.

   Probes:

   - Describe how you learned this concept.
   - Why is this concept important?

6. Overall, what would you say you learned about how elementary school teachers should think about science instruction?

- What helped you to learn this?

Evaluation of Course Design and Instruction

For the next set of questions, think about the activities in which you engaged, the assignments that were required of you, and the experiences you had in a course that was co-taught.

Let's talk about the assignments for the class.

Instructional Practices

7. Describe a typical class.
8. Give some specific examples of class activities that helped you learn science.
9. How would you explain the methods used by your instructors to teach you how to teach science to elementary students? You can use specific examples from the class to explain.

   Probes

   - How did you feel about experiencing this approach as a student?
   - How do you feel about implementing this approach in your future science classroom?
10. This course was different than most you've experienced in that it was co-taught by Amy Lewis and Chris Bloom. Explain what it was like to have two instructors teach you how to teach science?

    Probes

    - How would you describe to someone else the teaching of your two instructors in this class?
11. Can you give an example of how having two instructors affected your understanding of the content presented? Explain.

12. What was it like to have two instructors evaluate your work?

13. What were some of the benefits of being taught through this approach?

14. What were some of the challenges you experienced with having two teachers?

Okay, let's talk a little more about the assignment for this course.

15. Describe some of the assignments that you were required to complete for this course.

16. Which required assignments do you feel best assessed your science content knowledge?

- Explain the assignment.
- Describe how you went about completing it.
- Tell about how you feel the instructor used it to assess your understanding.

17. Which required assignments do you feel best assessed your understanding of how to teach elementary school science?

- Explain the assignment.
- Describe how you went about completing it.
- Tell about how you feel the instructor used it to assess your understanding.

18. If you had a wish list about anything you could change about the course what would you change? Why would you suggest this change?

Before we end our conversation, we have one more question.

19. Is there anything you would like to say or suggest?

Thank You. Thank you for your time and willingness to share your thoughts.