Knowledge and Use of the Science Practices from a Content Course to Student Teaching: A Study of Preservice Elementary Teachers

by

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Dedication

To my family. Brittany, this is just one testament to the fact that when we support each other in our dreams and ambitions, we can accomplish anything. Thank you for your love, encouragement, and support. Even during one of the craziest years of our lives (2020, may you rest in peace). Matthew, Ella, Hyrum, Marcus, and Ezra, I have always defined myself as a father first. I am inspired to be more because of you and for you. You can accomplish the goals you set for yourselves and realize your dreams. Let grit, determination, hard work, and prayer be your guide.

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Abstract

The National Research Council developed a framework for science education that has become an important element in current reform efforts in science education. A major component of this framework is a set of science practices meant to be integrated with disciplinary core ideas to provide students authentic learning experiences. To better understand the connection between science practices and teaching, this study examines the knowledge and use of the practices by a group of preservice elementary teachers. While many studies have researched the practices individually or in small sets, few have looked at the practices holistically. Those that have, examined preservice teachers' knowledge and teaching either in their methods course, or a little beyond that into their first years of teaching.

This dissertation addresses this gap by looking at several science practices and tracking a group of preservice elementary teachers' engagement, knowledge, and teaching with the science practices from a physics course, through a methods course, and into student teaching. Using qualitative methods, this longitudinal study draws on lab work, participant generated lesson plans, interviews, and videorecords of teaching enactments to understand the preservice teachers' experiences and knowledge. This study follows nine participants drawn from a group of 30 preservice elementary teachers enrolled in a science methods course and who took physics either that academic year or the year before. Four of the nine continued with the study into their student teaching.

To evaluate the participants' engagement, knowledge, and use of the practices in teaching, I developed a set of rubrics to determine their level of sophistication. The participants engaged in the practices at a novice level, which was consistent with their prior experiences. For every practice, the participants understood the practices with more sophistication than they were able to engage in them. This suggests that their knowledge of the practices did not constrain their engagement. The participants' lesson planning and teaching sophistication scores were a measure of how appropriately they incorporated the practices into their lessons, aligned the practices with the subject matter, and considered the age and grade level of their students. From the beginning to the end of the study, the participants' sophistication in planning and teaching increased for three of four practices.

These findings suggest that teacher educators should consider the experiences their preservice teachers have had with the science practices. For example, many preservice elementary teachers have had few experiences with modeling, especially designing their own models. Their experiences with modeling in the physics course likely increased their knowledge of the practice, and while they did not use it often in their teaching, they did so at a strong level. Second, teacher educators should consider the possible positive effects that content courses can have when they are included within the contextual discourses of the teacher preparation program. This is especially true for elementary programs that are already pressed for time. The preservice teachers' knowledge and understanding of the practices can influence how they teach with the practices. For example, if they have a limited understanding of a practice (e.g., Data Analysis & Mathematical Thinking), they might use the practice less often with their students, or they could overestimate the abilities of their students with a practice based on their own knowledge and experience with the practice.

Chapter 1 Introduction

The *Framework for K-12 Science Education* (National Research Council, 2012), used to develop the Next Generation Science Standards (NGSS), represents a critical shift in how science should be taught throughout the United States. It is a departure from the linear and sometimes rigid view of science found in the "scientific method" (Stroupe, 2015), and offers teachers a more honest and authentic way to represent and engage students in their science classrooms. The most notable feature of this change is the concept of three-dimensional learning. Three-dimensional learning is an integration of core science standards, boundary crossing and unifying themes, and a set of authentic science practices (National Research Council, 2012). The goal is to promote active engagement in the practices of science (such as conducting investigations and using scientific models) guided by the fundamental concepts of a science discipline. These changes in science instruction are meant to be applied across all grades and all students.

This study focuses on the learning and use of the science practices by preservice elementary teachers. Roth (2014) outlined five problematic features of science in the elementary context: first, a "right-answer" focus to instruction; second, few opportunities to engage in science; third, a high priority to "like" science rather than develop knowledge; fourth, an infrequent focus on complex scientific thinking; and fifth, inequities that result in achievement gaps. More alarming is the absence of science teaching in some elementary schools. In a report by the National Survey of Science & Mathematics Education (2018), for grades K-3, 43% of teachers claimed to only teach science "some weeks, but not every week" (p. 77), and for grades 4-6, 29% of teachers made the same claim. While much of the research done on elementary science instruction is in the space of instructional strategies rather than classroom experience (Roth, 2014), there are examples of excellent elementary science teaching in the literature.

In many of these examples of excellence, authentic practices of science feature prominently. In studies of project-based learning (e.g., Bell, 2010) or the use of inquiry-based instruction (e.g., Cuevas et al., 2005; Zembal-Saul & Hershberger, 2020), researchers found that the inclusion of modeling or science investigations in elementary science classrooms helped students to improve their critical thinking skills, ability to ask appropriate questions, or draw conclusions.

Each of the gains shown by the students in these studies can be connected to science practices found in NGSS. The vision of NGSS for science teaching provides a solution for the "problematic features" defined by Roth (2014), which is to "engage [children] with fundamental questions about the world and with how scientists have investigated and found answers to those questions" (National Research Council, 2012, p. 9). This vision can be accomplished by implementing three-dimensional science learning in elementary classrooms. One of the pillars of this learning is the science practices which play a critical role in how preservice elementary teachers learn science and eventually teach it.

Defining the Problem

Preservice teachers enter their methods courses having experienced different approaches to teaching throughout their education. These experiences often become a part of the preservice teachers' future pedagogy (Lortie, 1975). It is important for teacher educators to know what experiences their preservice teachers have had and how those experiences could be connected to their current instruction (Ricketts, 2014). In this study, I focus on the knowledge and experience that a group of preservice elementary teachers had in science by studying how they performed in an investigation-based physics content course that intentionally called out the science practices. The study follows these preservice teachers into their science methods course and student teaching experience to track how their use and understanding of the science practices evolved over time.

Engaging in the science practices requires complex thinking and reasoning skills that have not been present in traditional science classrooms (Tekkumru-Kisa et al., 2015). One reason for this is the science practices are a move away from the linear model of science found in the scientific method (Ford, 2015; Osborne, 2014b). According to Osborne (2014b), "the primary purpose of engaging in practice is to develop students' knowledge and understanding required by that practice, how that practice contributes to how we know what we know, and how that practice helps to build reliable knowledge" (p. 189). This illuminates two purposes for use of the practices in the classroom. The first is to develop knowledge and understand content, and the second is to learn how a specific practice is able to develop that knowledge. The science practices also help students better understand the nature of science (Osborne, 2014a), and to better understand and identify with the science community (Stroupe, 2014) among other things.

One critique of science instruction in schools is that it often does not portray "authentic" science practice (Abd-El-Khalick et al., 2004). Mody (2015) noted that the science taught in schools is often too ordered. He said, "scientific practice, it turns out, is messy and contradictory" (p. 1027). Mody (2015) continued to reason that the "messier" version of science practice would do a better job of preparing students for future careers in science. Authentic experiences in science also helps students to develop their ability to reason (Passmore et al., 2014). The issue of authenticity plays out in two different ways in this study. First, I track how the preservice teachers engaged with the science practices during the physics course. Second, I evaluate the types of experiences with the science practices they prepared and taught their own students during their science methods course and student teaching.

This study also tracks the preservice teachers over time and across different contexts. Thompson and colleagues (2013) mention that few studies have traced the development of ambitious practice "across the institutional and social contexts that make up preservice preparation" (p. 575). This also applies to tracking how knowledge of the science practices is developed over time (Schneider & Plasman, 2011). I hope to add to this literature base as I track the preservice teachers' sensemaking and use of the practices through their program.

Research Questions and Study Overview

While science in the classroom may not be completely authentic, "students can be taught, in some basic form, scientifically powerful ways of reasoning and acting that capture what is particular about science" (Ford, 2015, p. 1041). This applies to both the preparation of preservice teachers while they learn science and to the future lessons they will teach. Helping preservice teachers to reason and act in that way is why engaging in the science practices matters. Having these kinds of near-authentic experiences as students can prepare preservice teachers to better enact those practices with their own students.

In this study I followed preservice elementary teachers through a physics course I taught, through their science methods course that I assisted with, and through their student teaching. At the time of the physics course, I selected nine preservice teachers to be the focus of the study. Four of these nine were able to continue with the study through to the end of their student teaching. To better understand what experiences the preservice teachers had with the science practices and how they planned on using the practices in their teaching, I ask the following questions:

1) *How do the preservice elementary teachers engage in the science practices while they are learning science content?* To study how the preservice teachers engaged in the science practices, I developed a set of rubrics based on the grade-level progressions found in the *Framework for K-12 Science Education* (National Research Council, 2012) and relevant literature. I used this framework to score each focal participant's engagement through analysis of their lab sheets in the physics class supported by video records of their engagement in select labs.
2) *How do the preservice elementary teachers make sense of the science practices while they are learning science content?* To study the preserve teachers' sensemaking about the science practices, I wrote a set of questions probing the preservice teachers' knowledge and placed them in post-lab reflections for the physics class. I also asked them direct questions about their experiences with and understanding of the practices in their interviews at multiple timepoints. In this section, I use the Content Knowledge for Teaching framework (Ball et al., 2008) to characterize the preservice teachers' understanding and knowledge. Last, I used the rubrics to score their knowledge of the practices to use in later comparisons.
3) *How do the preservice elementary teachers use the science practices in their lesson plans and enactments? How does that use change over time and from one context to another? How do the lesson plans and enactments showcase the sensemaking that the preservice elementary teachers have about the science practices?*

To understand how the preservice teachers planned with and used the science practices in teaching, I drew on data from each phase of the study (physics course, science teaching methods, and student teaching). I analyzed their lesson plans and video records of instruction using the Knowledge of Content and Teaching and Knowledge of Content and Students sub-sections of the Content Knowledge for Teaching framework, (Ball et al., 2008). I also applied an adjusted version of the rubrics I designed for the engagement in the practices to see at what level they planned to engage their own students and if this changed over time. Last, I used questions in the interviews to explore why the preservice teachers made the instructional choices they did with the science practices in their lessons.

4) *How do the preservice teachers make sense of how their use of the science practices in instruction promotes student learning? How do these views change over time and from one instructional context to another?* To answer this question, I asked the preservice teachers this question directly in their interviews. After open coding their responses, I looked for patterns in how each of them connected the science practices to student learning to see if those patterns changed over time.

Overview of the Findings and Following Chapters

In my analysis, I used the rubrics I developed to study the preservice teachers' engagement with, knowledge of, and use of the science practices in lesson plans and teaching. This allowed me to make comparisons between these different aspects of the preservice teachers' experience. I found that in every case the preservice teachers' knowledge was higher than their engagement. Looking across each of the science practices, the focal participants' engagement averaged around the novice level which aligned with their prior experiences with science instruction. General engagement at this level can be described as a focus on basic functions of the practice (e.g., making a prediction without justification, collecting data that is clear but without the use of multiple trials or not sufficient to strongly support a claim). Their teaching with the practices shifted from the beginning of the study to the end, becoming more sophisticated. In the end, their prior experiences and current understanding of the science practices seemed to influenced how they aligned the practices with the subject matter they taught and at what level they chose to engage their students in the practices. These relationships clearly play out in the case studies presented in Chapter 8.

Chapter 2 outlines the literature that supports this work and describes the science practices. The chapter concludes with a description of the theoretical framework that guides this study, as well as the constructs I use to understand the preservice teachers' knowledge. Chapter 3 details the methods, context of each phase, the participants, data sources, and the coding and analyses of the data. The data sources include course materials (e.g., student lab sheets, student reflections), interviews, student lesson plans, and video records of enactments. Chapters 4, 5, 6, 7, and 8 outline the findings derived from the analysis of the data. Specifically, Chapter 4 shows what opportunities the preservice teachers had to engage in the science practices and at what level they engaged in those practices based on their rubric scores. Chapter 5 breaks down how the preservice teachers made sense of the science practices while they were learning the content. It showcases their understanding of each practice by organizing their comments by science practice and their related sub-practices. Chapter 6 describes how the preservice teachers used the science practices in their lesson plans and enactments over time. I also score the use of the practices in teaching with an adjusted version of the rubrics and compare those scores to the ones in the previous chapters. I detail how their use of the practices connects to their overall sensemaking about the science practices. Chapter 7 explains how the preservice teachers make sense of how their use of the science practices connects with student learning and how these views change over time. Chapter 8 presents the cases of two participants from the study and compares their understanding and use in instruction of one of the practices to see how a participant's knowledge and engagement connect to instruction on an individual basis. Finally, Chapter 9 presents a discussion that connects the findings from the previous chapters with the literature, as well as the illuminating contributions the study makes to the field.

Chapter 2 Literature Review and Theoretical Framework

In this chapter, I describe some of the key elements of science teacher preparation and argue for the need for coherence across preservice teachers' experiences. Next, I turn to the science practices, specifically, as one key element of the vision of the NGSS about which preservice teachers need to learn. From there, I review the literature on how preservice elementary teachers have engaged in and used the science practices. Next, I outline the theoretical framework I use to understand the use of science practices in the classroom and how I conceptualize teacher knowledge. Finally, I show how I define the science practices in this study.

Science Teaching Preparation for Preservice Elementary Teachers

The foundation of a preservice elementary teacher's science preparation is the science methods course. These courses vary from one university to another in terms of central themes and goals. For example, some science methods courses focus on the nature of science (e.g., Akerson et al., 2006), inquiry-oriented teaching (e.g., Davis & Smithey, 2009), or spiral-based inquiry teaching (e.g., Kelly, 2001). Despite slight variations in theme, methods courses are responsible for teaching science specific pedagogy, equitable science teaching practices, and giving preservice teachers opportunities to practice teaching among other things.

As an example of an elementary science methods course, Schwarz (2009) engaged her preservice teachers in modeling-centered scientific inquiry which emphasizes "creation, evaluation, and revision of scientific models that can be applied to understand and predict the natural world" (p. 722). Schwarz's preservice teachers used computer simulation software to investigate solar system motion and electricity, engaging with the phenomenon as students learning science. Engaging preservice teachers in authentic science practice in the role of students is a unique and needed feature in science teacher training (Capps & Crawford, 2013; Newman et al., 2004). These preservice elementary teachers also prepared and taught lesson plans that included the modeling software they experienced in field placement classrooms. In essence, preservice teachers in this methods course experienced modeling-centered scientific inquiry in the role of a student, and then used that experience to develop and teach science lessons of their own. Learning to teach science in this way connects experiences the preservice teachers have as students directly to their own teaching.

A unique feature of Schwarz's program is a second science methods course. This is notable because a single methods course is often not enough to develop and maintain rich understanding (Akerson et al., 2006). In programs with one methods course, gains made by preservice teachers can fall away by the end of the following semester. This contributes to the troubles preservice teachers have when they first attempt to apply their new skills to the complex contexts of public-school classrooms, often called "problems of enactment" (Kennedy, 1999). How then can elementary education programs that are pressed for time support their preservice teachers to enact reform-based science teaching?

To answer the above question, the work of Thompson and colleagues (2013) provides a helpful framework. These researchers refer to "contextual discourses" (p. 575), which are different or competing norms and teaching practices that preservice teachers negotiate. These norms and teaching practices have many sources including methods courses, content courses, field placements, mentor teachers, etc. Within this framework, preservice teachers adopt different norms and teaching practices to develop their own pedagogical discourse that informs their science teaching practice. These pedagogical discourses are a manifestation of "consistent patterns of participant talk in which the roles, identities, and responsibilities of actors … are conceptualized and negotiated within frameworks of loosely articulated theories about ‘what counts’ as knowing, learning, and effective teaching” (Thompson et al., 2013, p. 579). A possible solution for the lack of time experienced by many elementary education programs could be to align the contextual discourses of the program’s coursework. One of these spaces is the science content courses. If the norms and teaching practices of the content courses could be better aligned with the contextual discourse of the methods course, the preservice teachers might build a more coherent pedagogical discourse for their science teaching.

For most preservice teachers, their content coursework only reinforces the poor “apprenticeship of observation” (Lortie, 1975) they built about science teaching from their years of being students in different science classrooms. Fortunately, there are cases where education programs have leveraged content courses to better prepare their preservice teachers. For example, in a life science course, Haefner and Zembal-Saul (2004) studied preservice elementary teachers who “worked in small groups to design and conduct science investigations … based on questions they developed about insect cultures” (p. 1656). They found that after eight weeks, the preservice teachers placed greater emphasis on experimental design and scientific investigations. In another setting, an integrated Earth science and physics course for preservice elementary teachers, researchers changed the curriculum of the traditional science classes. This included an emphasis on the connections between Earth and physical science as well as including more inquiry-based instruction (Plotnick et al., 2009). The course designers wanted to model instruction that would be meaningful for the preservice teachers and their future teaching. They found that there is a delicate balance between the depth and breadth necessitated by the college level content and the future teaching needs of preservice teachers.

In the two content course examples above, preservice teachers learned science content in a context intentionally designed to highlight teaching practices or reform-based teaching. These courses better prepared the preservice teachers who took them for their science methods courses. If preservice teachers have these types of experiences, they will likely develop more coherent "contextual discourses" and be better prepared to engage their own students in the kind of science and engineering work described in NGSS -- including engaging them in the science practices, a focus that is described next.

The Science Practices

In an important shift from previous standards documents, the Next Generation Science Standards (NGSS) integrates science practices with content (NGSS Lead States, 2013). *The Framework for K-12 Science Education*, on which the NGSS are built, states: "helping students learn the core ideas through *engaging in* [emphasis added] scientific and engineering practices will enable them to become less like novices and more like experts" (National Research Council, 2012, p. 25). This is a distinct shift from how the science practices were valued in the past. Putnam and Borko (2000) stated, "how a person learns a particular set of knowledge and skills, and the situation in which a person learns, become a fundamental part of what is learned" (p. 4). Preservice teachers enter their methods courses having experienced science instruction in one form or another. Those experiences and their contexts will have an effect on their future teaching (Windschitl, 2003).

The science and engineering practices, as defined by the Next Generation Science Standards (NGSS), include eight related practices:

1) Asking questions (for science) and defining problems (for engineering)
2) Developing and using models
3) Planning and carrying out investigations
4) Analyzing and interpreting data

5) Using mathematics and computational thinking
6) Constructing explanations (for science) and designing solutions (for engineering)
7) Engaging in argument from evidence
8) Obtaining, evaluating, and communicating information (NRC, 2012)

The roots of these practices are found in previous national standards (National Research Council, 1996) linked to the "science as inquiry" section. Although science as inquiry is an important part of science education, this area of focus was placed separate from the rest of the content knowledge. Inquiry has also become a vague term that is widely and loosely applied throughout science education (Abell et al., 2006). The NGSS's *integration* of the science practices with the content makes a clear statement about how content knowledge should be experienced by students. The science practices, as well as being their own form of content knowledge are also the means by which the standard content should be learned (García-Carmona et al., 2017; Tekkumru-Kisa et al., 2015).

One of the important things that NGSS accomplished with the science and engineering practices is it makes the skills for these disciplines explicit for teachers (Antink-Meyer & Brown, 2017). In order for teachers to engage their students in these practices they must have a clear idea of what they are and also how to "execute [their] performances appropriately" (Ford, 2015, p. 1045). This means that the preservice teachers need to have had meaningful experiences with the practices themselves (Capps & Crawford, 2013; Hanuscin & Zangori, 2016). Stroupe (2015) cautions that "establishing a definition of 'science practice' does not automatically result in opportunities for students to engage in such work" (p. 1033). This means that along with the definitions of the practices, preservice teachers need to know how to use the practices to provide meaningful learning experiences for students. Teacher educators have the responsibility to help preservice teachers make connections between the experiences they have had with the practices, their knowledge of the practices, and their teaching practice.

The individual practices outlined by NGSS are not new to science education, and researchers have studied their use and implementation in various classrooms and settings. For example, with regard to Planning and Carrying Out Investigations, in a study done by Forbes and Skamp (2017) with a group of primary schools, the students identified testable questions, conducted investigations, and analyzed data for patterns. These students reported a sense of belonging to the science community. They valued student choice which they felt enabled their learning and gained an increased understanding of the nature of science. In a second study, Shim and Ryu (2017) conducted open-ended exploratory chemistry investigations with preservice elementary teachers and reported that when given the freedom to design their study, preservice teachers reported increased levels of stress. The researchers concluded that this practice required the preservice teachers' agency (to design and control experiments) to be gradually grown in order to build confidence in the new skill set.

Other practices, such as Developing & Using Models, include studies where preservice teachers used models to understand student reasoning (Lehrer & Schauble, 2000; Passmore et al., 2014), and develop learning progressions by evaluating how student models change (C. V. Schwarz et al., 2009). With the practices of Constructing Explanations and Argument from Evidence, researchers have studied the overlapping and supporting meanings of explanation and argumentation (Berland & McNeill, 2012; Osborne & Patterson, 2011), the use of technology to support students' explanations (Sandoval & Reiser, 2004), and the role of argumentation in investigations (Reiser et al., 2012). These studies highlight the way explanations or argumentation facilitate students in making sense of science content.

In each of the above studies, researchers worked with two or three of the science practices. Missing from the literature is a holistic view of preservice and novice teachers' experiences with the science practices over time. Speaking about science practice, Stroupe (2015) noted that "more studies are needed to better understand how to provide novice educators with practice-based science learning experiences and to help beginners use their science learning experiences to design similar opportunities for students" (p. 1038). These studies need to look at that development of the preservice teachers over time (Schneider & Plasman, 2011). Thus, in this study, I bring together these two issues, developing a study of preservice teachers' engagement in multiple science practices in a physics content course and following them through their methods course and into student teaching.

As I described above, how preservice teachers learn the science practices matters. Working with the science practices can be challenging. In many cases, preservice teachers have limited opportunities to engage in them, resulting in a poor initial understanding of them (Smith & Anderson, 1999; Zembal-Saul, 2009). The following section describes preservice elementary teachers' knowledge of and challenges with the science practices when working with them.

Preservice Elementary Teachers' Knowledge of and Challenges with the Science Practices

Since the release of NGSS, few science education researchers have looked at the science practices as a whole in the context of elementary science teacher preparation. In studies that have, the researchers focused on the science methods course (Hanuscin & Zangori, 2016; Ricketts, 2014), or the methods course and their first years of teaching (Bennion et al., 2020; Bismack et al., 2020). The current study includes science content coursework as well as the participants' methods and student teaching experience. Looking at the science practices more generally, Hanuscin and Zangori (2016) found three themes that connected their participants to the science practices: first, they saw them as a useful guide for planning instruction; second, as a benchmark for self-evaluation; and third, as a vision for teaching and learning science. The other studies looked at specific practices more closely and investigated the preservice teachers' preliminary understanding of the practices as well as their use of them in teaching. Ricketts (2014) looked across each of the practices the participants used in methods course lesson plans and enactments and developed a set of themes describing preliminary understandings of the science practices they had. For example, her participants struggled to understand what constituted a scientific model and how they can be used to generate data, or they viewed investigations only as experiments and did not consider the data that could be collected through observations of phenomena. Bismack and colleagues (2020) looked across a wide range of science practices and found that the participants in their study were able to leverage their pedagogical knowledge and tools (e.g., high leverage practices, back pocket questions, group work) to teach with the science practices successfully even when their understanding of the science practices might have been insufficient. Bennion and colleagues (2020) used interviews and lesson plans to examine the beliefs and planned use of the practices of novice elementary teachers. They found that their participants emphasized the cross-curricular nature of the practices as well as how the practices allow students to engage in real science. There were also instances where the participants' planned use of the practices did not yet align with their beliefs. For example, they believed that reasoning was an important part of scientific explanations but there were few instances of their use of reasoning in their lesson plans. The current study adds to these findings by expanding the scope to include the influence of a content course as well as taking data from a wide range of sources (e.g., lesson plans, student lab work, interviews, enactments).

Preservice elementary teachers face the daunting task of mastering content within each subject matter as well as training to teach children across a wide range of ages and development.

As a part of the content knowledge developed by preservice teachers, they need to know the practices of each discipline and how to engage students in those practices. In a review of science teacher education literature, Davis and colleagues (2006) outline the challenges new teachers face and what we know about their preparation. From this review, I highlight three relevant findings. First, a teacher's subject matter knowledge is related to the sophistication of their instructional practices. Second, many preservice teachers "have unsophisticated understandings of inquiry and related skills, though of course individuals vary" (p. 616). Third, at the time of the review, relatively little work had been done on science inquiry, and what they did know was that "some studies investigating preservice teachers' knowledge of science processes or thinking skills indicate that these teachers' knowledge would be inadequate to prepare them for teaching through science inquiry" (p. 617). Based on the National Science Education Standards (NRC, 1996), Davis and colleagues (2006) included in their definition of science inquiry "abilities such as questioning, predicting, explaining, and communicating findings" (p. 615). This gives the sense that many preservice teachers, especially those in the elementary field, were not being adequately prepared to engage in the kind of teaching now suggested in the *Framework* and the NGSS. More recently Stroupe (2015) also suggested that opportunities for students (at all levels) to learn the practices of science are rare. He was adamant that it will take more than just "exposing students to definitions" (p. 1036) to help them develop knowledge of the disciplinary work of science.

Furthermore, soon after the release of NGSS, Trygstad and colleagues (2013) used data from a national sample of approximately 10,000 science and mathematics teachers in grades K-12 to determine how prepared teachers were for NGSS. They found that for elementary teachers, fewer than half of them had taken at least one college course in either chemistry or physics, many self-reported that they had “perceptions of preparedness to teach science paling in comparison to reading/language arts and mathematics” (p. 4), and at the time of the study, “students may [have had] limited opportunities to engage in the scientific practices described in the NGSS” (p. 13). Limited opportunities to engage in the practices lead to a limited understanding of the practices which could inhibit their use in the classroom as a means to learn science. In a recent national survey of educators, Banilower and colleagues (2018) reported similar results (e.g., only 31% of elementary teachers have taken a course in physics, and 31% also feeling “very well prepared” to teach science). The “apprenticeship of observation” (Lortie, 1975) could also contribute to the limited use of science practices observed in the nation's classrooms. According to Lortie, teachers tend to reproduce the same educational practices they experienced as a student because that is how they learned.

These studies show that teacher educators need to pay particular attention to the science teaching preparation that preservice elementary teachers receive, including how the science practices are experienced. One way to conceptualize engagement in the science practices is through a situated perspective.

Theoretical Framework

In this section, I look at how the science practices can be situated in different settings. The settings of this study include a physics content course for preservice teachers, a science teaching methods course, and the student teachers’ field placement classrooms. I also discuss why it is important to provide authentic experiences that are guided by experts in both spaces of learning science and learning to teach science. Then, I discuss a model of knowledge for teaching that I use to describe the knowledge of the preservice teachers.

Situated Learning and the Science Practices

Mikeska and colleagues (2009) defined several problems of practice that elementary science teacher educators face. One is "engaging in science: finding ways to teach content that is meaningful and engaging to students" (p. 697). My argument is that preservice teachers who have had meaningful experiences with the science practices will be able to make science engaging in their own classrooms. To achieve this, it is important to understand what meaningful engagement looks like. One of the key aspects of this is what Brown and colleagues (1989) called "authentic activity". They explained that the "ordinary practices of the culture" (p. 7) are the only way for learners to understand the practitioner's viewpoint. Students can achieve this through a "cognitive apprenticeship", meaning they experience activities and social interaction in situations similar to those of craft apprenticeship (Brown et al., 1989). To illustrate this, Korthagen (2010) argued that knowledge cannot be transmitted to teachers, instead "learning emerges from our own actions in relation to those of others" (p. 99). He was interested in why learning opportunities like student teaching can be more salient than what happens in a typical methods course. Korthagen claimed that the learning that occurs during student teaching allows preservice teachers to be "a part of the process of participation" (Korthagen, 2010, p. 99). In a similar way, meaningful engagement in the science practices must give preservice teachers an experience that allows them to participate in the work and social interactions of science.

Lave and Wenger (1991) described this participation as "legitimate peripheral participation". This is where an individual engages with a community of practitioners and they gain skill and knowledge as they progress towards full participation in the community. Learning then becomes the process of "becoming a full participant in a sociocultural practice" (Lave & Wenger, 1991, p. 29). This appears in two different ways throughout this project. The first is within the physics classroom. As the preservice teachers had meaningful laboratory experiences and engaged in various science practices, they should move a small way toward full participation in the science community. The second scenario is the periphery of science teaching. Even in the physics course, as the preservice teachers write lesson plans, they begin their journey towards full participation as elementary science teachers. They close the gap even more during the science methods course and approach the end of their journey as they student teach and apply the science teaching pedagogy they have experienced over time. The important thing is that within each space, they have legitimate members of the community to help them move toward full participation (Lave, 1991). In the physics course, they worked with a faculty member from the physics department, and throughout their education program they have contact with several science elementary educators (e.g. methods instructor, and mentor teacher).

Sadler (2009) added “knowing and learning are not processes that transpire independent of context” (p. 2). We need to consider the context in which the preservice teachers learned the science practices. Did they learn them through authentic activities during their methods and content courses? Or, did it happen in some other, less authentic way? By authentic, I mean learning experiences that are an approximation of the work done by scientists. Unless the science practices are learned within a meaningful context, preservice teachers will have a difficult time including them in their own teaching (Capps & Crawford, 2013; García-Carmona et al., 2017). Despite the hesitancy of some scholars to accept classroom science as authentic (Hodson, 2014), students can be taught in ways that capture the essence of science (Ford, 2015). Korthagen (2010) concluded “we need a pedagogy of teacher education that combines fruitful practical experiences … [with] reflection” (p. 103). Grossman and colleagues (2009) made a similar argument when talking about teacher education. They claimed that the focus needs to shift away from curriculum and move towards developing knowledge and skill through "the process of learning to practice" (p. 274). We gain meaningful and useful skill in the opportunities we have to practice.

In the end, it matters *how* preservice teachers learned the science practices. Aligning the contextual discourses (Thompson et al., 2013) of the physics course and the methods course within a situated perspective will provide a clearer set of options for the preservice teachers as they construct their own pedagogy. This goes beyond enabling preservice teachers to better understand content, but to broaden the curriculum to include what Greeno (1997) describes as "more coherent accounts of learning":

> As we develop concepts that give more coherent accounts of learning in terms of social participation and individual identities, our contributions can be more supportive of practices in which students' participation in their learning more actively includes formulating and evaluating questions, problems, conjectures, conclusions, examples, evidence, explanations, and arguments. We can work toward developing the arrangements for this broader range of participation by students so they can understand that the skills and knowledge they are acquiring have significance. (Greeno, 1997, p. 15)

Engaging in science teaching recommended in NGSS is complementary to a situated perspective because students experience the content through legitimate practice. Preservice teachers will have a better chance of applying these practices in their teaching when the context and social interactions of their coursework are designed to approximate authentic practice and are aligned in the language and scaffolding provided. In this way, preservice teachers will have the background they need to provide similar experiences to their own students.

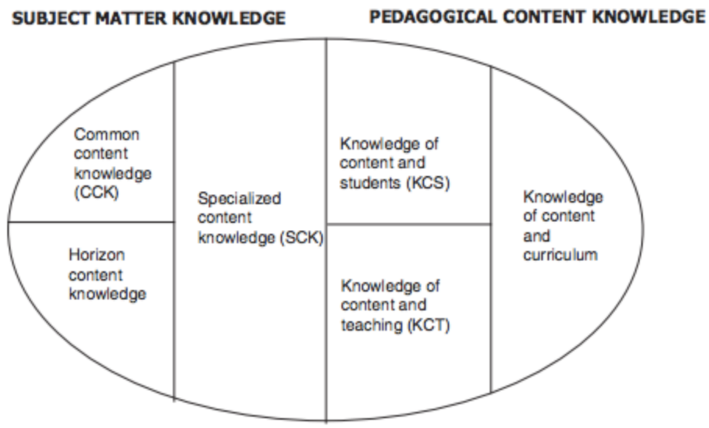
In addition to the right background and experiences, preservice teachers are also developing their knowledge for teaching during their coursework and throughout the education program. This knowledge is multifaceted and the next section explains how their knowledge connects to this work.

A Model of Content Knowledge for Teaching

Ball and colleagues (2008) developed a model to understand the domains of mathematical knowledge for teaching (see Figure 2-1). This model applies equally well for science knowledge for teaching (Bismack et al., 2020; Johnson & Cotterman, 2015; Kademian, 2017; Nixon et al., 2016). In the model, content knowledge is separated into subject matter knowledge and pedagogical content knowledge. Subject matter knowledge includes a teacher's knowledge of the substance of the subject. This includes how topics relate and progress, the practices of the community, and a unique way of knowing the content that relates to teaching. Influenced by Shulman's work, pedagogical content knowledge represents how a teacher knows and uses pedagogy to help students understand content (Shulman, 1986; Magnusson et al., 1999). The following sections show how specific elements of these two dimensions of content knowledge for teaching apply to this project, with a focus on common content knowledge (an aspect of subject matter knowledge) and a pairing of knowledge of content and teaching and knowledge of content and students (aspects of pedagogical content knowledge).

Figure 2-1

Domains of Mathematical Knowledge for Teaching (Ball et al., 2008)



Common Content Knowledge. Of the three subcategories contained within subject matter knowledge, the development of common content knowledge (CCK) is the primary objective of the physics course. Common content knowledge is defined as the knowledge and skills that are used by other practitioners (engineers, doctors, scientists, etc.) that are not associated with teaching (Ball et al., 2008). Ball and colleagues (2008) clarified that they are not suggesting that such knowledge is commonplace or generally known by everyone. CCK represents more than just the facts associated with the subject but also the practices found in the community. Unfortunately, preservice teachers have mixed experiences with the practices as a part of their subject matter knowledge training (Melville, Fazio, Bartley, & Jones, 2008). If preservice teacher subject matter knowledge training focuses on content alone, they lose the connection to the nature of science and work under the idea that science is only a body of isolated facts (NRC, 2012).

Knowledge of Content and Teaching & Knowledge of Content and Students. From the second half of Ball and colleagues' (2008) framework (pedagogical content knowledge), I am interested in knowledge of content and teaching (KCT) and knowledge of content and students

(KCS). KCT includes understanding how the design of instruction intersects with content, the selection of examples, how practices pair with content, and the dimensions of scientific literacy to be included in a unit (Ball et al., 2008; Magnusson et al., 1999), similar to a combination of what Shulman (1987) called content knowledge and curriculum knowledge. KCS combines what teachers know about their students and what they know about the content (or in this case the practices), similar to what Shulman (1987) called knowledge of learners and their characteristics. Preservice teachers explore these aspects of their knowledge as they design lessons and teach in their field placement classrooms during the science methods course. Specifically, they connect their understanding of the science practices and how they are employed by experts to different aspects of their students (e.g., adjusting the practices so they can be engaged in by children of various ages and grade levels, adjusting the practices to align with the cultures and backgrounds of their students).

One last way to characterize teacher knowledge is to examine what knowledge teachers have *FOR* practice and the knowledge they display *IN* practice (Zangori & Forbes, 2013). Preservice teachers could have well developed knowledge of a practice (similar to CCK), but that does not guarantee that they can translate that knowledge into teaching with the science practice (KCT and KCS) (Bismack et al., 2020; Davis et al., 2006; Zangori & Forbes, 2013).

Summary

The science practices play several different roles in the trajectory of preservice teachers' subject matter knowledge development. In addition to developing knowledge related to the disciplinary core ideas and crosscutting concepts, preservice teachers must learn about two aspects of CCK related to the practices (what the practices are, and how professionals engage in them). They also must develop the pedagogical parts of this knowledge (KCT and KCS) with the practices by learning how to use them effectively in the classroom. Tangled in these elements of the preservice teachers' knowledge is the situated nature of the science practices. Preservice teachers need to have had their own authentic experiences with the science practices where they were in the role of "newcomers" and guided toward full participation by an "oldtimer" (Lave, 1991). This will better position the preservice teachers to begin to play the role of the "oldtimers" when they have their own students. In this study, I investigate the nature of each of these elements so that preservice elementary teachers can be better prepared to engage in reform-based science teaching that privileges the science practices.

How the Science Practices are Defined in this Study

In this work, I studied how preservice elementary teachers engaged with select science practices prior to their teacher preparation program and how they used them in their teaching and lesson planning. In order to narrow the scope of the study, I focused on the following practices: Developing & Using Models, Planning & Carrying out Investigations, Analyzing & Interpreting Data, Using Mathematical & Computational Thinking, Constructing Explanations, and Engaging in Argument from Evidence[1].

The authors of the *Framework* deliberately designed the science practices to overlap and share common features (Ford, 2015; National Research Council, 2012). Certain practices have more in common with each other and these similarities can be seen when practitioners compare the stated goals and grade level progressions for each practice. For the purposes of coding and

[1] Although this study does not explicitly focus on the practices of Asking Questions and Obtaining, Evaluating, & Communicating Information, elements of the omitted practices are found in the included ones. For example, a main feature of Asking Questions is to have students formulate a question that can be answered empirically, this student outcome is mirrored in Planning & Carrying Out Investigations (National Research Council, 2012). In addition, parts of Obtaining, Evaluating, & Communicating Information (e.g. use tables and graphs to communicate understanding, produce oral presentations, and engage in critical reading) are found in Using Mathematical & Computational Thinking, and Engaging in Argument from Evidence. In this way, aspects of these two practices appear in this study.

data analysis, I combined Analyzing & Interpreting Data with Using Mathematical & Computational Thinking into one practice: Data Analysis & Mathematical Thinking. I also combined Constructing Explanations and Engaging in Argument from Evidence into one practice: Explanation & Argumentation.

An example of the overlap that exists in Data Analysis & Mathematical Thinking is that one of the student outcomes in the grade level progression of the original Mathematical & Computational Thinking is to have students "analyze and interpret data". When attempting to identify key elements of each of these practices, Pasley and colleagues (2016) also noted the amount of overlap present between them and how it is inauthentic to treat practices like these in isolation.

In the literature the practices of Constructing Explanations and Engaging in Argument from Evidence are often used together. Osborne and Patterson (2011) argued that there needs to be a distinction between scientific explanations and arguments, but Berland and McNeill (2012) wrote a rebuttal where they claimed the two practices are complementary and they feared that if treated separately, students may gain the impression that scientific explanations could be made without ever challenging them in argumentation. The two practices are synergistic, making engaging in them together more manageable for preservice teachers. Within the physics course, the practices were connected in a progression. Preservice teachers used the claim, evidence, and reasoning (CER) framework (McNeill & Martin, 2011) to develop scientific explanations which they later present as arguments to their peers. Within the grade level progressions of the *Framework*, the practices of Constructing Explanations and Argument from Evidence both use the CER language. One other element to consider is the experience and ability of the preservice teachers. In general, preservice elementary teachers have had little to no experience with this type of engagement in science (Ricketts, 2014; Trygstad, 2013; Zembal-Saul, 2009). Because of this, the preservice teachers can be considered novices with respect to the science practices and their initial use and engagement in these practices may make it difficult to differentiate between them. Combining these practices for coding and analysis purposes then gives me a conceptually coherent set of sub-practices to study.

In combining the above practices, I am not suggesting that educators should do so in their teaching practice. Each practice does contain unique elements which students should experience in combination with other practices depending on the circumstances of a given lesson. I only combine them in this work for the purposes of coding and data analysis.

Table 2-1 provides the definitions I used when looking for evidence of the target science practices throughout this work. The definitions are statements I adapted from the *Framework* (National Research Council, 2012, pp. 50–53) and they allowed me to be consistent in my use of the science practices across the project; these definitions guided my development of coding schemes, discussed in chapter 3.

Table 2-1

Definitions of the Science Practices Used in this Study

	Practice	Description
SP 2	Scientific Modeling	Scientists use and construct models to represent ideas and explanations, collect data, and make predictions.
SP 3	Plan & Conduct Investigations	Scientists plan and carry out investigations that are systematic with clearly defined variables or parameters by asking questions, collecting data, and making observations.
SP 4&5	Data Analysis & Mathematical Thinking	Scientists analyze data to find patterns with a variety of tools. Often this requires mathematical and computational thinking to develop representations that are meaningful in the real world.
SP 6&7	Scientific Explanation & Argumentation	Scientists produce explanations through the process of argumentation. Scientific explanations and arguments include claims, evidence, and reasoning.

In addition to the definitions in Table 2-1, I broke each of the science practices down into sub-practices using the student goals stated in the *Framework* (National Research Council, 2012) and the grade-level progressions for each practice found in *Appendix F* of the *Framework* (NRC, 2013). Table 2-2 through Table 2-5 give the descriptions of each sub-practice associated with the overarching science practice. I used these definitions to give a fine-grained view of the science practices throughout the study.

Table 2-2

A description of the sub-practices of Scientific Modeling

Sub-practice	Description
Model "OF"	Use or construction of models as representations of scientific phenomenon that can link aspects of the phenomena to the real-world.
Model "FOR"	Design or use a model for the purpose of sensemaking, data collection, making predictions, or other purpose.
Identify Models and Limitations	Distinguish between a model and the phenomenon and to discuss and evaluate the limitations of a given model. Make suggestions or redesign a model to address limitations.

Table 2-3

A description of the sub-practices of Plan and Conduct Investigations

Sub-practice	Description
Investigation Question	Formulate a question that can be investigated within the scope of a classroom or school laboratory.
Make Predictions	Make predictions about what would happen if a variable changes or regarding the outcome of observations and provide reasoning supporting the prediction.
Collect Data	Systematically collect data to serve as the basis for evidence to answer scientific questions.
Plan Procedures	Plan experimental or field-research procedures. Consider trials, controls, tools, and other appropriate elements of the investigation.

Table 2-4

A description of the sub-practices of Data Analysis & Mathematical Thinking

Sub-practice	Description
Find Patterns	Organize and analyze data systematically, either to look for patterns or to test whether data are consistent with an initial hypothesis.
Use Tools	Use tools such as spreadsheets, tables, charts, graphs, mathematics, and technology to summarize and display data for the purpose of exploring relationships between variables.
Apply Algebra	Apply techniques of algebra and statistics to represent and solve scientific problems or to characterize data.
Consider Limitations	Consider the limitations of data analysis when analyzing and interpreting data.

Table 2-5

A description of the sub-practices of Scientific Explanation & Argumentation

Sub-practice	Description
Make Claim	Make a quantitative or qualitative claim regarding the relationship between the variables or the outcome of observations.
Use Evidence	Use evidence in various forms to support scientific explanations.
Use Reasoning	Apply scientific reasoning, theory, or models to link evidence to claims.
Engage in Argumentation	Participate in (construct or listen and respond to) oral or written arguments supported by empirical evidence.
Identify/Evaluate Arguments	Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments.

In the chapter that follows, I discuss how I used these definitions of the science practices and their sub-practices in studying how the preservice elementary teachers used and engaged in them throughout the study.

Chapter 3 Methods

In this longitudinal study, I followed a group of preservice elementary teachers through their physics content course, elementary science teaching methods course, and student teaching experiences, to better understand how they engaged in the science practices and used them in their teaching. In each phase of the study, the preservice teachers engaged with the science practices in unique ways, showcasing their different types of knowledge for teaching. I used qualitative methods (e.g., interviews, analysis of videorecords, a priori and open coding) to interpret the experiences of the participants and to apply the collected data to answer the research questions. This chapter describes my design, different settings, and the research methods I used. In the following sections, I discuss the study setting and participants, as well as the role of the researcher. Then I describe the limitations, data coding and analysis, and lastly the trustworthiness of the findings. The research questions for the study are:

1) *How do the preservice elementary teachers engage in the science practices while they are learning science content?*
2) *How do the preservice elementary teachers make sense of the science practices while they are learning science content?*
3) *How do the preservice elementary teachers use the science practices in their lesson plans and enactments? How does that use change over time and from one context to another? How do the lesson plans and enactments showcase the sensemaking that the preservice elementary teachers have about the science practices?*

4) *How do the preservice teachers make sense of how their use of the science practices in instruction promotes student learning? How do these views change over time and from one instructional context to another?*

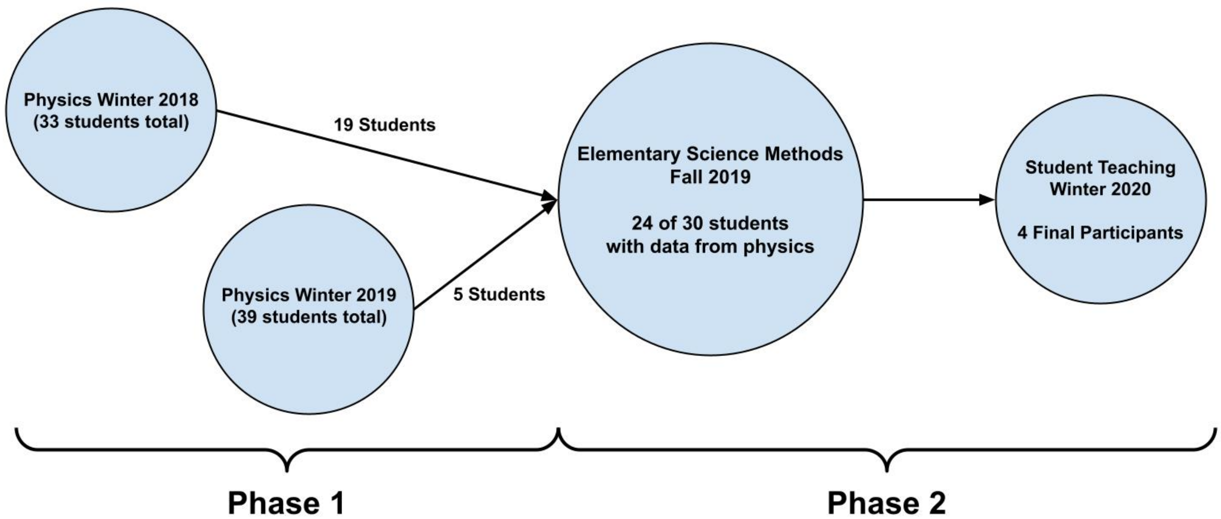
Study Setting and Participants

Overview of the Study's Phases

I completed the study in two phases. First, the participants enrolled in a physics content course designed specifically for preservice elementary teachers. They either attended this course during the 2018 or 2019 winter semester. The science teaching methods course and student teaching experience were the second phase of the study. I combined these two experiences because the number of participants who could continue with the study into student teaching was small and they did not teach the full time due to school closures because of the pandemic. The participants who took physics in 2018 as sophomores and those who took it in 2019 as juniors, took the methods course in the fall of 2019 and proceeded to do their student teaching in the winter of 2020. See Figure 3-1 for a visualization of each phase of the study and to see how the participants transitioned through from beginning to end.

Figure 3-1

Visualization of how each course fits into the two different phases of the study



The following sections give the details of the context for each phase of the study and explain how I selected the participants and who they are.

Study Contexts for the Physics Courses

The participants attended a physics course designed specifically for preservice elementary teachers with the intent to help them learn physical science content through engagement in science practice. The physics course met twice a week for an hour and a half per session. While the course content was centered on physics principles typical for an introductory physics class (e.g., Newton's laws, conservation of energy, electricity and magnetism, etc.), I designed the course to engage the preservice teachers in the science practices through daily investigation or modeling labs. A typical day in the course started with a review of the previous day's concepts via a non-graded quiz or demo. Next, the students spent the majority of the time (30 - 45 minutes) working in groups to complete the investigation. Each investigation included a short small group discussion about the students' prior knowledge of the phenomenon at the beginning. In most cases, I reserved the last 15-20 minutes of the class as a time for the groups to present and debate their findings. The preservice teachers also developed 5 science lessons plans based on the content they were studying at the time. Appendix A shows a record of the course content, lab work, and featured science practices. Across the 2018 and 2019 years, the courses were essentially the same with only minor changes made to the labs between each year.

Study Contexts for Methods and Student Teaching

The science methods course took place in the 2019 fall semester. For some of the preservice teachers, this was the semester immediately following their physics course, and for others, it was one year later. The course met weekly for 9 weeks for 3 hours each meeting. According to the course syllabus, the course goals included: teaching toward a vision of science learning described in the Next Generation Science Standards, enacting science teaching practices that make science accessible to all students, and learning to prepare, teach, and reflect on elementary science investigations. The program concurrently enrolled the preservice elementary teachers in a field placement. As a part of this field placement, they spent a few hours each week observing and teaching in local elementary classrooms.

The preservice teachers had two major teaching opportunities during the methods course (Davis & Marino, 2020). First, they planned three mini teaching experiences (which they taught in class to small groups of their peers). Each of these mini lessons made up a part of an overall science lesson designed to fit within the program's engage, experience, and explain & argue (EEE+A) framework[2] (Kademian & Davis, 2020). The EEE+A framework draws inspiration from the 5E Model (Bybee, 2009). I refer to the combination of these three mini teaching

[2] To help build continuity into the overall program, I designed the lesson plan template used in the physics course (used by the participants to write their five lessons) to mirror the EEE+A framework.

experiences as the peer teaching experience from here on. Second, the preservice teachers taught a full EEE+A science lesson in their field placement classroom. In some cases, a few of the preservice teachers could only teach a portion of the EEE+A framework (most likely the experience portion) due to time constraints in their mentor teacher's classroom. I refer to these lessons as the field lesson from here on. As a part of each of these field lessons, the preservice teachers analyzed curriculum materials, modified them to fit the EEE+A framework, taught the lesson, reflected on their teaching, and received feedback.

The following semester (winter 2020), the preservice teachers continued in their field placement classrooms taking a more active role as they began their student teaching experience. They collaborated with their mentor teacher and field instructor as they assumed all the responsibilities of a full-time teacher. The teacher education program placed the participants in elementary schools near the university. I describe the demographics of each school in the following section. Generally, each school was well resourced with not very diverse student populations. The data collection during the student teaching phase of the study was interrupted when the schools closed in March due to the coronavirus pandemic. Although I was not able to collect as much data as I would have liked during that part, most of the remaining participants had the chance to teach a little science before all of their instruction moved online. Unfortunately, many of the elementary schools quit teaching science for the rest of that year so they could support students in other subjects.

Participants and Selection of Participants

At the time the physics courses took place, the majority of the preservice teachers were sophomores with a few juniors. The majority of the preservice teachers in each section were female and white, which is typical for undergraduate elementary programs across the US. I notified the preservice teachers at the beginning of the physics course that I was working on a study and would like to use course assignments, videorecords of their course engagement, and possible interviews to better understand how aspiring teachers like themselves thought about and used the science practices. They knew that they would have a chance, once the semester was over, to opt into the study. Of those who elected to participate in interviews, I chose four participants from the 2018 course and all five from the 2019 course, knowing that only five of these participants could take the methods course the following fall. I selected the original participants based on factors that made them unique (science or math concentrators, amount of data I was able to collect, quality of their physics lesson plans, and for their level of enthusiasm for teaching science) (Stake, 2005). I refer to these nine participants as the focal preservice teachers or participants here on. Table 3-1 provides details about their backgrounds and field placements. I changed the names of the participants and schools to protect their identity.

Table 3-1

Information about the focal preservice teachers who participated in this study

Participants	Program Concentration	Prior Experience with Science Practices	Field Placement	Grade Level
Physics 2018				
Angie*	English Language Arts (ELA)	Minimal	Waldon	2nd Grade
Brad*	Science	Extensive	Barley Park	4th Grade
Edith*	ELA	Mid-level	Eaton	5th Grade
Heather	Social Studies	Mid-level	Eaton	5th Grade
Physics 2019				
Amber	Science	Minimal	Waldon	5th Grade
Emily	ELA	Minimal	Ephraim	5th Grade
Jamie	ELA	Mid-level	Waldon	Young 5
Justin*	Math	Minimal	Nickel – STEAM school	4th Grade
Morgan	Science	Extensive	Price	1st Grade

*These participants continued with the study through student teaching

I determined the focal preservice teachers' prior experience with the science practices by looking at their replies to a question in the first interview about their past experiences with science in different courses. Those in the "extensive" group (Brad and Morgan) took many science classes and qualified their past experiences as being very "hands-on" and they remembered doing a lot of investigations and lab work in class. The participants in the mid-level group (Edith, Heather, and Jamie) claimed to have had some experiences with the practices but did not take very many science courses prior to the physics class. Those in the "minimal" group (Angie, Amber, Emily, and Justin) claimed to have taken primarily lecture-based science courses or ones where they only remembered working on a lot of story problem type exercises involving a lot of math.

As the focal preservice teachers transitioned into the student teaching part of their program, I met with each one to talk about how much science they would be able to teach during the last half of the school year. (One of the focal preservice teachers decided not to continue with the study due to worries about time constraints.) I asked those who remained if they could meet with their mentor teachers to see if they would be able to teach at least three full science lessons at some time during their student teaching. Only four of the nine said that their teachers' schedules included that much science teaching during the student teaching window. This was due to different reasons. For example, some said that they taught most of the science content prior to that time and they would be focusing on social studies units. In some cases, science was a special that students had once a week with a different teacher. Last, with testing approaching, the teachers had to carve out time to prepare their students for their end of year exams.

In the end, my final sample of four preservice teachers (Angie, Brad, Edith, and Justin) was a sample of convenience (Etikan et al., 2016) because they were the only ones who would have the opportunity to teach science extensively during their student teaching. Despite this, they are a unique sample because half of them are male which is not typical for the preservice elementary teachers. I refer to these four preservice teachers as the student teaching preservice teachers (STP teachers) here on. Each of the schools they taught in were located in the same town as the university. Three of their schools shared similar student demographics (Barley Park, Waldon, Eaton: ~65% - 74% White, 9% two or more races, 5% - 9% Black, 4% - 11% Asian, 6% - 8% Hispanic)[3]. Nickel was more diverse (~55% White, 14% two or more races, 12% Black, 11% Asian, 7% Hispanic). It drew on a large community of graduate student families which allowed for greater diversity than the rest of the city. Each school had fewer than 18% of their students from low-income families. 100% of the full-time teachers at each school had certifications and at least 80% of the teachers had three or more years teaching experience. Nickel focused on science, technology, engineering, arts, and mathematics (STEAM) and built its curriculum around project-based learning.

Each of the STP teachers were in their early twenties at the time they did their student teaching. Angie and Brad took the physics class together and were lab partners throughout the course. They had backgrounds with the science practices on opposite ends of the spectrum. Brad was a science concentrator (meaning that he took more science course work as a part of his program) and Angie concentrated in English language arts. They worked well together in the labs and each made strong contributions to the physics course. Both Angie and Brad had many opportunities to teach science in their field placement classroom and designed their program's featured unit around science curriculum. Edith was in the same physics course as Angie and Brad. She concentrated in English language arts and had mid-level prior experiences with the

[3] The school and teacher information was taken from the website www.greatschools.org.

science practices before the physics course. In her field placement, her mentor teacher used science curriculum materials from *Project Lead the Way* and she planned to leverage those lessons to showcase her science teaching. Justin was the only preservice teacher from the 2019 physics course who knew he would teach a significant amount of science and could continue with the study. He had a minimal exposure to the science practices before the physics course and described his prior science experiences as being lecture based and memorizing different science facts. Justin was the only focal preservice teacher who concentrated in math, and he identified closely with the science practices related to math (Data Analysis & Mathematical Thinking). Justin's field placement in Nickel elementary was also unique because his school placed a high priority on science teaching. He designed his student teaching science unit on energy conservation and transformations and planned to have his students build small windmills to measure energy transformations and efficiency.

Role of the Researcher

My teaching background is in high school physics and astronomy. I have always been interested in engaging students in science. My teaching philosophy is that to learn science, students need to do science. The state I taught in prior to coming to graduate school had just adopted a version of the Next Generation Science Standards. I was excited by the prospect of integrating science practice with content requirements. It has been a delight to work with the preservice elementary teachers and to think about teaching science in a way different than my own experiences.

I had the dual role during this first phase of the project as a researcher and teacher of the course. While class was in session, my priority was to fill my primary role as the instructor. Collaborating with a co-instructor from the physics department, I designed each lab activity for the course. I spent my research time outside the class as I planned labs, wrote questions, and kept a log of daily activities. My intention in designing the course was to primarily attend to the learning needs of the preservice teachers and secondly to generate meaningful data for my research.

In the second phase of the study, my role shifted to primarily being a researcher. I attended each session of the science methods course and collaborated with the instructor to build in a few extra opportunities to collect data. On each of the peer teaching days, I assisted as a teacher educator. In this role, I participated as a student during the peer teaching rehearsals and provided feedback during the reflection portion of the teaching experience. During the student teaching part of phase two, I stayed in contact with the STP teachers through email and conducted short interviews with each of them after their science teaching experiences. During this time, I offered to help any of them with their science planning. Justin accepted my offer and he and I exchanged a few emails and had a phone conversation where I reviewed his prepared materials and helped him to think about his project.

Study Methods

Using qualitative research methods (Maxwell, 2013; Miles et al., 2014) I developed a set of a priori codes defining the science practices and different levels of sophistication related to their engagement and use. Using these codes in a form of analytic induction (Erickson, 1986), I assessed the focal preservice teachers' engagement in and use of the science practices. I also applied grounded theory and open coding (Charmaz, 2004) to develop a set of themes related to how the focal preservice teachers make sense of the science practices, how they teach with them, and how they are connected to student learning.

Data Collection and Sources

This study drew on four data sources from the physics phase: original and student lab sheets, student lesson plans, video recordings of selected investigations, and interviews with the focal preservice teachers. By "student lab sheets", I mean the lab sheets that contain all of the students' work for each investigation. Each of the sheets contained a pre-lab question, places to collect and analyze data, and scaffolding within the lab to focus the preservice teachers on different aspects of the content and the science practices. They also included a space for the preservice teachers to write a scientific explanation (usually using the claim, evidence, and reasoning [CER] framework; (McNeill & Martin, 2011)), and finally a set of post-lab questions designed to help them reflect on the science practices, their future teaching, or the content in general (see Appendix B for a list of the post-lab questions). The reflection questions represent one of the main ways I connected the work of the course to the research questions without disturbing the regular flow of the classroom. Table 3-2 outlines the data from each phase of the program and connects it to the research question

Table 3-2

Overview of total data sources across each phase of the study

Data Source	Phase of the study	Amount of Data Collected	Description
Research Question 1 and 2: How do the preservice elementary teachers engage in the science practices while they are learning science content? & How do the preservice elementary teachers make sense of the science practices while they are learning science content?			
Original Lab Sheets	1	49	Original lab guidelines and scaffolding that the preservice teachers used to navigate the physics labs (~25 from each course).
Focal Preservice Teacher Lab Sheets	1	217	Focal participants' copies of the Original Labs Sheets that include all of their written work on the labs.
Physics Videorecords	1	~15 hours	Video data of the focal participants engaged in various labs during the physics course.
Physics Interviews	1	9	Interviews done with the focal participants at the end of the physics course.
Research Question 3 and 4: How do the preservice elementary teachers use the science practices in their lesson plans and enactments? How does that use change over time and from one context to another? How do the lesson plans and enactments showcase the sensemaking that the preservice elementary teachers have about the science practices? & How do the preservice teachers make sense of how their use of the science practices in instruction promotes student learning? How do these views change over time and from one instructional context to another?			
Lesson Plans	1 & 2	65	Science lesson plans the participants could enact in their future classrooms or with their current students (44 from physics, 18 from methods, and 3 unit plans from student teaching).
Interviews	1 & 2	19	Interviews done with the participants at the end of the physics course (9 total and same as above), the end of the methods course (4 total), and after each teaching experience from the student teaching phase (6 total).
Videorecords of Enactments	2	~ 20 hours	Videorecords of the participants teaching the lessons they prepared in phase 2 (18 hours from methods course and 2 hours from student teaching).

Original lab sheets. The original lab sheets are the guidelines and scaffolding provided to the preservice teachers to help them through each of the labs in the physics class. The level of scaffolding varied throughout the course. For example, in the beginning, when I asked the preservice teachers to write a scientific explanation, the lab sheets included a space for each element of the CER framework, along with a short description of what each element is. In the beginning, I also provided data tables and blank graphing grids to help them think about their data collection and analysis. I coded the original lab sheets using the definitions of the practices and sub-practices as described in Chapter 2 (see Tables 2-1 through 2-5), to find out what opportunities to engage in the science practices existed in the course. See Appendix C for an example of one of the original lab sheets.

Focal preservice teacher lab sheets. The nine focal preservice teachers' lab sheets (n=217) contain all of the participants' written notes and work related to the physics investigations. I used this written work to gauge how sophisticatedly the participants engaged in the science practices. The lab sheets showcase how they organized their data, planned procedures, analyzed the data, and developed explanations among other things. Each lab sheet also included a set of post-lab reflection questions that directly asked the preservice teachers about their experiences with the science practices. I used the answers to these questions to develop themes for their knowledge through open coding (Maxwell, 2013).

Physics Videorecords. During the physics course I recorded lab groups as they engaged in the investigations. I planned the days to record to try and capture the preservice teachers engaging in labs that featured different science practices. Each physics class had eight lab groups and I could only record four groups at a time. Because I didn't know who my participants would be at the time, I tried to get equal time recording all of the students. This meant that in the end, while I was able to get videorecords of the focal participants engaging in the physics labs, I did not have a consistent set of videos for any one participant. After coding the focal preservice teacher lab sheets, I used the videorecords to check the codes and scoring applied to that data. This allowed me to verify the written work with a visual record of the engagement in cases where it was available. In this way I was able to triangulate those codes with additional data (Huberman & Miles, 1994).

Interviews. At the end of the physics course, I conducted semi-structured interviews (Cohen & Crabtree, 2006), each lasting approximately 30 minutes, with the focal preservice teachers (see Appendix D for the interview protocol). I customized each interview for the specific preservice teacher and included examples and quotations from their lesson plans and other coursework as a way to help them recall what happened in the course (O'Brien, 1993). In each interview, I intended to obtain a personal narrative regarding their experiences in the course and to directly engage them with the research questions (Weiss, 1994). The interviews at the end of the methods course followed a similar pattern to the physics interviews. I only interviewed the four STP teachers after the methods course (see Appendix E for the interview protocol). When the STP teachers taught a science lesson during their student teaching, I tried to set up an interview with them no later than two days afterwards. This was to keep the details of their teaching experience as clear in their minds as possible. In each case, I watched a videorecord of the lesson prior to the interview so that I could include examples of their teaching (O'Brien, 1993) in the protocol (see Appendix F). In these interviews, I asked them about the choices they made regarding the science practices in their lessons and why they thought it could help their students learn. I used the last post-lesson interview as a longer final interview to close the research project and to see how some of their perspectives may have changed since the beginning of the study. Because of the way the student teaching semester unfolded due to COVID-19, I ended up with an uneven number of interviews with the STP teachers, ranging from 1 to 2 interviews with each.

Lesson plans. During the physics course the focal preservice teachers each wrote five science lessons plans related to the content they learned at the time (total n=44). They used a lesson planning template (a simplified version of the teacher education program's template) to write their lesson plans (see Appendix G). For many of the preservice teachers, this was their first time writing science lesson plans and other than feedback given on submitted work, they received only a small amount of instruction on how to complete the assignment. I intended the lesson plans to be a space where the preservice teachers could engage with the content in a new way, while also giving them a chance to think about their future work as teachers. In the methods course, the preservice teachers wrote lesson plans for their peer teaching experience and the field teaching experience (total n=18). These followed the EEE+A format described above (see Appendix H for the template). The STP teachers did not have an official lesson planning template for the science lessons they planned and the three of them who were able to plan science lessons did so by designing an entire unit (total n=3). They wrote their units to include eight to ten mini lessons and I found evidence of the EEE+A format within these mini-lessons. I coded each of the lesson plans looking for which practices the preservice teachers used and to see how they used them (Erickson, 1986).

Videorecords of teaching enactments. The focal preservice teachers recorded each of the lessons from the methods course (peer teaching and field teaching). In total, each peer teaching lesson was approximately an hour and the field teaching lessons were about as long on average. To analyze these lessons, I took a modified version of field notes (Derry et al., 2010;

Emerson et al., 2011) on what the focal preservice teachers did, what they said, and how they interacted with the students. During the student teaching part of the study, I only obtained two hours of videorecords (from four different lessons). The STP teachers planned to teach more science, but were unable to due to the closure of the schools. I coded each set of field notes in a similar manner to the lesson plans and compared the codes of the related lesson plans to the videorecord fieldnotes to see how well they aligned. In other words, I wanted to compare the sophistication of the use of science practices between the enacted lessons and the lesson plans.

Limitations of the Study

One of the major limitations of the study was the size and selection of the final sample of preservice teachers. I selected the focal preservice teachers from the 2018 physics course using purposive sampling criteria (Miles et al., 2014) because I had a larger pool of preservice teachers to choose from. The focal preservice teachers from the 2019 physics course were the only ones moving on to the methods course in the following fall so I had to select each of them (although I believe they made an interesting and important addition to the overall sample). I also had little choice in the final sample and had to take a sample of convenience (Etikan et al., 2016) when choosing the STP teachers because they were the only ones who would have the opportunity to teach science during their student teaching. While the STP teachers were a sample of convenience, they did showcase some diversity in thought and experience from the original group. For example, the STP teachers included the two males included in the overall study (an underrepresented group among elementary educators); represented in the group were ELA, science, and math concentrators; and the sample contained each level of previous exposure to the science practices. Because I did not randomly generate the sample and because the final sample was so small, I do not make generalizations about preservice elementary teachers and the science practices. This data does offer examples of what could be possible given certain conditions and shows a narrative of what these participants experienced throughout their program.

The longitudinal nature of the study, while unusual in the literature and generally a strength of the study, can also be seen as a limitation. For example, when I compared how the focal preservice teachers used the science practices in their lesson plans, the differences in context from one teaching situation to another (e.g., different age students, different subject matter, different resources) made it difficult to track changes in how the focal preservice teachers used the science practices. While the shifting context of the longitudinal study made comparisons difficult, it also allowed me to see the wide variety of experiences that the preservice teachers are exposed to and how they adapt to those scenarios.

Last, I collected a limited amount of data during the participants' student teaching experience because the schools closed due to the pandemic. Because of this, I included the student teaching data with the methods course rather than using it as its own phase of the study. The data from the student teaching acted as an extension of the ideas and data from the methods course.

Data Coding and Analysis

This section describes the data coding and analysis methods used to answer the study's research questions. As a reminder, the research questions are:

1) *How do the preservice elementary teachers engage in the science practices while they are learning science content?*
2) *How do the preservice elementary teachers make sense of the science practices while they are learning science content?*

3) *How do the preservice elementary teachers use the science practices in their lesson plans and enactments? How does that use change over time and from one context to another? How do the lesson plans and enactments showcase the sensemaking that the preservice elementary teachers have about the science practices?*
4) *How do the preservice teachers make sense of how their use of the science practices in instruction promotes student learning? How do these views change over time and from one instructional context to another?*

In this section, I also detail the rubrics I constructed to score how sophisticatedly the participants used and engaged in the practices and the themes I developed through open coding.

Question 1 Data Coding: Opportunities to engage

First, I wanted to know what opportunities the preservice teachers had to engage in the science practices during the physics course. To do this I used the definitions of the science practices and sub-practices (see Table 2-1 through 2-5) I developed from the *Framework* (National Research Council, 2012) as a priori codes. I applied the codes to the Original Lab Sheets from the physics courses and compared them to see the differences in opportunities from one year to the next. I took each Original Lab Sheet and broke it down into stated and implied tasks. I assigned an overall practice and corresponding sub-practice to each task. I double coded some of the individual tasks. For example, if the preservice teachers had a space to graph, I would have coded it as both *Find Patterns* and *Use Tools* in the Data Analysis & Mathematical Thinking practice.

Question 1 Data Coding: Level of Sophistication

After seeing what practices the participants had the opportunity to engage in, I needed to know how they engaged in that practice. To do this in a way that would be consistent across preservice teachers I developed a set of rubrics for each science practice and their sub-practices that rated their engagement on a scale of 1 to 4 or from “pre-novice”, “novice”, “intermediate”, to “experienced”. These rubrics are similar to those used by other science education researchers (Bismack et al., 2020; McNeill, 2011; Sampson & Clark, 2008). To develop the rubric, I used the descriptions of the goals for students outlined in the *Framework* (National Research Council, 2012) and the grade level progressions for each practice found in *Appendix F* of the *Framework* (NRC, 2013). These documents gave me a starting point. For example, I assigned skills aligning with the grade range 9-12 (e.g., “planning individually and collaboratively to produce data to serve as evidence” (NRC, 2013, p. 7)) to the experienced category, and I assigned skills aligning with the grade range K-2 to the pre-novice level. Some descriptors could be found in more than one grade level. For those items, I adjusted the rubrics to include a gradient type feature. For example, from a list of qualifiers, if the preservice teachers included one element, I considered that a pre-novice sophistication or if they used more, they could show a higher sophistication.

The grade level progressions in the Framework can also be seen as a continuum of how able learners are to engage with the science practices. By design, students are meant to gain skills with the science practices over time. For students who have had little experience with the science practices (whether they are second graders, high school seniors, or college sophomores), they will likely engage with the practices at the lower levels of the rubric, not because they lack the capacity to do more, but because they have not been give the experience or scaffolding to do more.

My last major source for building the rubrics was the book, *Helping Students Make Sense of the World Using Next Generation Science and Engineering Practices* (Schwarz et al., 2017). The second section in the book is titled “What Do The Practices Look Like In Classrooms?”, it unpacks each practice, giving examples of student engagement. I used descriptions and theories about the focal practices from this section to fill in the gaps in the rubrics. For the Scientific Modeling practice, I also drew on the work of Passmore, Gouvea, and Giere (2014) to define the sub-practices *Model "OF"* and *Model "FOR"*. See Table 3-3 for an example of the Level of Sophistication (LOS) rubric for two of the sub-practices of Plan & Conduct Investigations, (see Appendix I - L for the full set of LOS rubrics for each focal practice of the study).

Table 3-3

A sample of the Level of Sophistication rubric for Plan & Conduct Investigations

Level of Sophistication -- SP3 Plan & Conduct Investigations

L1 → "pre-novice" L2 → "novice" L3 → "intermediate" L4 → "experienced"

Investigation Question

Level 1 Sophistication (at least one)	Level 2 Sophistication (at least one)	Level 3 Sophistication	Level 4 Sophistication
Nature of question is more about facts and definitions		Nature of question is about the *how/why* of phenomenon	
❏ Ask or identify question that can be answered by investigation ❏ Question is of a **Yes or No nature** or simple answer	❏ Asks questions about what would happen **if a variable changed** or compares two variables ❏ Question **asks only for** empirical evidence	❏ Question asks about the **how/why** of the phenomenon	❏ **Evaluate question** to determine if it is relevant and testable

Make Predictions

Level 1 Sophistication	Level 2 Sophistication	Level 3 Sophistication (includes 1 element)	Level 4 Sophistication (includes both elements)
❏ Make prediction based on prior experience **(statement or fact)**	❏ Make a prediction **that is testable**	❏ Prediction includes content related **justification or rationale** ❏ Prediction establishes a relationship between the **dependent and independent variables**	

While the rubrics were influenced by the grade level progressions, they are not intended to say that if the preservice teachers average a score of 2 they can only engage in the practices at the level of a 3rd - 5th grader. They are intended to suggest that, with regard to that sub-practice and given their prior experience, the participants were likely only ready to engage at that level along the continuum. This could shift given different prior experiences or scaffolding during the investigation. Implicit in this model is the idea that it takes time to develop sophistication. Engaging in the practices requires complex thinking and reasoning (Tekkumru-Kisa et al., 2015), and traditionally, students have few experiences to engage in them (Banilower et al., 2018; Plumley, 2019).

I used the LOS rubrics to score each coded instance of the science practices in all of the focal preservice teachers' lab sheets. I organized each score by science practice and sub-practice and used the scores in different ways in the data analysis. Examples of what the preservice teacher engagement looked like at each level are presented in Chapter 4.

Question 1 Inter-rater Reliability

To test the validity of my coding scheme and the LOS rubrics, I went through two rounds of inter-rater reliability. In the first round, a colleague and I tested the reliability of the codes used to define the science practices and sub-practices (see Tables 2-1 through 2-5). While the individual sub-practices did not have enough instances in the original lab sheets to allow for a Cohen's Kappa score, the scores for the main practices ranged from 85% to 88% agreement. This is above the 70% threshold for acceptable initial agreement (Campbell et al., 2013; Sun, 2011). We began the process by talking through and editing the code book to make sure we understood the codes, their descriptions, and the examples of each code in the same way. We each coded at least 10% of the data from the original lab sheets and then compared our codes. We discussed any instances where our codes differed and eventually reached 100% agreement on the items we coded. These discussions led to further improvements and clarifications of the codes defining the practices.

In the second round of inter-rater reliability, I tested the LOS rubrics and their scoring methods with a different colleague. Because the LOS rubric scores are data at the ordinal level, I had to use a different inter-rater reliability test than I used with the science practices codes (nominal data). In this case, I chose to use percent positive agreement (Chaturvedi & Shweta, 2015). Agreement in ordinal data is different from nominal data because it is not an all or nothing type of agreement. If two raters are within 1 level of agreement, that is more acceptable than if they were within two or three levels. I chose to measure the percent positive agreement with scores that were either equal or within one level of agreement. While this method does not account for chance agreement (Hallgren, 2012), it still shows a level of agreement between raters that can be used if more strict limits are applied to the outcome. My colleague and I independently scored approximately 10% of focal preservice teachers lab sheets to evaluate their engagement. Within this set of data, our initial agreement ranged between 82% and 90% for each overall practice. For each case where we disagreed, we came to a consensus with the scores until our overall agreement reached 100%. These rounds of inter-rater reliability allowed me to adjust the rubrics until I found a consistent scoring method and could then use the LOS rubrics throughout the rest of the study.

Question 1 Data Analysis

To analyze the opportunities to engage in the science practices, I organized the counts of each practice and sub-practice into charts to see the patterns in the data. I wanted to know what proportion of the physics course's time was spent working on each science practice and if the course favored one practice over another. I also separated the engagement by content theme (mechanics, matter, electricity & magnetism, and waves & heat) to look for patterns at that level.

As an initial reading of the LOS rubric scores for the focal preservice teachers' engagement, I organized all the data by science practice and built bar graphs to see at what level the general engagement occurred. I then computed averages for each sub-practice and used those to calculate a weighted average for the overall science practice. This allowed me to see which sub-practices were a strength for the preservice teachers and how they contributed to the overall science practice. Next, I separated the overall weighted averages for each science practice into the content themes to see if the preservice teacher's engagement changed given the content they were learning at the time. To do this I used an ANOVA to test for differences between the averages of the practices within each content theme. In the cases where I found differences, I applied a Bonferroni adjustment to the ANOVA to see which science practice averages were significantly different from the others (Agresti, 2018). I then provided examples of the participants' engagement at each level for each practice and sub-practice. To triangulate these findings within the data, I used the videorecords of the participants' engagement to see if their interactions in the course matched the level I found in the lab sheets.

Question 2 Data Coding: Knowledge of the Science Practices

To characterize the knowledge of the focal preservice teachers and to see how they made sense of the practices at the time of the physics course (see chapter 5), I organized data from two primary sources. Each lab sheet ended with a set of post-lab questions that asked the preservice teachers about their knowledge and experience with the science practices relevant to the given lab. For example, in a lab with iterations of a model, I ask, "what does a scientific model look like to you? Can it have different forms? What is the purpose of a model?" (Phy_L5). I took the participants' responses to the post-lab questions as well as comments from their physics interview and organized them by science practice. I then went into each practice and open coded the participants' comments looking for themes (Maxwell, 2013). Table 3-4 describes each theme and gives examples of the participants' comments.

Table 3-4

Themes related to the preservice teachers' knowledge and sensemaking about the science practices

Code	Description	Example
Scientific Modeling		
Visual Nature	Models help make different aspects of a phenomenon visible.	"Models are used to demonstrate an idea that a student is unable to see due to size, speed, and many other factors. They assist in the visualization of processes and concepts in ways that cannot be done without a model." (Heather_Phy_Int)
For Understanding	Models help us to make sense of a certain aspect of a phenomenon.	"A scientific model breaks down a particular concept, and makes the concept easier to understand" (Brad_Phy_Lab6)
Limitations	All models have limitations.	"Some models skew one thing while preserving another" (Justin_Phy_Lab21)
Plan & Conduct Investigations		
Consider the "Why"	Investigation questions should get at the "why" of phenomena.	"[investigation questions should] ask students to *consider why* something is happening and not just simple yes/no or observational questions with no greater purpose" (Brad_Phy_Lab15)
Predictions and Critical Thinking	Predictions can help students to think critically.	"[predictions] force them to engage in critical thinking and to draw from past knowledge" (Angie_Phy_Lab23)
Joint Planning	Students will need help planning investigations.	"The teacher needs to put some observation skills, structure, and expectations in place. That said, students learn by asking and doing" (Justin_Phy_Lab11)
Data Analysis & Mathematical Thinking		
Patterns and Reasoning	Finding patterns is the essence of mathematical reasoning.	"Mathematical reasoning allows us to identify patterns in science" (Angie_Phy_L2)
Tools and Analysis	Tools can assist students to analyze data.	"[Technology] allows for the focus to be on critical thinking and analysis, not on tedious plotting" (Justin_Phy_L3)
Algebra and Difficulty	Using algebra can increase the difficulty but gives students additional insights.	"Without doing the math, it'd be impossible to really see the lost energy you'd just have to trust the teachers. The disadvantage may be that it makes things a little more difficult" (Edith_Phy_L7)

Inspect Data	Students need to inspect their data.	For conflicting data "ask another group to share the part of their collected data and explain how they got it" (Heather_Phy_L20)
Explanation & Argumentation		
Claims are Sensemaking	When students write claims, they are making sense of the data.	"I think making claims about the data that they collected is important because it helps students make sense of the data … and the related scientific concepts" (Jamie_Phy_L24)
Explanations need Evidence	To be scientific, a claim must be supported by evidence.	"It is scientific when students can back up what they are explaining with evidence and solid reasoning" (Morgan_Phy_L14)
Reasoning Makes Connections	Reasoning is what connects the evidence to the claim.	"Without the reasoning, nothing connects the evidence to the claim. The reasoning demonstrates understanding of the concepts behind why the observations happened" (Heather_Phy_L16)
Argumentation and Validity	Argumentation helps students validate their claims.	"Argumentation is the process where students can debate the validity of a particular theory or hypothesis" (Brad_Phy_L21)

Question 2 Data Analysis

After using open coding to develop the themes describing the participants' knowledge, I went through each set of the quotations that I had grouped by practice and applied the LOS rubrics. I scored each participant's individual comments and then averaged their scores within each sub-practice. I used these averages to calculate a weighted average for the practices' overall knowledge score. I did not separate the knowledge scores by individual participants but looked at their knowledge as a whole and compared the group knowledge scores to their group engagement scores because I wanted to see a more holistic view of what the preservice teachers knew. This made it easier to compare their knowledge to the group engagement and teaching scores from other chapters.

Question 3 Data Coding: Making Sense of Teaching

Research question three focuses on how the preservice teachers taught with the science practices and how that teaching and their sensemaking surrounding it changed over time. I treated the lesson plans from each phase of the study with the same procedure. I started by coding each plan using the descriptions of the science practices and sub-practices to determine which of them the participants used in their lessons. Then I used an adjusted version of the LOS rubrics to score how the participants used each sub-practice in the lesson plans.

To understand the preservice teachers' sensemaking about teaching with the practices, I open coded (Maxwell, 2013) the answers they gave to the interview protocol questions, "what role will the science practices play in your future teaching?", and "why was it important to include {insert practice or practices} in this lesson?". Prior to asking the second question, I either read to them a portion of their lesson plan or described a scene from the videorecord of their enactment as a simplified version of stimulated recall (O'Brien, 1993). I used their responses to these questions to develop themes presented in Chapter 6 (see Table 6-7). For example, some of the themes that emerged were *Build Student Understanding* and *Skills Beyond Science*.

Question 3 Data Analysis

I had a more difficult time analyzing this data compared to my analysis of the engagement and knowledge data. This was due to the shifting contexts of the study, as alluded to in the section on the limitations of the study. In the physics course, the preservice teachers had to write lesson plans connected to the content they were learning at the time. This was very different from most of the content they used for their lesson plans in the second phase (over half of the lessons in the second phase had connections to life science). During the second phase, the preservice teachers also planned lessons they knew they would teach to real students (either their peers or the children in their field placement classrooms). These changes in context made it difficult to track changes over time in the participants. In some cases, I could not tell if the differences in the scores was due to changes in their understanding or changes in the context.

Another aspect that made directly comparing the teaching scores to the engagement and knowledge scores difficult was the target grade level of the lesson plans. Because the LOS rubrics have roots in the grade level progressions of the science practices, I would expect the preservice teachers to intentionally engage their students at different levels (and example of applying their knowledge of content and students). For example, if they prepared a lesson for first grade students, I would expect their lessons to use practices primarily at the pre-novice level and occasionally at the novice level. Intentionally using practices that would score lower on the LOS rubric scale, in a case like this, actually displays a *strong* level of knowledge of content and students (KCS) with the practices. Therefore, I could not make direct comparisons of their teaching LOS scores and the other LOS scores. Instead, I rated their teaching score as either *Strong, Expected*, or *Weak*, based on how the LOS score related to the target grade level of the lesson plan (see Table 3-5 for descriptions)[4].

[4] Within the descriptions are cut off percentages. For example, the *Strong* level indicates that at least 60% of the LOS scores are at the target grade level of the lesson plan with no more than 30% above the grade level for a given science practice. While these numbers are somewhat arbitrary, I assigned the cut off percentages this way because this would put the majority of the use at the target grade level of the classroom with no more than approximately one third of the engagement above the student's recommended ability. Allowing for some use of the practices above the students' recommended ability could help them grow and increase their skills. This is especially true when there is an expert present to help bridge the gap, similar to zones of proximal development (Vygotsky, 1978). To find more exact cut off percentages for these levels, I would need to test them against student outcome data. This study does not have that level of data, so this could be an area for future research.

Table 3-5

Description of the knowledge of content and students (KCS) sophistication levels

Score	Description
Strong	At least 60% of LOS scores at the target grade level with no more than 30% above
Expected	At least 40% of LOS scores at the target grade level with no more than 30% above
Weak	Less than 40% of LOS scores at the target grade level

In the final part of the analysis for this question, I compared the videorecord enactments to the lesson plans (21 lessons each occurring during phase two). I watched each enactment, taking a modified version of field notes (Derry et al., 2010; Emerson et al., 2011), and then I scored how the focal preservice teachers used the science practices with LOS rubric. Then for each individual focal preservice teacher, I compared the average LOS score for each practice in a given lesson plan to the averages I found in the enactments to see if there was a difference in how they used the practices in each format. The results related to these analyses are presented in Chapter 6.

Question 4 Data Coding: Beliefs About the Science Practices and Student Learning

The fourth research question asks about how the participants connect student learning to the science practices. The themes I developed from their work in this section share some common features to the teaching themes from the third research question. I also wanted to know how these ideas changed over the course of the study. I primarily drew on data from the interviews of each phase of the study. In each interview, I asked the participants a form of the question: how can engaging in the science practices help students learn? Using the focal preservice teachers' responses to this question, I organized them by phase of the study and then went through several rounds of open coding (Maxwell, 2013) to develop themes for each phase.

For example, some of the themes that emerged were *Autonomy & Curiosity* and *Chance for Reflection*. These themes are presented in chapter 7 (see Tables 7-1 and 7-2).

Question 4 Data Analysis

To analyze the learning themes, I started by comparing the themes from phase 1 to phase 2 to find any similarities and differences. For the overlapping themes, I used examples from each phase of the study to show how the participants' thinking was similar. For themes that did not persist, or for themes new to the second phase, I looked for contextual features to try and explain the differences. For example, in the second phase, the preservice teachers talked about the group nature of working with the science practices. Working with their own students in small groups helped the preservice teachers see how working together, by sharing reasoning or comparing data, helped their students learn more than they could have on their own. I also compared the learning themes to the teaching themes developed for research question three to find patterns and make connections.

Case Study Analysis

The last results chapter takes up the analyses done for each research question and presents them in the form of two cases. I selected Brad and Angie to represent these cases because they worked together in the physics course and their prior experiences with the science practices different greatly. In this chapter, I highlight the participants' experiences with Data Analysis & Mathematical Thinking. I use this practice because they both showed higher levels of sophistication with it relative to their own work, and because of how they valued the practice in their interviews. Brad represents the case of a well-prepared beginner and Angie is the case of a minimally-prepared beginner for this practice. The cases are organized around the focuses of the chapters preceding it: engagement, CCK, and KCT + KCS. I did not do any additional coding or analyses for these cases beyond the work described above aside from making comparisons within and between each case. These results are presented in Chapter 8.

Trustworthiness of Findings

Throughout the study I used several strategies to defend my work against threats to its validity. First, I drew on multiple sources of data to make claims to answer each research question. This triangulation allowed my claims to be supported by multiple sources and provided a source of internal validity (Erickson, 1986). For example, in order to make stronger claims about the sensemaking preservice teachers engage in about the science practices during the physics course, I drew on data from their lab sheets, videorecords of their engagement, and the post-course interviews. Within each of these data sources, I looked for instances of both confirming and disconfirming evidence. It was important to collect and include instances of disconfirming evidence. Out of these ideas, I drafted possible alternative explanations and I made predictions about possible reasons for the divergence (Patton, 2002). For example, when I analyzed how the preservice teachers used Plan & Conduct Investigations in their instruction, I found a disconnect between how they believed the procedures of an investigation should be planned (although there was not complete agreement among the participants here) and how they used them in actual lessons. In my analysis, I included all of the instances of how the participants used the science practices, both those that are in line with my expectations and those that are not.

Second, in order to establish the reliability of my coding scheme, I went through rounds of inter-rater reliability as described above, where a colleague and myself coded at least 10% of the artifacts (Hallgren, 2012) to test the validity of the codes and coding methods. I calculated Cohen’s Kappa (Sun, 2011) values for the nominal codes and I used percent positive agreement (Campbell et al., 2013) for the ordinal rubric codes. Through rounds of coding and discussion, I was able to narrow the definitions and use of my codes until we reach acceptable values (at least 80% initial agreement).

Finally, I provided highly detailed descriptions supported by excerpts and examples of the preservice teachers' work (Merriam & Tisdell, 2015). These rich descriptions allow the readers to assess my work and test the assertions for themselves. I constructed the descriptions and themes through regular memoing. I discussed and refined these themes through conversations with my colleagues and advisor.

Conclusion

The following chapters outline the findings from my analyses. To answer the first research question, Chapter 4 shows what opportunities the preservice teachers had to engage in the science practices during the physics course and their level of sophistication. Chapter 5 details the common content knowledge (CCK) the preservice teachers have for the science practices in answer to research question two. I also score their CCK using the LOS rubrics to make a comparison with their engagement scores. To answer research question three, Chapter 6 looks at how the participants used the science practices in their planned teaching and enactments. I look to see how that teaching changed across the study and what sense the preservice teachers made of their use of the practices. Chapter 7 presents the themes I developed about how the participants connect student learning to the science practices to answer the fourth research question. Chapter 8 presents the cases of two participants comparing their knowledge and experiences over the course of the study and within one of the science practices. Finally, Chapter 9 discusses the connections between the findings and themes to the current literature in science education about the science practices.

Chapter 4 Preservice Elementary Teacher Engagement in the Science Practices in Physics

In this chapter, I present the findings related to the first research question: *How do the preservice elementary teachers engage in the science practices while they are learning science content?* To answer this question, I drew on data collected in the physics course, specifically from the original course lab sheets, the 9 focal preservice teachers' lab sheets, and the video records of the 4 student teaching preservice (STP) teachers (who are a subset of the focal preservice teachers). To understand how the preservice teachers engaged in the science practices, I scored each of the focal preservice teachers' lab sheets using the level of sophistication (LOS) rubrics for each science practice. I focused this analysis on the written work of the participants. This limited the scope of the analysis because it does not capture the group or social nature of engaging in the science practices. I use the video records of the STP teachers to triangulate the results found in the lab sheets, but those records were not extensive enough to stand as their own source of analysis. That said, the written work of the preservice teachers is able to shed light on the complex nature of engaging in the science practices.

The preservice teachers had roughly the same number of opportunities to engage in each science practice across the physics course. In general, they showed an overall novice level of sophistication depending on the practice and likely commensurate with their past experiences with the science practices. Each practice is constituted of a set of sub-practices, and the preservice teachers varied in the sophistication they showed across them. I unpack these findings in the sections that follow.

Specifically, I outline the focal preservice teachers' past experiences with the science practices and the opportunities the preservice teachers had to engage in the science practices while taking the physics course. Next, I present the LOS rubric scores for the focal preservice teachers. I then break down those scores by the content area of the physics course to see if there was any variation in the LOS scores based on the content or over time in the course. Finally, I showcase what the engagement looked like at each level of the rubric by examining the STP teachers' work.

Focal Preservice Teachers' Past Experience with the Science Practices

In order to interpret how the focal preservice teachers engaged in the science practices, it is relevant to know what past experiences and interest in science the preservice teachers had. As a part of their program, each preservice teacher's major included a content focus (Language Arts, Social Studies, Mathematics, or Science). Three of the nine participants (Morgan, Amber, and Brad) chose science as their concentration (see Table 3-1). This means that they took more science content courses as a part of their undergraduate studies. For example, each preservice elementary teacher was required to take a semester of life science, earth science, and physics. The science concentrators took additional courses such as environmental science and chemistry, which often were accompanied by a lab course.

During the first interview (held at the end of the physics course), I asked each focal preservice teacher what past experiences they had with the science practices throughout their schooling. As expected, these experiences varied and I used their responses to separate the preservice teachers into three groups. In the first group is Morgan and Brad, who claimed to have taken a lot of science and who mostly perceived those classes as being "hands-on" or investigation based. Morgan said, "[the science practices] weren't as spelled out and explicitly stated as they were in this class … [we did] a bunch of using mathematics and computational thinking. Lots of planning and carrying out investigations" (Morgan_Phy_Int). The second group includes Jamie, Edith, and Heather. They also claimed to have some experience with the science practices, but they did not take many science classes in secondary school and college. Of her experience in a high school chemistry class, Jamie said, "Although I didn't really understand a lot of it sometimes, the labs we did, we would make models of things and carry out investigations … investigations with different chemicals and stuff like that" (Jamie_Phy_Int). The last group includes Emily, Justin, Angie, and Amber. These students took varying amounts of science, but interpreted their experiences as "lecture based" or focused on story problems and mathematics with few "hands-on" experiences. Angie mentioned her geology course, "[it] was a lot of note taking, which is fine. But then I didn't really learn too much" (Angie_Phy_Int). Amber described her experience like this, "maybe in lab write ups you would have an interpreting data section on it … [the practices were] not necessarily in like classroom activities or anything" (Amber_Phy_Int).

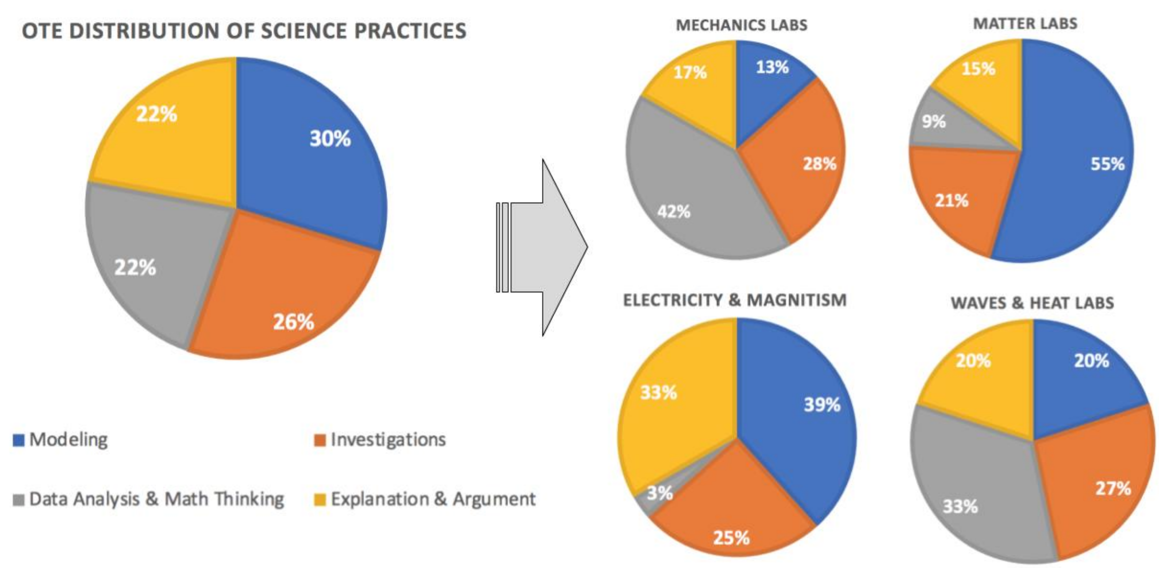
The prior experience with the science practices that Morgan and Brad had did not appear to be typical among the preservice elementary teachers and is not typical of most college students (Arthurs & Kreager, 2017). Most of the preservice teachers were new to engaging in science through a practice based focus. Even those preservice teachers from the second group who had some experience stated that the practices were never explicitly taught to them. They could see how, at times, they had engaged in some of the listed practices but had never stopped to consider what implications the practices themselves might have. We can consider this group novices with regard to their experiences in practicing science and in the further analysis, we will see what possible implications this has.

Opportunities to Engage in the Science Practices

To begin to understand how the preservice elementary teachers engaged in the science practices during the physics course, I needed to know what opportunities the course offered to engage in them (keeping in mind that the purpose of the engagement was to learn science content). To identify each opportunity, I coded the original lab sheets from the physics courses. I broke each section of the lab sheets down into their stated and implied tasks and coded them using the a priori codes found in Tables 2-1 through 2-5. Figure 4-1 displays the distribution of the 200 opportunities to engage (OTE) from the Winter 2018 course.

Figure 4-1

Distribution of the Opportunities to Engage (OTE) in the Science Practices



Note. This is data from the Winter 2018 physics course.

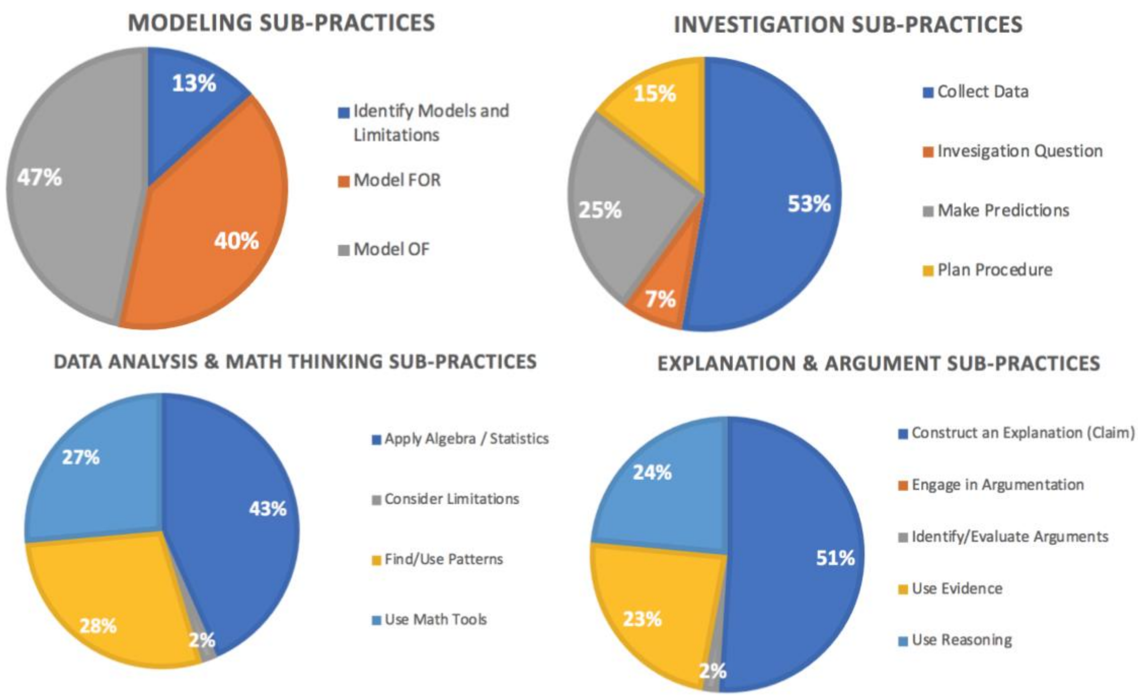
As seen Figure 4-1, there was a general balance between the amount of OTE's in each practice, with the exception of Modeling which had a slightly higher count. To get a better sense of the progression through the course, I further separated the OTEs by the four overarching conceptual topics in the course. Each of these had a different number of labs (Mechanics - 9 labs, Matter - 4 labs, Electricity & Magnetism - 7 labs, and Waves & Heat - 5 labs). Within each conceptual topic, the primary science practice changed. These differences showcase how the material was experienced by the preservice teachers as well as how the instructors decided to present the concepts. For example, the Matter labs had many more OTE's in Modeling because of the abstract nature of atoms. In the Electricity & Magnetism labs, there were far fewer OTE's in Data Analysis & Mathematical Thinking. This was because the physics professor and I chose to focus on the conceptual nature of these topics, rather than explore the computational side of the content.

The distribution of the OTE's from the 2019 physics course was very similar to the 2018 year (Modeling 26%, Data Analysis & Mathematical Thinking 25%, Planning & Conducting Investigations 27%, Explanation & Argument 22%). The distribution of the OTE's within three of the conceptual topics remained unchanged. In the Matter labs, the preservice teachers engaged in more Data Analysis & Mathematical Thinking (5% increase), and less Modeling during the 2019 year.

Figure 4-2 shows the distribution of the OTE's for the sub-practices of each science practice as found in the Original Lab Sheets of the 2018 physics course. Across the science practices, each of the sub-practices, except for *Engage in Argumentation*, was evident in the Original Lab Sheets. (While the preservice teachers did engage in this sub-practice during the course, it was not evident in the lab sheets due to the social and spoken nature of the sub-practice.) Within a given science practice, the distribution of the OTE's for the sub-practices was not even, as illustrated in Figure 4-2. For example, over half of the OTE's in Plan & Conduct Investigations were the sub-practice *Collect Data*. The distribution of the OTEs for the sub-practices in the 2019 course closely mirrored the patterns found in the 2018 course.

Figure 4-2

Distribution of the OTEs for the Sub-practices of each Main Practice



Note. This is data from the Winter 2018 physics course.

In summary, during the physics course, the preservice elementary teachers had roughly equal opportunities to engage in all four of the science practices that I focused on in this study. The physics professor and I tailored the OTEs to match the content the preservice teachers were learning at the time. The amount of engagement in the practices and the open discussion of the science practices was a style of science instruction which was new to most of the preservice teachers. This was especially true of the Science Modeling practice which both Amber and Morgan claimed to have seen very little of in their past science classes (Amber_Phy_Int, Morgan_Phy_Int). The following sections describe how the focal preservice teachers engaged in the science practices while in the course.

Level of Sophistication Scores for the Science Practices

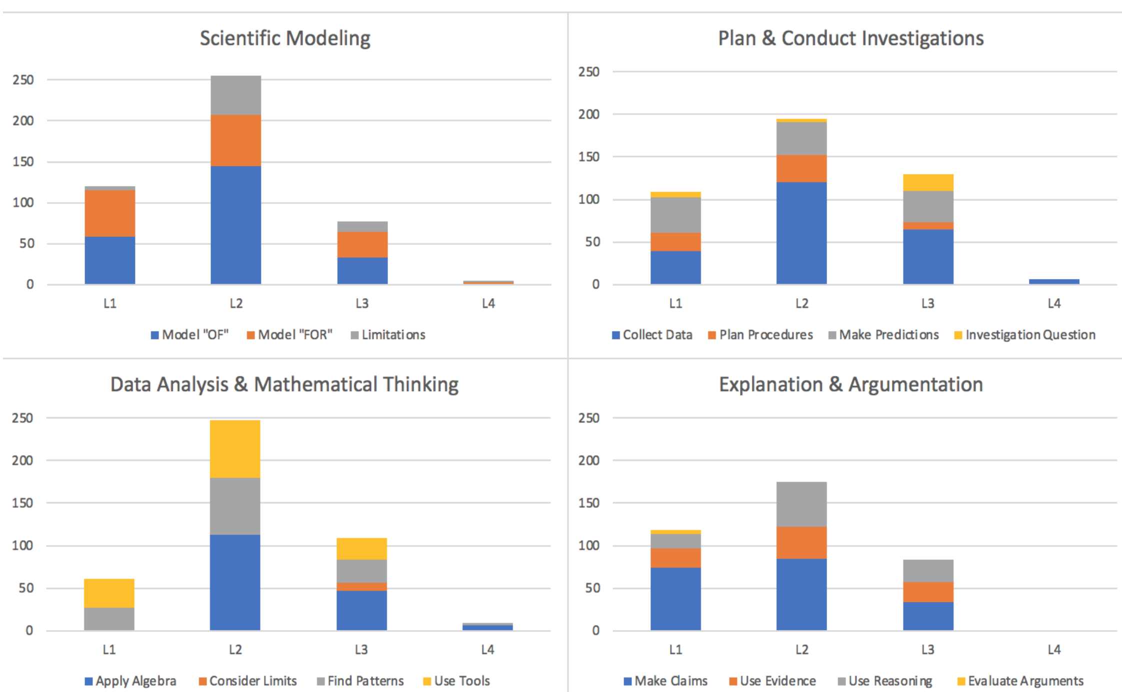
Knowing which practices the preservice teachers engaged in builds a frame for what the engagement looks like but it does not provide details. Using the Level of Sophistication (LOS) rubrics, I scored the lab work of the focal preservice teachers to fill in the picture for how the class as a whole engaged in the practices. The rubrics provided a score for the sophistication of the engagement within each sub-practice that separated it into four levels. I modeled these levels after the grade level progressions of the science practices found in *Appendix F* of the *Framework for K-12 Science Education* (NRC, 2013). This does not imply that preservice teachers who score a 2 are only as sophisticated as 3rd or 5th graders, rather each score shows a progression of familiarity and ability within a given science practice. In an ideal setting, students would have years to progress through each stage of the LOS rubrics, gaining familiarity and skill within a practice over time. As seen above, for many of the preservice elementary teachers, the physics class was the first time many of them engaged in these practices in a rigorous way.

As an overview of the sophistication of the engagement, Figure 4-3 shows the distribution of the scores within each science practice. The contributions of the sub-practices are displayed within the different levels as separate colors of the bar. Looking across the practices, the preservice teachers primarily engaged at the second (novice) level, less in the first (pre-novice) and third (intermediate), and almost no engagement at the fourth (experienced) level. This is an indication of how much experience the preservice teachers as a whole might have had with the practices prior to the physics class as well as their current level of skill. The novice level of sophistication aligns most closely with engagement in the practices that relies on the aid of the instructor (e.g., using instructor provided equations or planning procedures with their help), or working in a conceptual space that is still focused on surface level aspects of the phenomenon rather than the “how” or “why” (e.g., developing a model that links physical or diagrammatic parts of the model to the real world or asking questions that only seek empirical evidence).

With many of the preservice elementary teachers being new to doing this kind of work in science, the novice level of sophistication is a natural place for them to engage with the content. While the general level of engagement was at the novice level, there were practices where the preservice teachers showed higher levels of sophistication. At the intermediate level of sophistication, the preservice teachers had the most engagement with Plan & Conduct Investigations and Data Analysis & Mathematical Thinking. When engaging at this level, the preservice teachers transitioned from using the practices to understand the content at a surface level to thinking about and investigating the “why” or “how” of a phenomenon. These are both practices where the focal preservice teachers claimed familiarity, especially with science classes that leaned heavily on working out mathematical solutions.

Figure 4-3

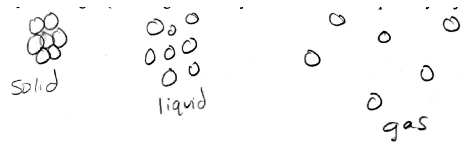
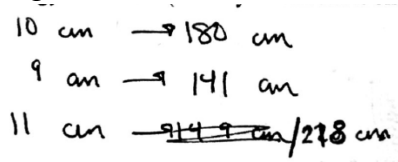
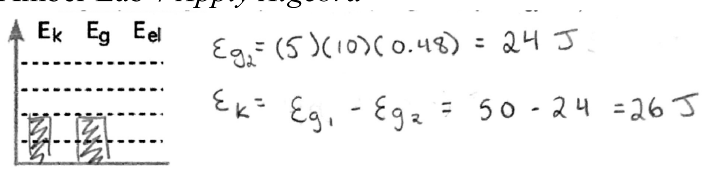
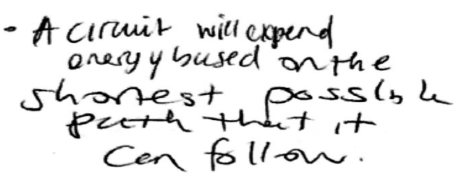
Distribution of the Level of Sophistication Scores for the 9 Focal Preservice Teachers



As seen in Figure 4-3, the primary level of engagement is the novice. To illustrate what this looked like for the preservice teachers, Figure 4-4 shows an example of a preservice teachers' work from each science practice. I chose each example to illustrate work that best fit the novice level for each practice while trying to pick work from different preservice teachers. Looking across each example, the nature of the novice level showcases the science practices being used primarily to engage with the content at the surface level. None of the preservice teachers pushed their engagement in these spaces to investigate the "why" of a phenomenon. For example, Jamie's use of *Model "OF"* was only a depiction of the arrangement of atoms without any accompanying reasoning. In Morgan's example of *Collect Data* she did not use multiple trials to verify her measurements and with only three data points, she would not be able to make a strong claim for the patterns found in the data. With each of these examples, I am not making the claim that these preservice teachers could not have engaged at a higher level, but I do claim that with more experience working with the science practices, they would have been more likely to engage at a higher level.

Figure 4-4

Examples of the Focal Preservice teachers' Work at the 2nd LOS

	Focal Preservice Teachers' Work
Scientific Modeling	Jamie Lab 12 *Model "OF"* 
Plan & Conduct Investigations	Morgan Lab 8 *Collect Data* 
Data Analysis & Mathematical Thinking	Amber Lab 7 *Apply Algebra* 
Explanations & Argument	Emily Lab 16 *Construct an Explanation* 

Another way to view the preservice teachers' engagement in the practices is to average their performance across each practice. Table 4-1 gives the weighted averages for each practice and sub-practice over the duration of the physics course. Reflected in Table 4-1 are the similar patterns found in Figure 4-3. For example, both Plan & Conduct Investigations and Data Analysis & Mathematical Thinking have averages over 2.0 which indicates these are practices that the preservice teachers were more familiar with when starting the physics course (this also aligns with comments from interviews). Seen more clearly in Table 4-1 are the sub-practices that the preservice teachers had more experience with. For example, within Plan & Conduct Investigations, the focal preservice teachers scored above a two in *Investigation Question* and *Collect Data*. Both of these are critical elements of the standard investigations that they would have engaged in with previous science classes. On the other hand, in *Plan Procedures* they scored much lower than the other three sub-practices. Traditionally, this is a sub-practice that few students engage in during their coursework.

Table 4-1

Computed Averages for the Level of Sophistication Scores

	N	Average	Weighted Average
Scientific Modeling			*1.92*
Model "OF"	237	1.89	
Model "FOR"	152	1.88	
Identify Limits	69	2.14	
Plan & Conduct Investigations			*2.05*
Collect Data	233	2.14	
Plan Procedures	64	1.72	
Make Predictions	117	1.97	
Investigation Question	31	2.42	
Data Analysis & Mathematical Thinking			*2.11*
Apply Algebra	175	2.25	
Consider Limitations	9	3.00	
Find Patterns	127	2.02	
Use Tools	126	1.93	
Explanation & Argumentation			*1.88*
Make Claims	194	1.78	
Use Evidence	87	1.91	
Use Reasoning	100	2.08	
Evaluate Arguments	4	1.00	

In summary, the focal preservice elementary teachers primarily engaged with the science practices at the novice LOS rubric level. I found more variability within the sub-practices of an overall practice, which indicates that the preservice teachers' ability to engage in the practice, and past experience with the practice, was not consistent from one sub-practice to another. To develop skills within any given practice takes time and mastery of a practice cannot happen over the course of a single semester. Each intentional experience with the science practices that the preservice teachers have will help move them towards mastery.

Engagement in the Science Practices by Conceptual Topic

The first research questions asks what the preservice elementary teachers' engagement in the practices looked like when they were learning their science content. To investigate this further, I separated the LOS rubric scores by the content of the physics course (see Table 4-2). Not only does this give us a view of their performance by content matter, but it also could give us an idea of how their engagement could have changed over the duration of the course because the content progressed from Mechanics to Waves & Heat. In Table 4-2, the variation of the averages by content is shown across the rows for a given practice. To test for a significant difference between the averages of each content with a given practice, I ran an analysis of variance (ANOVA). I found that for the 9 focal preservice teachers, there was no significant difference between the content averages for the practices of Plan & Conduct Investigations (ranging from 2.01 to 2.30) and Data Analysis & Mathematical Thinking (2.00 to 2.18). This could indicate that the preservice teachers' ability to engage in those practices was not constrained (or bolstered) by the content being covered. It also shows that there was no significant change in those practices over time. Importantly, these were also the practices that the preservice teachers claimed to have the most prior experience with. This could indicate that the few short weeks of the physics course was not enough time to produce a measurable change in their level of sophistication, given the amount of time they had already spent with those practices.

Table 4-2

Average Level of Sophistication Scores Broken Down by Physics Content

	Mechanics	Matter	Electricity & Magnetism	Waves & Heat
Scientific Modeling	2.06	1.98	1.74*	1.99
Plan & Conduct Investigations	2.01	2.30	2.02	2.03
Data Analysis & Mathematical Thinking	2.09	2.09	2.00	2.18
Explanation & Argumentation	1.98	1.77	1.75*	2.05

*The difference between these scores and the others in their science practice group was significant

The ANOVA did show a statistically significant difference within the different content averages for Scientific Modeling (1.74 to 2.06) and Explanation & Argumentation (1.75 to 2.05). In order to determine which content average was significantly different from the others, I also applied the Bonferroni adjustment to a series of t-test of differences of means between each category average. From those tests I found that for Scientific Modeling, the average for the topic of Electricity & Magnetism (E&M) was significantly different from each other average. In other words, the preservice teachers scored significantly lower in content related to E&M, than for the other content areas. Similarly, for Explanation & Argumentation, the average of E&M was significantly lower than both the Mechanics and the Heat & Waves content scores, but not different from the Matter content score.

These results could indicate that there is a connection between a student's ability to engage in certain science practices and the content they are learning. Electricity & Magnetism has traditionally been a more difficult subject for learners to master (Finkelstein, 2005; Karal &

Alev, 2016), and it could be the case that the preservice teachers' struggle to master the difficult content inhibited their ability to engage in these science practices at the same level as they did with other content. Alternatively, it is possible that challenges with the Scientific Modeling practice stood in the way of their making sense of E&M content.

Examining the content scores of Scientific Modeling and Explanation & Argumentation over the length of the course does not show consistent improvement, but they do each display the same pattern. For these practices, there was a drop from the beginning as the participants moved into Matter and Electricity & Magnetism (a significant change), but the scores came back up to approximately the same level for the last few labs of the Waves & Heat content. Again, the study shows that over the length of the course there was not a significant change, but these two practices did drop when the difficulty of the content increased. This could be additional evidence that significant gains in how students engage with the science practices needs to be measured over longer periods of time.

Examples of Engagement in the Science Practices from the STP Teachers

This chapter has shown how the general engagement of the focal preservice teachers engaged in the science practices has been at the novice level of the LOS rubric. To provide a fuller depiction of these findings, the following sections show how the four STP teachers engaged with the science practices. Each section compares examples from different STP teachers within each sub-practice and at each level of the LOS rubric. While each STP teacher scored close to or slightly above the novice level across the overall practices, Brad and Edith have slightly higher LOS average scores. This is consistent with their prior experience with the science practices. Brad was in the first group (meaning he took many science classes where he had experiences with the science practices) and Edith was in the second group (she took fewer science classes but did claim to have experience with the science practices). Angie and Justin were both in the third group, which means they claimed to have more lecture-based experiences with science and fewer experiences with the science practices. I begin by presenting the results for Scientific Modeling and follow with examples from each of the other science practices.

Scientific Modeling

Table 4-3 shows the distribution of the LOS rubric scores for Scientific Modeling (ranging from an average of 1.74 for Justin to 2.00 for Brad) and the sub-practices (ranging from 1.61 to 2.57) for each STP teacher. Among the sub-practices, the STP teachers' engagement was generally the highest for *Identify Limits*, except for Justin whose score for this sub-practice was lower than his peers.

Table 4-3

Average Level of Sophistication Scores in Scientific Modeling for the STP Teachers

	~N	Angie	Brad	Edith	Justin
Scientific Modeling	*54*	*1.80*	*2.00*	*1.88*	*1.74*
Model "FOR"	19	1.63	1.95	1.61	1.77
Model "OF"	27	1.79	1.93	1.88	1.76
Identify Limits	8	2.38	2.38	2.57	1.63

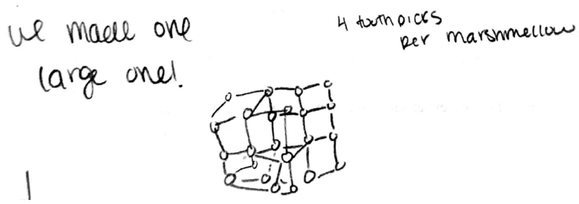
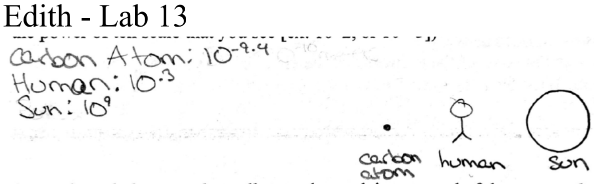
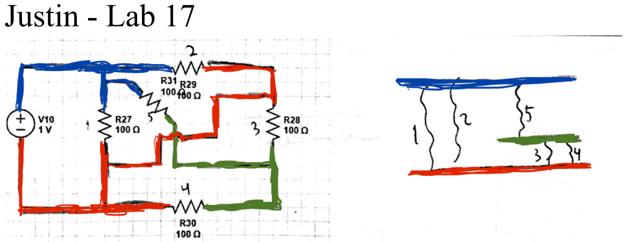
In the sub-practice, *Model FOR*, the STP teachers' LOS scores were near the novice level. This means that they mostly used *Model FOR* to generate data as well as to reason about the phenomenon. Figure 4-5 shows examples of *Model FOR* at each level of the rubric[5]. In these

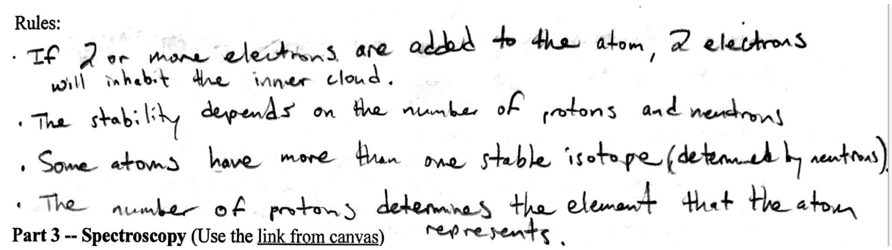
[5] For each of the figures, I tried to choose an example from each of the STP teachers so that there would be a wide range of examples from each of these preservice teachers across the sub-practices. Each example is meant to be characteristic of that level of engagement. In cases where there are no examples for a given level, this means that none of the STP teachers scored within that range across their work.

examples, Angie used a model to generate data (although her group only generated one data point). At the novice level, Edith used an online simulation to collect data and then compared the relationship between the data points with an illustration. Although the intermediate and experienced levels were not as prevalent, Justin used a representation of a circuit to reason about which bulbs would be brightest and Brad used an online simulation that modeled atoms to collect data and develop a set of rules for how atoms behave.

Figure 4-5

Examples of the STP Teachers' Work for the Model FOR Sub-practice

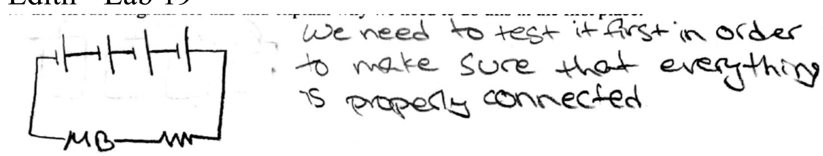
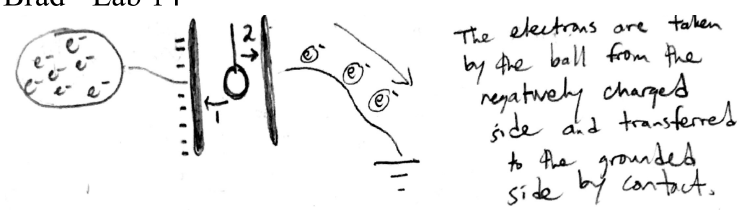
	Example of STP Teacher's work
Level 1	Angie - Lab 12 
Level 2	Edith - Lab 13  *Data generated from virtual model
Level 3	Justin - Lab 17 

Level 4	Brad - Lab 13  Rules: · If 2 or more electrons are added to the atom, 2 electrons will inhabit the inner cloud. · The stability depends on the number of protons and neutrons · Some atoms have more than one stable isotope (determined by neutrons) · The number of protons determines the element that the atom represents. **Part 3 -- Spectroscopy** (Use the link from canvas) *Analysis done from virtual model of an atom

The *Model OF* sub-practice had a similar distribution to the *Model FOR* sub-practice. This means that they most often developed or used models of a phenomenon to link certain aspects of the physical world to the representation in a way that was tied to what the phenomenon was rather than how or why it worked. Figure 4-6 provides examples of their work at each level except the experienced (which had no data available). At the pre-novice level, Angie drew a representation of the particles in two different blocks but did not give enough detail to connect this back to the phenomenon. At the novice level, Edith drew a representation of a circuit she was working on in class. This representation linked back to aspects of the phenomenon being studied by using the correct symbols for the different elements of the circuit as well as providing an explanation of the need for testing. While there were fewer cases of the intermediate level for the STP teachers, in this example, Brad's representation showcased the "how" of the phenomenon, as shown by the transfer of electrons to the ground.

Figure 4-6

Examples of the STP Teachers' Work for the Model OF Sub-practice

	Example of STP Teacher's work
Level 1	Angie - Lab 2 
Level 2	Edith - Lab 19 
Level 3	Brad - Lab 14 
Level 4	NA

In the final sub-practice *Identify Limits*, the average score for the group was between the novice and intermediate levels. The STP teachers' engagement for this mainly consisted of comparing models to find similarities and differences or to identifying specific content related limitations. Figure 4-7 presents examples of the STP teachers' work with *Identify Limits*. Progressing from one level to another, the figure displays how the preservice teachers' engagement differed. For example, between Level 1 and Level 2, Justin commented on how difficult it was to make an airtight boat without pointing to any particular part of the model. Angie's comments looked at the limitations of the materials, while also commenting on the overall task of keeping the boat afloat. At the intermediate level, Brad introduced content specific limitations to his description of the model. Last, at the experienced level, Edith suggests changes that her group could make to improve their current model.

Figure 4-7

Examples of the STP Teachers' Work for the Identify Limits Sub-practice

	STP Teachers' Work
Level 1	Justin - Lab 10 It was difficult to make a properly air-tight boat.
Level 2	Angie - Lab 10 a limitation we had was the amount of foil we could use. The aluminium is flimsy, easy to dent/concave so it was difficult to make sure the sides stayed sturdy enough to not fold in when an object - maily the alluminum cube - was placed into the boat. another limitation was the boat could not take on water - leads to sinking.
Level 3	Brad - Lab 23 No, we learned that different materials can hold different amounts of heat and that they can affect the temperature of the water differently. *In reference to a flawed mathematical model his group created
Level 4	Edith - Lab 12 The number of molecules is still the same, but as a gas it takes up about 1000x more volume. For the penny model, they'd need to be spread apart a lot more.

The STP teachers had several opportunities to engage in Scientific Modeling during the physics course. According to the focal preservice teachers, modeling was a practice they did not have much prior experience with. Because of this most of their engagement was at the surface levels of modeling, some of them did transition into the more sophisticated uses of modeling by using their models to investigate the "how" or "why" of a phenomenon and using their models to reason about the phenomenon. In many cases of those more advanced engagements, the higher engagement was prompted by scaffolding in labs.

Plan & Conduct Investigations

Table 4-4 presents the Plan & Conduct Investigations LOS rubric scores for the STP teachers. As a whole, the STP teachers' weighted averages were grouped around the average of the larger sample of the focal preservice teachers (2.05), ranging from 1.81 (Angie) to 2.30 (Brad). Similar to Scientific Modeling, Brad and Edith who had more prior experience, had higher weighted averages. At the sub-practice level, each STP teacher had instances where their scores were above the novice level. This reflects the preservice teachers' comments about doing more investigations in their previous science classes. Sub-practices like *Collect Data*, are common features of most science classes and it is evident in these scores that most of the STP teachers had done this before.

Table 4-4

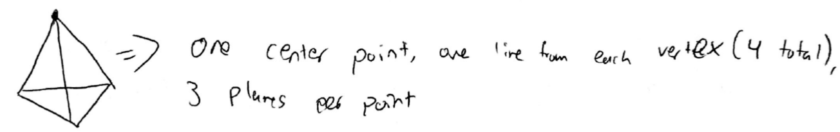
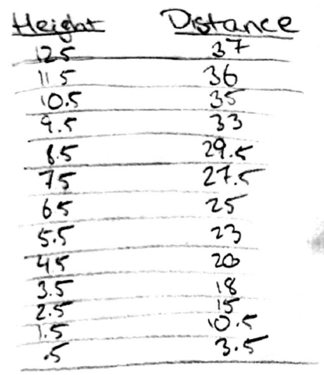
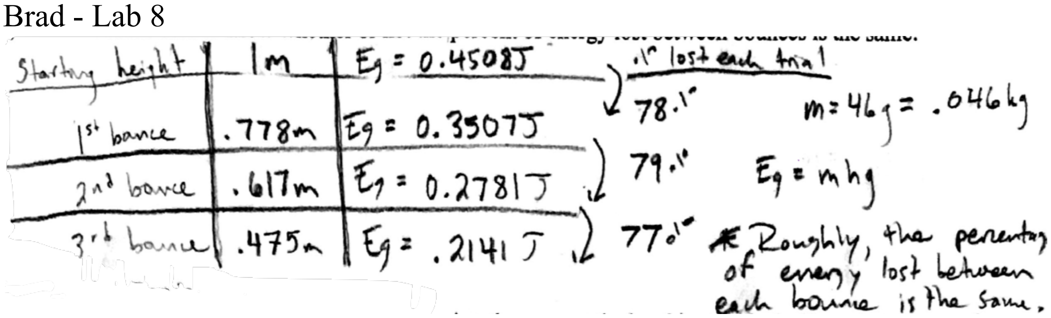
Average Level of Sophistication Scores in Plan & Conduct Investigations for the STP Teachers

	~N	Angie	Brad	Edith	Justin
Plan & Conduct Investigations	*50*	*1.81*	*2.30*	*2.28*	*1.83*
Collect Data	26	1.85	2.36	2.21	1.96
Plan Procedures	7	1.38	2.00	2.00	2.00
Make Predictions	13	1.71	2.31	2.33	1.54
Investigation Question	4	2.75	2.50	3.00	1.67

The STP teachers' engagement scores for *Collect Data* were each close to the novice level. Most of the data collected during the course was quantitative in nature. Figure 4-8 provides examples of the engagement at each available level. For the pre-novice level, Justin collected only one data point (in this first lab, the preservice teachers were investigating the geometry created by bubble sheets, lines, and points inside of different geometric objects), when he could have collected data on several shapes to make his claims. Edith organized her data into a table in the novice level (in Lab 11 they collected data on how far a stream of water would shoot relative to the height of the water in the container). Here, Edith collected enough data to make a substantial claim, but her data was not clear (units were not specified). At the intermediate level, Brad's data was organized, he had enough data points to make an accurate claim, and his data were clear (In Lab 8 they were investigating the amount of energy lost between the bounces of a ball). In Brad's case, he did not provide evidence of multiple trials and he did not test the accuracy of his data which could have moved the score to the experienced level. Most of the engagement in this practice was between the novice and intermediate levels.

Figure 4-8

Examples of the STP Teachers' Work for the Collect Data Sub-practice

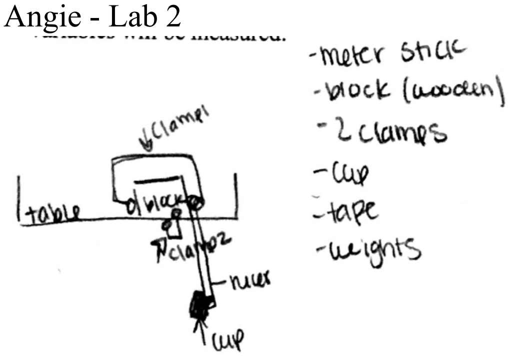
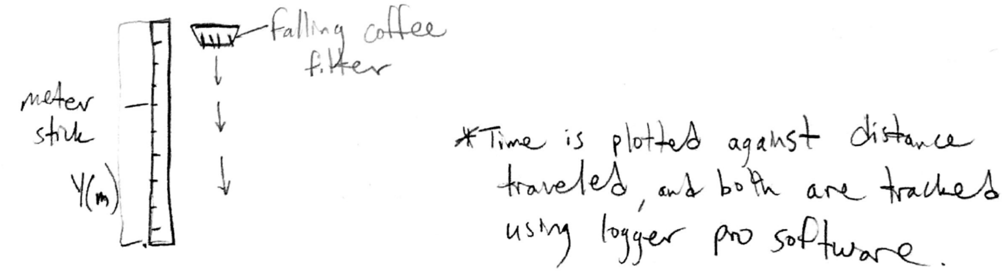
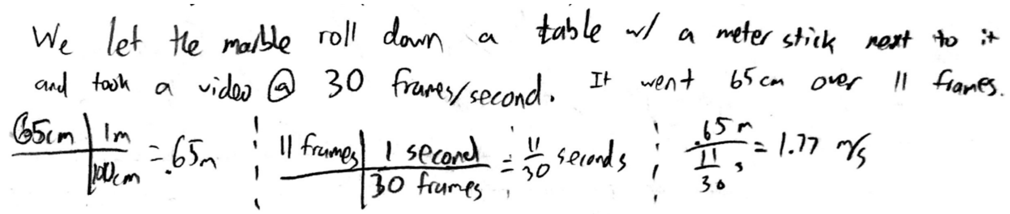
	Example of STP Teacher's work
Level 1	Justin - Lab 1 
Level 2	Edith - Lab 11 
Level 3	Brad - Lab 8 
Level 4	NA

In the LOS rubrics, the scores for *Plan Procedures* were separated into two groups. At the pre-novice and novice level, students would plan with different levels of guidance from the instructor. The intermediate and experienced levels turn the planning responsibility over to the students, either individually or in groups. Most of the STP teachers scored at the novice level.

Figure 4-9 gives examples of their work at each level. At the pre-novice level, Angie diagramed the lab and labeled much of the equipment. She did not take the next step of connecting the equipment to the investigations' variables. In the novice level, Brad included the variables as well as the method of collecting and analyzing the data. At the intermediate level, Justin explained an experiment he designed himself. His explanation included the variables studied and how he collected the data. The STP teachers collective score for this sub-practice was lower than the others in this practice. This could be explained by how infrequently students are allowed to plan their own procedures in traditional science classrooms.

Figure 4-9

Examples of the STP Teachers' Work for the Plan Procedure Sub-practice

	Example of STP Teacher's work
Level 1	Angie - Lab 2 
Level 2	Brad - Lab 3 
Level 3	Justin - Lab 7 
Level 4	NA

When the STP teachers engaged in *Make Predictions*, their engagement was split. Brad and Edith's scores were between the novice and intermediate level, and Angie and Justin scored between the pre-novice and novice level. Figure 4-10 provides examples of the engagement at each level. As an example of the pre-novice level, Justin made a prediction that is a partially testable statement of fact (it is not possible to quantify a loss of "much more energy"). In the novice level, Angie used two variables in her prediction that provided a testable relationship (the prediction is not specific but it is verifiable). At the intermediate level, Edith provided a prediction that was testable and she gave a rationale behind the prediction. In most cases the STP teachers used testable predictions, but only gave a rationale when prompted.

Figure 4-10

Examples of the STP Teachers' Work for the Make Predictions Sub-practice

	Example of STP Teacher's work
Level 1	Justin - Lab 7 I think it will lose much more energy
Level 2	Angie - Lab 11 higher water level will shoot a longer distance
Level 3	Edith - Lab 4 I predict that the more mass the "rocket" has, the smaller the acceleration will be because it requires more force to move the rocket with the most mass.
Level 4	NA

The STP teachers scored relatively high for the *Investigation Question* sub-practice. On average their scores were between 2.5 and 3.0 with Justin's score being a little lower than his peers. Figure 4-11 gives examples of the STP teachers' work with *Investigation Questions*. At the pre-novice level, Justin asked a set of "yes or no" questions looking to see if he could measure a change in the voltage of a battery. In the novice level and in the same lab, Angie asked a deeper question about what would happen when a variable changes. Her question left room for data collection and a possible explanation. At the intermediate level, Edith asked a question about how one variable could affect another, she explicitly asked to find the relationship between the variables. To progress to the last level, the STP teachers would have had to display evidence of them evaluating their questions and making revisions to them.

Figure 4-11

Examples of the STP Teachers' Work for the Investigation Question Sub-practice

	Example of STP Teacher's work
Level 1	Justin - Lab 15 more eletrolyte changes voltage? More metals? Two cups?
Level 2	Angie - Lab 15 - what will happen with the voltage when we use 100ml of monster? - with 100 ml of monster mixed w/ 100ml of pepsi?
Level 3	Edith - Lab 4 Investigation Question: How does mass affect an object's acceleration? What is the relationship between the mass of an object and its acceleration?
Level 4	NA

The STP teachers each claimed to have prior experience with investigations from their past science classes. While the lab experiences in traditional science classrooms can be more scripted, students in those classes do get to collect data, make predictions, and answer investigation questions. It appears as if experiences like these may have translated into higher engagement scores for the STP teachers.

Data Analysis & Mathematical Thinking

The preservice teachers had the highest overall average for this science practice. While I did not originally anticipate this result, it can be understood in possibly two different ways. First, in their interviews at the end of the physics course, those preservice teachers who had prior experiences with chemistry and physics mentioned the heavy use of mathematics in those classes. For example, Morgan said, “definitely in chemistry there's a bunch of using mathematics and computational thinking” (Morgan_Phy_Int). Having done a lot of mathematics in previous science courses could have prepared these preservice teachers to perform better with this practice compared to the others. Second, sub-practices in the LOS rubric like Apply Algebra do not have a score for level 1 because that type of mathematical thinking did not appear in the early grade bands that the rubric was based off of.

Table 4-5 shows the distribution of the LOS rubric scores for the STP teachers. Among the STP teachers the weighted average for the practice ranged from 2.57 (Brad) to 1.84 (Justin). The participants mostly scored above the novice level, signifying that the STP teachers most likely had prior experience using math in a science context. Justin’s score was surprising to me because his content focus was mathematics and I would have expected him to perform a little higher in this space. It could be that his mathematical knowledge did not translate well into the science practices space because he claimed to have experienced primarily lecture based science in the past. I also did not include an example of *Consider Limitations* because there was only one recorded instance of it and due the scaffolded way in which the students engaged with the sub-practice, they each scored a 3.

Table 4-5

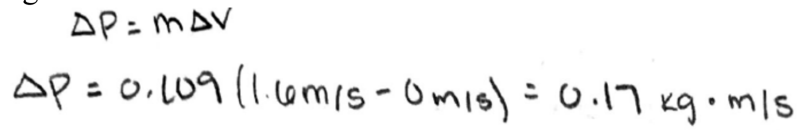
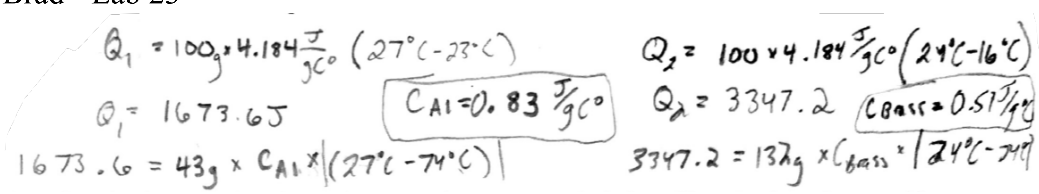
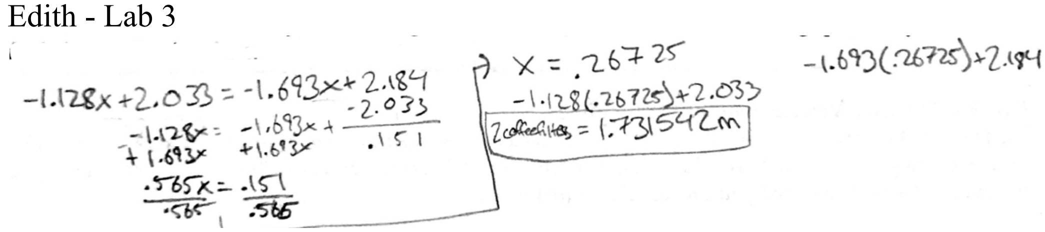
Average Level of Sophistication Scores in Data Analysis & Mathematical Thinking for the STP Teachers

	~N	Angie	Brad	Edith	Justin
Data Analysis & Mathematical Thinking	*49*	*2.02*	*2.57*	*2.17*	*1.84*
Apply Algebra	20	2.04	2.62	2.26	2.00
Find Patterns	14	2.00	2.62	2.23	1.75
Use Tools	14	1.93	2.43	1.93	1.64
Consider Limits	1	3.00	3.00	3.00	3.00

Figure 4-12 displays examples of the *Apply Algebra* sub-practice for the STP teachers. Their average scores for this sub-practice range from 2 to 2.62. At the novice level, Angie used a provided equation to generate additional data within a lab focused on momentum. In the intermediate level, Brad manipulated a given equation (dealing with heat energy) and then, using data from his lab, found a constant (the specific heat of a metal) that he could compare to real world values. In the experienced level example, Edith developed her own expression using the patterns discovered in the lab (she collected data on the terminal velocity of different falling objects). She then used her expression to make predictions about future behavior. Most of the scores for this practice were at the novice level.

Figure 4-12

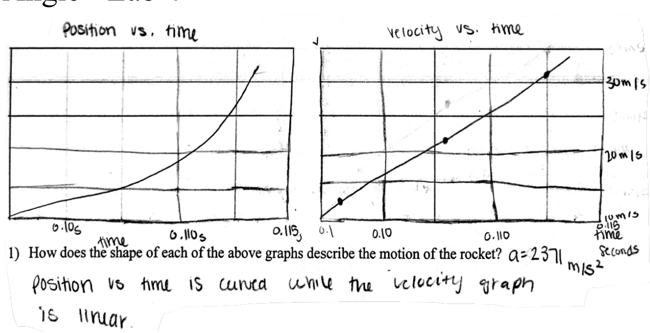
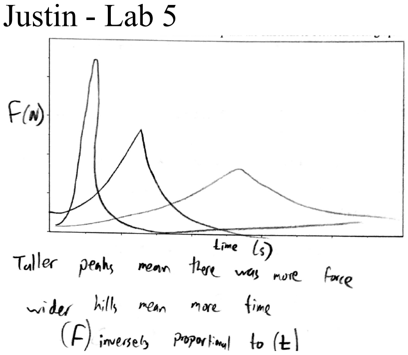
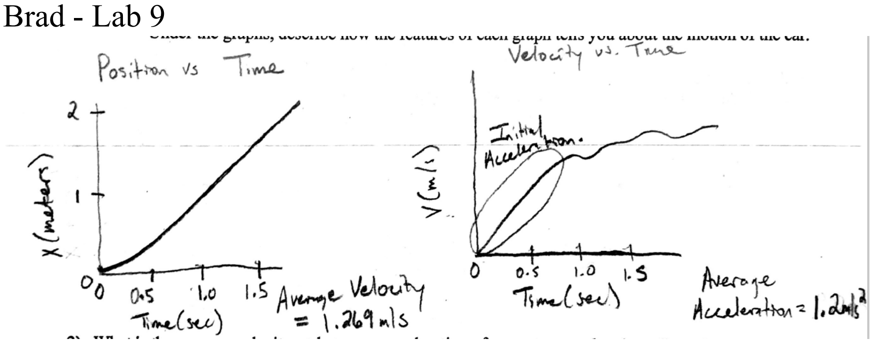
Examples of the STP Teachers' Work for the Apply Algebra Sub-practice

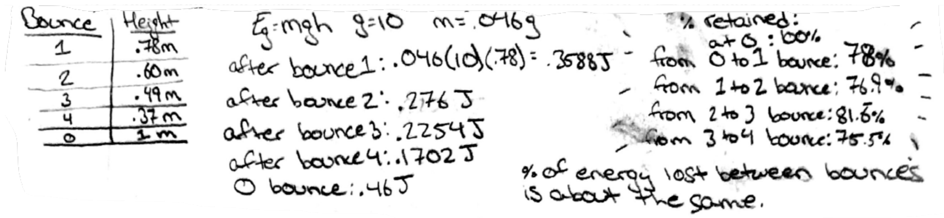
	Example of STP Teacher's work
Level 2	Angie - Lab 9 
Level 3	Brad - Lab 23 
Level 4	Edith - Lab 3 

The STP teachers each had relatively high LOS scores for the *Find Patterns* sub-practice. In this case the scores range from 1.75 to 2.62. Thus, the novice level characterizes the general engagement of the STP teachers well. Figure 4-12 displays their example work for each level of the rubric. At the pre-novice level, Angie recognized that there was a pattern in the data, but did not connect that pattern to the phenomenon (in a lab on accelerating objects). At the novice level, Justin used a series of overlapping graphs collected by the class to define a general relationship between two variables (in a lab studying impulse and its relation to force and time). Brad took his work a step further in level three by using the linear nature of his graphs to find a slope of the line. He then connected the slopes back to aspects of the phenomenon (in a lab reviewing motion and force). Although there were few occurrences of the experienced level, Edith used mathematical representations to find patterns within her data, she then was able to compare the patterns to her observations (in a lab investigating the conservation of energy). Although not displayed, she later checked her results against real world expectations.

Figure 4-13

Examples of the STP Teachers' Work for the Find Patterns Sub-practice

<table>
<tr><th></th><th>Example of STP Teacher's work</th></tr>
<tr><td>Level 1</td><td>Angie - Lab 4

</td></tr>
<tr><td>Level 2</td><td>Justin - Lab 5

</td></tr>
<tr><td>Level 3</td><td>Brad - Lab 9

</td></tr>
</table>

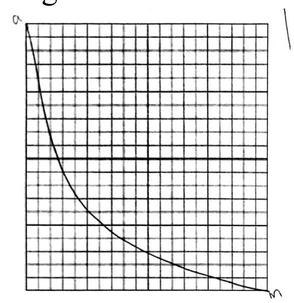
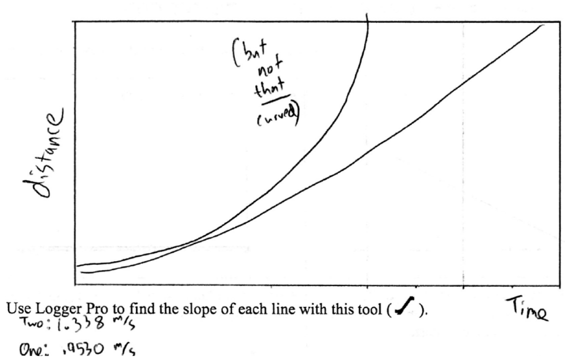
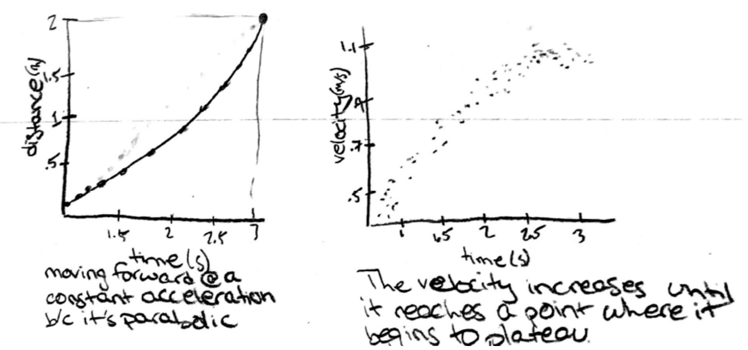
<table>
<tr><td>Level 4</td><td>Edith - Lab 8


</td></tr>
</table>

Throughout the physics course, the *Find Patterns* sub-practice was often connected with *Use Tools*. In most cases the preservice teachers used different mathematical tools to find patterns or reason with their data. Figure 4-14 shows examples from the STP teachers at each available level of the rubric. At the pre-novice level, Angie used a simple graph (no plotted points or scale) to depict a relationship between acceleration and mass (in this lab, they had data that could have been plotted). Justin used video analysis software to plot and find the slopes of his graphs at the novice level (a lab where we were studying falling objects). At the intermediate level, Edith also used video analysis software to generate her data, but she included an interpretation of her data pointing out linear and non-linear relationships (in a lab reviewing motion and force). The overall engagement in this practice for the STP teachers was just below the novice level, except for Brad whose average was a little higher than 2. *Find Patterns* is a skill that the preservice teachers may not have developed in their other science classes because it is not necessarily an algebraic application of mathematics but rather a sensemaking skill used to interpret data.

Figure 4-14

Examples of the STP Teachers' Work for the Use Tools Sub-practice

	Example of STP Teacher's work
Level 1	Angie - Lab 2 
Level 2	Justin - Lab 3 
Level 3	Edith - Lab 9 
Level 4	NA

As a whole the preservice teachers engaged well with Data Analysis & Mathematical Thinking. This could be due to their previous experience with mathematics in past science classes. It could also be partially attributed to the amount of scaffolding in place during some the early labs to help the preservice teachers navigate new tools. For example, the physics course used video analysis software (which was new to every student) to collect precise data on the motion of objects. They also used this software to graph and analyze the data. The preservice teachers were given a lot of guidance in the beginning to help them learn how to use the software, but eventually those scaffolds were removed.

Explanation & Argumentation

The STP teachers scored their lowest average, across all the practices, in Explanation & Argumentation and that trend generally holds true for focal preservice teachers as a whole. Table 4-6 shows the average LOS rubric score for each STP teacher across the sub-practices. The majority of these scores were between the pre-novice and novice level. In past science coursework some of the preservice teachers claimed to have experience writing explanations for their work (like in a lab write-up), but they were all new to the Claim, Evidence, and Reasoning (CER) framework used in this course. In other words, for most of the preservice teachers, this was their first time developing scientific explanations that were supported by evidence and reasoning.

Table 4-6

Average Level of Sophistication Scores in Explanation & Argumentation for the STP Teachers

	~N	Angie	Brad	Edith	Justin
Explanation & Argumentation	*44*	*1.62*	*2.02*	*1.74*	*1.65*
Make Claim	22	1.52	1.96	1.50	1.55
Use Evidence	10	1.91	2.10	1.67	1.78
Use Reasoning	11	1.58	2.17	2.40	1.73
Evaluate Arguments	1	1.00	1.00	1.00	NA

Of the sub-practices for Explanation & Argumentation, I expected the preservice teachers to be the most proficient with *Make Claims*. I assumed that this would be the case because many of them said they had written scientific explanations before (although not within the CER framework). It ended up being the case that focal preservice teachers scored the lowest with this sub-practice (1.78). Another factor was that, anticipating that the preservice teachers had never had experience with using evidence or especially reasoning with their explanations, I provided extra support for those sub-practices. Figure 4-16 gives examples for each available level of the LOS rubric for this sub-practice. As an example of level one, Edith made a claim about charges that was just a statement of fact. In the example for level two, Justin made a claim that set up a relationship between the mass of an oscillator and the period of oscillation. At the intermediate level, Brad's claim also established a relationship between the variables mass and acceleration, but he added a comment that included his controlling variable (force). In these cases, the sophistication of the claim increased as the preservice teachers added more elements from their experiments.

Figure 4-15

Examples of the STP Teachers' Work for the Make Claim Sub-practice

	Example of STP Teacher's work
Level 1	Edith - Lab 14 Claim: Opposite charges attract, while same charges repel.
Level 2	Justin - Lab 2 With some forgiveness to what appears to be user error, heavier objects make longer oscillations.
Level 3	Brad - Lab 4 As the mass of the rocket increases, the acceleration will decrease if the force remains the same.
Level 4	NA

Looking across the scores for *Use Evidence*, Angie performed her best with this sub-practice. Most of the STP teachers' scores were close to or slightly above the novice level. Figure 4-17 displays examples of their engagement. In the pre-novice level, Justin used a general reference to his data as evidence to support his claim about charges. At level two, Angie included specific data points that aligned with the claim she was trying to make about the difference between single and double paned windows. In the intermediate level, while Brad did not use specific data points, he did reference the analysis of his data and connected it back to the original variables.

Figure 4-16

Examples of the STP Teachers' Work for the Use Evidence Sub-practice

	Example of STP Teacher's work
Level 1	Justin - Lab 14 The pith ball changes attraction patterns after touching metal
Level 2	Angie - Lab 24 Single pane light on: 3min 42 sec Double pane light on: 1min 32 sec } Data from experiment
Level 3	Brad - Lab 11 The data we obtained shows a roughly linear correlation between water level and how far the stream of water was shot.
Level 4	NA

I was most surprised with the scores from the *Use Reasoning* sub-practice, where both Brad and Edith averaged above the novice level. This is normally a sub-practice that students of all ages struggle with because they have little experience with supporting their explanations in this way (e.g., McNeill et al., 2006). Figure 4-18 shows examples of what the engagement looked like at each level. In the pre-novice level, Justin attempted to talk about ionizing a magnet but did not connect this statement to his evidence or claim. As an example of level two, Brad referenced the phenomenon of current drops (in the place of the correct term, voltage drop) which did connect to his claim but was not used correctly. At level three, Angie drew on three different laws to correctly support the evidence and claim she used in a lab on heat transfer. Edith, who had the highest average for this sub-practice, correctly applied a theory that matched the explanation as well as assessed how well her explanation was supported.

Figure 4-17

Examples of the STP Teachers' Work for the Use Reasoning Sub-practice

	Example of STP Teacher's work
Level 1	Justin - Lab 18 Electrons push along & ionize the magnet
Level 2	Brad - Lab 18 As the current crosses the resistor the current drop should be the same with the same resistor!
Level 3	Angie - Lab 24 Conduction: single pane: conducts directly into the room Double pane: conducts into the air gap. Radiation: glass is a good reflector of radiation Convection: heat rises in our little demo room cold air falls.
Level 4	Edith - Lab 1 2 sheets can't make a line because it will collapse into 1 sheet. The minimum amount of sheets needed to make a line is 3 sheets. More sheets could come together to create a line, but perhaps Occum's law (the simplest correct answer is the correct one) keeps it at 3 sheets to make a line b/c we never observed a higher # of sheets coming together to make a line.

One thing to note is that Explanation & Argumentation was also the practice with the fewest opportunities to engage in throughout the course. In many of the labs, the participants had several opportunities to collect data, do analysis, or use a model, but we always ended with writing one explanation to wrap up the day's learning. In terms of time, the class spent much more time engaged in the other practices. This could help to explain why the preservice teachers seem to not have as much skill with this science practice compared to the others.

Summary and Conclusion

Table 4-7 summarizes the findings from each science practice, breaking them down by sub-practice. In each case, I use the table to highlight the preservice teachers' strength in engagement and the areas they could make improvements.

Table 4-7

Summary of Areas Where the Participants' Engagement was Strong and Areas for Improvement

Sub-Practice	Areas of Strength for Engagement	Areas of Improvement for Engagement
Scientific Modeling		
Model "OF"	• Develop models that link phenomena to physical world • Use models that represent non-visible phenomenon	• Develop models that focus on the "how" or "why" of phenomena • Develop or use a model to support argumentation
Model "FOR"	• Use models to generate data • Use models to reason about phenomena	• Use models to show relationships and patterns • Revise models to improve the model's function • Use models, and generated data, to build explanations
Identify Limits	• Identify physical limitations of model • Identify content related limitations	• Leverage limitations to revise models
Plan & Conduct Investigations		
Collect Data	• Clear presentation of data with use of units • Sufficient number of data points to establish a supported claim • Primarily collected quantitative data	• Conduct additional trials to improve accuracy • Test accuracy of collected data
Plan Procedures	• Able to plan with scaffolding provided by instructor • Plans included appropriate methods and tools	• When planning on their own, they did not consider number of trials or controlled variables • Need to evaluate the accuracy of their planned procedures (e.g., data collection methods) • Need to consider the safety and ethical implications of labs
Make Predictions	• Most predictions were testable • Occasionally used prior experience as justification	• Use of concepts or theory to justify predictions • Make predictions that establish relationships between variables

Investigation Question	• Questions asked about the how or why of phenomenon • Questions asked about changes in variables	• Need to evaluate the relevancy or testability of their question
Data Analysis & Mathematical Thinking		
Apply Algebra	• Use algebraic relationships to generate data • Apply algebra to analyze data (calculation of slopes)	• Create algorithms from data analysis • Apply concepts of statistics to characterize data
Find Patterns	• Use observations to recognize patterns • Organized data to find patterns (graphs and tables)	• Use mathematical representations to aid analysis • Compare predictions and patterns in analysis
Use Tools	• Use of graphs and other visual representations of data • Use of digital tools to test results and analyze data	• Use tools to reason about phenomena • Check results of tools to revise and improve application of the tool
Explanation & Argumentation		
Make Claims	• Construct an account of the phenomenon • Explanation can predict outcomes	• Construct an explanation that focuses on the "why" • Explanation accounts for controls or all variables
Use Evidence	• Use generic reference to data or trends as evidence • Evidence is related to the claim	• Use specific data as evidence • Use evidence from multiple sources
Use Reasoning	• Included theories or laws with explanation	• Use reasoning to link the data to the claim • Use reasoning to show why the data is adequate

This chapter has provided evidence for the question: *How do the preservice elementary teachers engage in the science practices while they are learning science content?* First, the physics course was designed to engage the students in a roughly equal distribution of opportunities to engage in the science practices as a means of learning the physics content. Within a given content area of the course the distribution between the practices was not equal, but over the length of the course the opportunities to engage in the practices balanced out. To get a clearer understanding of what that engagement looked like, I used the LOS rubrics to score the engagement of the focal preservice teachers' work evident in their lab sheets. On average, the focal preservice teachers scored a little above the novice level with Planning & Conducting Investigations and Data Analysis & Mathematical Thinking, and just under the novice level with Scientific Models and Explanation & Argumentation. In other words, over the duration of the physics course, the preservice teachers' engagement in the science practices was near the novice level of sophistication. I also saw that over the duration of the semester there was not a significant change in their LOS for each practice.

One way to interpret these results is to look at the preservice teachers' engagement with the science practices over the history of their education. According to their first interview, many of the preservice teachers described their previous science courses as being more traditional. This means that they did not have much if any experience with the science practices in the way that NGSS describes them. In essence, many of these preservice teachers were novices in relation to the science practices and were just beginning to develop their skills. It could be that the duration of one semester was adequate to engage them in initial experiences in the practices, but not enough time to make significant changes to their sophistication level. I assume that if given more time and engagement with the science practices that their overall level of sophistication would increase. By design, students should have years to progress through the levels of sophistication as they move from kindergarten through secondary school gaining experience and skills along the way.

One additional note to consider is that this study is not following typical science students. These are individuals who are preparing to become elementary teachers. This particular physics course was offered specifically for them with the hope of giving them an experience with science, as learning content through engagement in science practice, that they could then translate into their future teaching. Thus, in the following chapter, I report the findings on the participants' knowledge of the practices.

Chapter 5 Preservice Elementary Teacher Knowledge of the Science Practices

In this chapter I present the findings related to the second research question: *How do the preservice elementary teachers make sense of the science practices while they are learning science content?* In addition to knowing how the participants engaged in the practices, as explored in Chapter 4, it is important to know how they understood the practices. Being able to make connections between engagement and knowledge can inform how the knowledge is developed and if understanding limits engagement.

To answer the research question, I used data collected from the physics course interviews and from the post-lab questions that I added to the end of each lab. I designed these questions specifically to have the preservice teachers reason about their use of the science practices as well as define aspects of them. I coded each data source to separate all of the statements into which practice and sub-practice they referenced. Within each practice, I open coded the statements of each focal preservice teacher to develop a set of themes to characterize their knowledge. I also scored each group of statements using the level of sophistications (LOS) rubrics. This allowed me to make comparisons between how well the participants understood one practice compared to another. I also examine the relationship between the knowledge scores and the engagement scores.

In this chapter, I characterized teacher knowledge using the content knowledge framework developed by Ball and colleagues (2008). Specifically, under the umbrella of subject matter knowledge, I focused on common content knowledge (CCK). CCK is the knowledge and skills that are used by practitioners that is not associated with teaching, Shulman (1987) would have referred to this as an element of content knowledge. Here, I focus on CCK related to science practices. To define the base elements of this knowledge, I used the descriptions of the science practices found in the *Framework* (National Research Council, 2012) and indicators I developed for the sub-practices in the LOS rubrics.

In the previous chapter I found that the focal preservice teachers' past experiences in science could have established a baseline for the level of sophistication they showed as they engaged in the science practices. Those past experiences could have influenced the focal preservice teachers' knowledge in a similar way, as I show in this chapter. Specifically, this chapter shows that their general knowledge of the purpose of a given practice was strong (e.g., Scientific Modeling and Explanation & Argumentation are spaces of student sensemaking), but they gave few specific details about the sub-practices (e.g., practical uses of *Model "FOR"* or very little discussion of using rationales with *Make Predictions*). In every case, the overall average LOS knowledge score for a given practice was higher than the engagement average found in the last chapter. This could mean that the preservice teachers' knowledge of the practices did not inhibit their ability to engage in the practices at a higher level.

In the following sections I outline the themes I found for the science practices. I begin by looking at the science practices in general and how the preservice teachers describe their purpose and function. I follow this with sections describing how the preservice teachers made sense of and understand each science practice. The sections are broken down by sub-practices.

Making Sense of the Science Practices in General

As presented in Chapter 4, most of the preservice teachers mentioned in their interviews that before the physics course, they had little prior experience with the science practices. This inexperience might impact their initial knowledge of the practices (where they were at the beginning of the physics course). While the preservice teachers claimed to have engaged in practices like Planning & Conducting Investigations or Data Analysis & Mathematical Thinking, almost every participant said that they had never before explicitly discussed what the practices were or the kind of work that scientists do. For example, towards the middle of the physics course and in response to a question asking about the work of scientists, Justin said, “Honestly, I have no idea what scientists really do … but it would be nice to talk about the real work of science” (Jusint_Phy_Lab13).

Drawing on the above mentioned data, using open coding, I found a few themes related to how the preservice teachers thought of the science practices. The most common idea was about how much overlap existed between the practices. Morgan said, “there is a fair amount of overlap between the practices - it shows that these are not isolated practices and that they build well upon each other” (Morgan_Phy_Lab11). Brad even made a recommendation that the designers of NGSS might consider collapsing some of the highly overlapping practices into one practice to make things less confusing. The second theme that I found among the general comments connected the science practices to the nature of science (or the preservice teachers’ understanding of the nature of science). Edith said, “I think they do a good job of capturing the actual nature of science because science is about exploring and analyzing” (Edith_Phy_Lab11). These two ideas developed during the physics course as the preservice teachers engaged with the practices as students and applied the practices to their own teaching as they wrote lesson plans.

Three of the focal preservice teachers mentioned that the science practices as written were missing one key element. Amber described it this way, “I think they do a good job at capturing the skills necessary for science but fail to capture the curiosity and wonder that drives good scientific exploration” (Amber_Phy_Lab11). They claimed that without an emphasis on curiosity, students would not be motivated or interested in doing science. While these preservice teachers might apply the lack of curiosity to the science practices generally, they may have also been thinking about how they could use the practices to motivate their future students.

One of the goals of the physics course was to give the preservice teachers experiences with the science practices in conjunction with learning content, and to help them wonder about what the practices mean and how they can be used in teaching. In the end, Justin's comment in his physics interview captures well our overall objective, "[the practices] made it clear really immediately, we're not just learning science for the sake of knowing facts. We're learning science in the way of thinking and comprehending the world" (Justing_Phy_Int). Our hope was to help the preservice teachers see that the science practices could be used as a different way to understand the world.

Table 5-1 previews the weighted LOS rubric averages I found for the CCK of each major science practice. Along with the LOS scores for CCK, I also show the engagement LOS scores from chapter 4 as a point of comparison. In the following sections, I discuss the findings and details related to these scores. As Table 5-1 shows, in each case, the preservice teachers' CCK was stronger than their engagement in the practices.

Table 5-1

The Level of Sophistication Rubric Scores for the Engagement (Chapter 4) and CCK

Science Practice	**Engagement** (N = 1725)	**CCK** (N = 144)
Scientific Modeling	1.92	*2.52*
Plan & Conduct Investigations	2.05	*2.54*
Data Analysis & Mathematical Thinking	2.11	*2.91*
Explanation & Argumentation	1.88	*2.34*

Making Sense of Scientific Modeling

Of all of the science practices, the preservice teachers had the least prior experience with modeling. This included never before needing to define or explain what the practice was. For example, Heather said, "I kind of just thought of a model as … like maybe drawing a picture or building something to show, but not as many ways as we used it in the class" (phys_Heather_Int). For Heather and the other preservice teachers, their experiences with modeling helped shape their understanding of the practice. At the end of a model-focused lab, Brad explained that models should be "applicable to a more universal scientific process … If we just say our roller coasters are like real roller coasters, it is hardly a scientific model" (phys_Brad_Lab 7).

The focal preservice teachers believed that models should be *visual* and that the overall purpose of modeling was to help students *increase their understanding* of a given phenomenon. Although less frequent, each preservice teacher also discussed the idea that all models have *limitations* and cannot perfectly represent the real world. I used these themes as the foundation of their knowledge of modeling. Each theme fits neatly into one of scientific modeling's three sub-practices: *Model "OF"*, *Model "FOR"*, *Identify Models and Limitations*.

For the preservice teachers, models needed to be able to make certain aspects of a phenomenon visible (see Table 5-2 for examples of their ideas). They characterized this in different ways (e.g., using language like "shows", "visual representation", "observable", "to illustrate"). Visualization was often connected with the intent of helping students to understand or to make a connection between the phenomenon and the real world. Visualization fits most closely with the sub-practice *Model "OF"*. When a student engages in *Model "OF"*, they develop models that link aspects of the physical model to the real world. More sophisticated modeling in this sub-practice makes visible abstract and non-visible elements of the phenomena being studied. Angie and Heather commented on each of these qualities as seen in Table 5-2. On average, the focal preservice teachers had a LOS knowledge score in between the novice and intermediate levels for *Model "OF"* compared to their engagement score that was just below the novice level. That is, their knowledge about the practice was stronger than their ability to engage in it. This could be an indication of the relatively little experience they had with modeling prior to the course. They know what this aspect of modeling is, but lack the experience to fully engage in it. Their knowledge of *Model "OF"* covered each of the major themes in this sub-practice.

Table 5-2

Examples of Focal Preservice Teacher Descriptions of the Characteristics of Models

Preservice Teacher	The Visual Nature of Models – *Model "OF"*
Angie	"I just can't think of any other way to really show elasticity … I feel like you need to see how it stretches and to watch a rubber band reform … and nothing does a better way to show that other than using models because you can't draw it. It can't be 2D because you won't be able to see it" (Angie_Phy_Int)
Heather	"Models are used to demonstrate an idea that a student is unable to see due to size, speed, and many other factors. They assist in the visualization of processes and concepts in ways that cannot be done without a model." (Heather_Phy_Int)
	Models, Understanding, and Sensemaking – *Model "FOR"*
Edith	"Modeling is a skill in science to be able to demonstrate in maybe more easily understandable ways to see what is happening at a scientific level" (Edith_Phy_Lab12)
Brad	"A scientific model breaks down a particular concept, and makes the concept easier to understand" (Brad_Phy_Lab6)
Angie	"A scientific model makes a particular part of the world easier to understand … by referencing it to existing knowledge" (Angie_Phy_Lab6)
	Identify Models and Limits
Justin	"Some models skew one thing while preserving another" (Justin_Phy_Lab21)
Heather	"There will always be limitations … to identify other limitations, one must look carefully at the natural process and see how the model is different" (Heather_Phy_Lab12)

Linked to the sub-practice *Model "FOR"*, the preservice teachers made several connections between modeling and student understanding or sensemaking (see Table 5-2 for examples). The focal preservice teachers appeared to understand the need to move beyond only making a representation to helping students connect to their existing knowledge or to "break down a particular concept" (phys_Brad_Lab6). This is a hallmark of student sensemaking. In their narratives of *Model "FOR"*, the preservice teachers missed ideas related to using models to make predictions, generate data, or to show relationships. Heather and Emily each made a comment pointing to these ideas, but they were not a part of the majority. This is also not to say that the rest of the preservice teachers did not have that knowledge, but it did not come up in their comments. Scoring the answers they did give, the average LOS knowledge score for *Model "FOR"* was between novice and intermediate. Like *Model "OF",* they scored higher in the knowledge category than their engagement score (just below the novice level).

Aligning well with the last sub-practice of *Identify Models and Limits* is the last theme of model limitations (see Table 5-2 for examples). Each of the focal preservice teachers mentioned this theme at least once in their comments. In general, the preservice teachers looked for places where the model produced results different from the real world to find limitations. They discussed two kinds of model limitations: limitations related to the physical model (e.g., better to use small balls to represent atoms rather than pennies), and limitations connected to the phenomena (e.g., model cannot capture the constant motion of atoms). The one area where their knowledge seemed limited was using limitations to revise models. The preservice teachers averaged a LOS knowledge score between the novice and intermediate level. This was closer to their engagement score (just above the novice level) than the previous two sub-practices. This could be because we focused explicitly on model limitations for an entire lab and much of the engagement and knowledge data came from the same lab.

In summary, within each sub-practice, the preservice teachers' knowledge scores were between the novice and intermediate level. In each case their knowledge was at a higher level than what was displayed in their engagement. This could suggest that preservice teachers need more experience engaging in modeling to bring the level of their engagement up to the level of their knowledge. In terms of their CCK for Scientific Modeling, they are approaching an intermediate level (weighted average of 2.52) and discussed most of the elements of modeling at some point during the physics class. Their knowledge of modeling appears to be missing some of the more scientific perspectives and uses of modeling (e.g., collecting data, making predictions, revisions of models), but their understanding of the overall purpose of modeling (to engage students in sensemaking) was in place.

Making Sense of Planning & Conducting Investigations

Planning & Conducting Investigations was one of the practices that the focal preservice teachers claimed to have more experience with. When looking at this practice generally, the preservice teachers all talked about investigations as allowing students to explore a topic. They described this type of exploration as needing critical thinking and innovative methods. For them, important elements of investigations included questions and observations which should be aimed at developing a conclusion. They also discussed how investigations have a certain amount of order or "deliberate steps", similar to the scientific method. Talking about a lab investigating impulse and force, Justin said, "It seemed too frantic … to be an investigation" (Justin_Phy_Lab). This is in contrast to Mody's (2015) description of real science as messy.

The focal preservice teachers' knowledge of this practice broke down neatly by sub-practice. Their comments focused on the sub-practices *Investigation Question*, *Make Predictions*, and *Plan Procedures*. They made almost no mention of how to collect data but did discuss the difference between quantitative and qualitative data.

The preservice teachers believed that investigation questions were important because "they guide students to learn a certain thing and therefore define the purpose of a particular investigation" (Amber_Phy_L4). They said that investigation questions should focus on why things happen and not only on facts. They should also include elements that make them testable.

The preservice teachers emphasized that investigation questions should use student language and that students should play a part in their creation. See Table 5-3 for examples of focal preservice teacher quotes for this sub-practice. The preservice teachers' discussion of investigation questions averaged a LOS score close to the intermediate level. This was only a little higher than their engagement score. The preservice teachers' collective knowledge covered each of the major aspects of investigation questions except for having students evaluate their questions to see if they are relevant and putting them through a revision process.

Table 5-3

Examples of Focal Preservice Teacher Descriptions of the Characteristics of Planning & Conducting Investigations

Preservice Teacher	*Investigation Questions*
Brad	"[investigation questions should] ask students to *consider why* something is happening and not just simple yes/no or observational questions with no greater purpose" (Brad_Phy_Lab15)
Edith	"[Students] should think about the questions that they have about the topic and then throughout the lab working to either, like, answer those questions or find new ones" (Edith_Phy_Int)
	Make Predictions
Angie	"[predictions] force them to engage in critical thinking and to draw from past knowledge" (Angie_Phy_Lab23)
Brad	"a prediction is just a guess that is not substantiated by other scientific reasoning whereas a hypothesis is" (Brad_Phy_Lab15)
	Plan Procedures
Angie	"Instructions should be for harder concepts where if [students] don't have them they won't get the lab done in time" (Angie_Phy_Lab19)
Morgan	"[Working on our own] made us consider different options and use what we had known worked in the past" (Morgan_Phy_Lab7)
Justin	"The teacher needs to put some observation skills, structure, and expectations in place. That said, students learn by asking and doing" (Justin_Phy_Lab11)

When discussing the sub-practice *Make Predictions*, the focal preservice teachers had a difficult time differentiating between a prediction and a hypothesis. The *Framework* for the Next Generation Science Standards defines a hypothesis as “neither a scientific theory nor a guess; it is a plausible explanation for an observed phenomenon that can predict what will happen in a given situation” (National Research Council, 2012, p. 67). One way to tease apart the difference is that hypotheses are built from existing theories and predictions are made from past experiences. Some of the participants used the terms interchangeably and when asked to differentiate between the two, they said that a prediction was “more of a guess about what will happen” (Edith_Phy_L15), and that a hypothesis is “what you will test to prove (or disprove) in your experiment” (Angie_Phy_L15). One of the major elements of *Make Predictions* that was only mentioned by Angie is that predictions should be made with a rationale or justification. The participants' knowledge scored just below the novice level on the LOS rubric for *Make Predictions*. This was a little lower than their engagement score, which was very close to the novice level. *Make Predictions* is one of the only sub-practices where the preservice teachers scored slightly higher in their engagement. This difference could be attributed to their confusion between hypotheses and predictions.

The preservice teachers made the most comments about the *Plan Procedures* sub-practice. The participants’ ideas about the major feature of this sub-practice took opposite positions. This was the decision of who should do the work of planning procedures, students or teachers. Those considering teacher-led investigations supported this claim by discussing the safety precautions for certain labs or the amount that students could learn during the lab. For example, they argued that if students did it their own way, they could come to faulty conclusions or might not pick the best method given their inexperience. Those who argued for student-led investigations said that in their own experience, they liked having “the freedom to do it how it made sense to them” (Amber_Phy_L7). They also made arguments that it is more equitable for students, they might remember the material better, and if it is too teacher-led, it might not be considered an investigation at all. There was also not a clear line between those who thought one way versus the other. Some of the preservice teachers made comments contributing to both arguments. These preservice teachers were in a middle ground. The middle ground comments described it as a sharing of the planning to give both groups a say in the investigation. These preservice teachers made arguments like the following:

> I think that the general framework for scientific investigations needs to be provided by teachers (depending on age also). But then students should be able to follow the general outline. Maybe working up to be more independent throughout the year. (Edith_Phy_Int)

This approach implied that the teacher would provide a general framework for the investigation and that the students would have the freedom to work within that framework to meet the objectives of the investigation. They based decisions about the amount of framework on the students’ prior knowledge, age, and experience in the course. I built the physics course with a similar mix between instructor and student designed investigations. Angie summed up her experience in the class this way:

> If I had an objective to reach, … Um, it was frustrating sometimes but it was like it helped me learn the most because you weren't sitting there just telling me what to do and how it worked. Like we actually had to figure it out and really think about what we did and why it worked or why it didn't work. (Angie_Phy_Int)

In this comment, Angie recognized the additional mental effort made by students to do this work themselves, but she also saw how it benefited her as a student. The focal preservice teachers’ knowledge scored between the novice and intermediate level on LOS rubric. This was a little higher than their novice level engagement score, indicating that while some of the participants leaned more towards student led investigations, their overall engagement showed that they lacked skill in student led investigations. In their overall discussions, they focused most on the difference between how teacher versus student led an investigation should be rather than discussing the details of planning an investigation (e.g., deciding the number of trials, controlled variables, available tools).

Each of the focal preservice teachers claimed that quantitative and qualitative data are equally valid forms of data to use in science. They reasoned that the type of data you need depends on the circumstances of the investigation and that they are useful for different things. For example, Edith claimed that quantitative data can be used to find exact measurements, while qualitative data is better for observing the general idea of things. This view was held by many of the preservice teachers and Jamie took it a little farther saying that quantitative data might be more valuable when building an argument.

In summary, for each sub-practice but one (*Make Predictions*) the preservice teachers had a higher LOS knowledge score compared to their engagement, giving more evidence to the argument that knowledge could lead their ability to engage in the practices. In this case the scores between the two were closer together compared to the modeling scores showing how their extra prior experience could have made a positive difference in this practice. In the case of *Make Predictions*, this could be because of their confusion between a hypothesis and a prediction. With *Plan Procedures*, the preservice teachers made comments for either teacher led or student led investigations and they generally ignored the details of this sub-practice. For Planning & Conducting Investigations, the preservice teachers' CCK (weighted LOS score across each sub-practice) was between the novice and intermediate level (2.54) and was slightly higher than their CCK for Scientific Modeling. The focal preservice teachers commented on many of the main features of this practice (e.g., asking questions about the "why" of phenomenon, using a balanced approach between teacher and student designed investigations), but their ideas about other aspects were less sophisticated (e.g., using rationale with predictions, evaluating their investigation questions, giving attention to the details of planning).

Making Sense of Data Analysis & Mathematical Thinking

The focal preservice teachers claimed to have the second most experience with Data Analysis & Mathematical Thinking prior to the physics class. This was especially true for Brad and Edith who took other college science courses which used mathematics more regularly. Many of the preservice teachers saw the connection between mathematics and science. For example, Heather said, “science always has mathematical aspects to it, so it is necessary to have at least a basic understanding of the skills in order to successfully understand science” (Heather_Phy_L2). They emphasized the importance of mathematical reasoning, saying for example that “mathematical reasoning skills enhance one’s ability to do and understand science” (Edith_Phy_L2), and connected this idea to using formulas, comparing variables, solving equations, and understanding data. They also claimed that younger students may have difficulties with aspects of this practice due to their capacity to reason or lack of given math skills.

I organized the preservice teachers’ comments into themes by sub-practice, focusing on topics that the group shared more widely. For example, *Use Tools* broke down into two themes, one about their use of graphs and the second about their views on technology. See table 5-4 for examples of their comments related to each sub-practice.

Table 5-4

Examples of Focal Preservice Teacher Descriptions of the Characteristics of Data Analysis & Mathematical Thinking

Preservice Teacher	*Find Patterns*
Brad	"Mathematical reasoning skills are quite important in understanding science because they allow us to easily identify and record certain patterns" (Brad_Phy_L2)
Angie	"Mathematical reasoning allows us to identify patterns in science" (Angie_Phy_L2)
	Use Tools
Brad	"Graphs allow us to visualize the relationship between two variables … in a much better way than what can merely be shown on a chart" (Brad_Phy_L3)
Justin	"[Technology] allows for the focus to be on critical thinking and analysis, not on tedious plotting" (Justin_Phy_L3)
	Apply Algebra/Statistics
Edith	"Without doing the math, it'd be impossible to really see the lost energy you'd just have to trust the teachers. The disadvantage may be that it makes things a little more difficult" (Edith_Phy_L7)
Amber	"The ones that were directly tied to equations and things like that helped me … see what each piece of the equation actually is because sometimes I feel like it's hard to just theoretically think about what these things are doing" (Amber_Phy_Int)
	Consider Limitations
Angie	"If something seems out of the ordinary or if one point of data doesn't match the pattern … then it needs to be examined … if possible test the data again" (Angie_Phy_L20)
Heather	For conflicting data "ask another group to share the part of their collected data and explain how they got it" (Heather_Phy_L20)

Although *Find Patterns* made up a large portion of the engagement in the physics course, as shown in Chapter 4, the preservice teachers made the fewest comments about it. As seen in Table 5-4, they emphasized the connection between mathematical reasoning and finding patterns in the data. This appeared to be their main function for mathematical reasoning. Based on these answers, the participants scored just above the novice level on the LOS rubric compared to the novice score found in their engagement. They were not specific about how data is organized or what types of mathematical representations they could use to find patterns. Out of all of the preservice teachers, Edith went a little further and discussed the importance of linking her analysis back to real world results and situations.

I separated the preservice teachers' discussion of *Use Tools* into two categories. First is their discussion of the use and function of graphs in science. They discussed graphs as the main tool used to find patterns in data. The preservice teachers commented on how much easier it was to visualize patterns or to compare data with graphs. Edith claimed that graphing helped her to think more about her data and Morgan cautioned that students should not "blindly trust the conclusions from the graph and not question them" (Morgan_Phy_L3), which is an advanced idea. Connected to using graphs, the participants also highlighted using technology. The preservice teachers' experience with technology led them to comment on how much the accuracy of their data improved. They claimed that technology helped them to save time during the labs and it also "allow[ed] for the focus to be on critical thinking and analysis, not on tedious plotting" (Justin_Phy_L3). Overall they scored just below the intermediate level in their knowledge LOS average. That was higher than their engagement score just below the novice level. The participants' score differed by an entire level with this sub-practice, indicating that there was a noticeable difference between these quantities. While the preservice teachers' comments focused on the use of graphs, they did not provide many details about what types of relationships can be found with a given tool and expanded their use of tools to include mechanisms to analyze qualitative data as well.

The preservice teachers' comments related to *Apply Algebra* mainly dealt with using and solving equations. Most of them appreciate how using equations helped them to make connections between the data they collected and the real outcomes they observed. They also noticed that working out the numbers allowed them to see things about abstract concepts, like energy loss, that were invisible to them in the real world experiment. For example, when sending a marble through a roller coaster they designed, the preservice teachers could see that gravitational energy was becoming kinetic energy, but they did not notice how much of the energy was lost until they did the calculations. The one concern that arose was for times when the calculated values did not match the experimental values. Amber said that this could make students skeptical about the concept. The focal preservice teachers' knowledge LOS average was just below the intermediate level compared to their engagement score, just above the novice level. The participants did not discuss the need for student generated expressions.

Even though the preservice teachers had few opportunities to engage in *Consider Limitations*, they made several comments about the sub-practice. When they thought about the limitations and the accuracy of their data, they used things like the amount of correlation in their trendline, outliers in the data, and their prior knowledge of the topic. To resolve these conflicts in the data, the preservice teachers suggested collecting additional data or collaborating with other groups to compare results and methods. They scored an average just above the intermediate level on the LOS rubric. This score was only a little higher than their engagement right at the intermediate level. With these two scores being so close, and considering the small sample size, the difference between these aspects may not be meaningful. This could indicate that they engaged at the same level as their knowledge in this case. The preservice teachers did not discuss the limitations possible in their methods of analysis as well as limitations they saw in their data.

In summary, the focal preservice teachers displayed higher knowledge LOS averages relative to their engagement in the sub-practices for making sense of data. This could mean that outside of the pressures of the lab, they knew what tools they could use and how to find patterns in data, but struggled to do in the real environment. They frequently referenced mathematical reasoning and connected it to the tools they used (graphs and technology) to find patterns in the data they had collected. The weighted LOS knowledge average for Data Analysis & Mathematical Thinking, across each sub-practice, was 2.91 which is very close to the intermediate level. This represents the preservice teachers' strongest CCK level across all the practices. This could be due to their prior experience using mathematics in science and the emphasis on mathematical skills inherent to physics. In most of these sub-practices, the preservice teachers knew the general purpose and function. They did not get into the details of any of these sub-practices (e.g., use of student generated expressions, how specific tools are used, using mathematical representations to find patterns).

Making Sense of Explanation & Argumentation

The focal preservice teachers had their lowest LOS engagement score in Explanation & Argumentation. For many of them, their engagement in constructing scientific explanations prior to the physics class consisted of writing unstructured conclusions statements at the end of lab reports. In the physics class, I introduced many of the preservice teachers to the Claim, Evidence, and Reasoning (CER) framework (McNeill & Martin, 2011). Morgan said, "it was a bit of a challenge at first because it was not something I was used to, but I found it helpful in making sense of the lab … [this] is where a lot of the real solidification of the learning happens" (Morgan_Phy_Int). Using the CER framework provided a scaffold to guide the preservice teachers' thinking about scientific explanations in a way that aligns well with NGSS. Of this new method, Justin said, "it connects observations to science, and it adds justification / clarity / defensibility to a claim. It ensures that thinking always requires logic to be valid" (Justin_Phy_L16). Emily and Edith described this practice as a "meaning-making" (Emily_Phy_L21) process or a space where students can explore the "why?" of a phenomenon. Brad argued that the practices of explanation and argumentation are similar and work together to help students "reach an understanding of scientific principles" (Brad_Phy_L21).

The preservice teachers threaded student sensemaking and the need to defend their claims throughout their comments about Explanation & Argumentation. Table 5-5 provides examples of the focal preservice teachers' comments regarding their knowledge of the sub-practices. The following sections give the details of this knowledge, starting with *Make Claims* and finishing with *Engage in Argumentation*. There were so few comments related to the sub-practice *Identify/Evaluate Arguments* that it is not included in this analysis.

Table 5-5

Examples of Focal Preservice Teacher Descriptions of the Characteristics of Explanation and Argumentation

Preservice Teacher	*Make Claims*
Jamie	"I think making claims about the data that they collected is important because it helps students make sense of the data … and the related scientific concepts" (Jamie_Phy_L24)
Edith	"Based on that data a conclusion is formed and then it is necessary to back that conclusion with the evidence from the data" (Edith_Phy_L4)
	Use Evidence
Morgan	"It is scientific when students can back up what they are explaining with evidence and solid reasoning" (Morgan_Phy_L14)
Amber	"Evidence can be both qualitative like observations or background knowledge, or quantitative like data and statistics" (Amber_Phy_L15)
	Use Reasoning
Heather	"Without the reasoning, nothing connects the evidence to the claim. The reasoning demonstrates understanding of the concepts behind why the observations happened" (Heather_Phy_L16)
Morgan	"Bringing in knowledge of scientific principles that you know and data that you collected … Pulling those together and making connections between that knowledge and what you saw in the lab" (Morgan_Phy_Int)
	Engage in Argumentation
Brad	"Argumentation is the process where students can debate the validity of a particular theory or hypothesis" (Brad_Phy_L21)
Heather	"In a classroom setting it's really important for you to hear other students' ideas. to learn about, even if they got it wrong, just to discuss it and maybe they got it wrong, but they found something that another group didn't" (Heather_Phy_Int)

The focal preservice teachers made relatively few comments regarding *Make Claims*. Many of these were simple statements saying that claims need to be supported by evidence. Jamie and Amber described scientific claims as being an answer to the initial investigation question and that by making a claim, students are trying to make sense of the scientific concept they are studying. Justin added that a claim must also be a falsifiable statement saying that, "a claim of 'because God said so' is not scientific" (Justin_Phy_L14). The focal preservice teachers scored at the novice LOS, this was only a little higher than their engagement score 1.78 (just below the novice level). This is another example of a difference between engagement and knowledge scores that might be too small to be substantial. This could mean that if the participants learned more about this sub-practice, the added understanding might improve their engagement. The largest element of this sub-practice missing from the comments was a differentiation between claims that are simply an account of their data or a definition of the phenomenon, compared to claims that explain observed relationships to detail the "why?" of a given concept.

The focal preservice teachers made clear statements that all scientific claims must be backed up with evidence. They said that by using evidence, they established the credibility of their claims. The preservice teachers included the following as reliable sources for evidence: observations, data, trends, other scientific laws, and calculated values. They made no distinction between quantitative or qualitative data as evidence, other than to say that quantitative data is sometimes given more credit in arguments compared to qualitative data. The focal preservice teachers scored just above the novice level for their LOS knowledge score. This was only slightly higher than their score just below the novice level in the engagement. Like *Make Claims*, the difference between these scores may not be large enough to be substantial. Their overall description of scientific evidence closely matches what is described in NGSS. They were not typically clear about needing specific references to data rather than generic references. They also did not discuss choosing evidence that fits the aspects of the phenomena being studied.

The focal preservice teachers commented on *Use Reasoning* the most. Their discussion broke down into two themes: connecting the claim and the evidence, and using scientific theory. Edith explained it this way, "[reasoning is] an analysis of how and why you are interpreting the data the way you are" (Edith_Phy_L4). They made general comments about using reasoning to connect their evidence to the claim. Heather explained a little more saying, "reasoning demonstrates understanding of the concepts behind why the observations happened" (Heather_Phy_L16). The last function of reasoning is for "students [to] use scientific principles they understand to describe phenomena they don't understand" (Brad_Phy_L14). By applying laws or theories they are already familiar with, this becomes a space where student sensemaking happens. The average LOS knowledge score for this sub-practice was between the novice and intermediate level compared to their novice level engagement score. While the preservice teachers explained most of the elements of reasoning, they did not discuss the need to assess and evaluate their reasoning to see how well the claim and evidence are connected and supported.

Due to the spoken nature of *Engage in Argumentation*, the preservice teacher lab sheets contained no records to score for an engagement LOS average. The preservice teachers did have the opportunity to engage in this sub-practice which consisted of comparing and defending their claims with other lab groups as well as whole group presentations of their explanations and supporting data. The preservice teachers described argumentation as needing to convince or make an explanation against other possible arguments. This was in contrast to a scientific explanation just being "explaining why something is that way" (Edith_Phy_L21). In their descriptions of argumentation, they mentioned needing to either prove or disprove something. Many of the preservice teachers also discussed using their results, findings, and logic to defend their positions. The focal preservice teachers scored between the novice and intermediate LOS levels for their knowledge of *Engage in Argumentation*. Missing from their dialog were comments that focused on the listening end of an argument. These are things like probing the reasoning and challenging the ideas of the presenter.

In summary, as seen among most of the other sub-practices, the participants scored higher in their LOS knowledge (CCK) compared to their engagement, although in some cases the differences were minimal. The focal preservice teachers showed the strongest knowledge for *Use Reasoning*. They valued this sub-practice and tied it to student sensemaking in science. Across each sub-practice, the overall weighted average for Explanation & Argumentation was 2.34 for their knowledge LOS. This placed their CCK for this practice just above the novice level which is consistent with how new they were to the CER framework. Throughout these sub-practices, the preservice teachers emphasized the need to support findings with evidence and the essential role this practice plays in student sensemaking.

Summary and Conclusion

Table 5-6 summarizes the findings from each science practice, breaking them down by sub-practice. In each case, I use the table to highlight the preservice teachers' major understandings and the topics they understood less well.

Table 5-6

Summary of Areas Where the Participants Have Well-Established Knowledge and Areas for Improvement

Sub-Practice	Areas of Strength for CCK	Areas of Improvement for CCK
Scientific Modeling		
Model "OF"	• Make connection between the phenomenon and real world • Make abstract phenomena visible	• More emphasis on the "how" or "why"
Model "FOR"	• Use models to make connections, for understanding	• Use models to: make predictions, collect data, or show relationships
Identify Limits	• All models have limitations • Limitations are places where the model does not match the real-world data	• Use known limitations to revise and adjust models
Plan & Conduct Investigations		
Collect Data	• Gave equal weight to both quantitative and qualitative data	Not enough data to make a judgment for this sub-practice
Plan Procedures	• Plan collaboratively with students (mixed agreement)	• The details of planning: number of trials, controlled variables, tools, …
Make Predictions	• Based on prior knowledge • Must be testable	• Differentiate between hypotheses and predictions • Need rationale or justification (scientific)
Investigation Question	• Questions guide investigation • Questions should focus on the "why" and not just facts	• Students should evaluate and revise questions for relevance

Data Analysis & Mathematical Thinking		
Apply Algebra	• Equations can connect variables to observed outcomes • Numeric analysis can make invisible phenomena visible	• Need to not only have students use equations and expression, but generate them as well
Consider Limitations	• Consider the accuracy of data • Look for outliers • Identify general trends in data	• Look for limitations beyond the data, for example in the analysis as well
Find Patterns	• Main function of mathematical reasoning	• Description of methods of analysis • Test patterns against real world data and solutions
Use Tools	• Use of graphs as a major tool, they make data visible • Use of technology to improve data analysis	• Additional tools for data analysis, especially those for analyzing qualitative data
Explanation & Argumentation		
Make Claims	• Need to be supported by evidence • An answer to the investigation question	• Claims are more than an account of the data, they should address the "why" of a concept
Use Evidence	• Establishes the credibility of a claim • Can come from a variety of sources (data, trends, calculations, …)	• Evidence should be specific references to data not general
Use Reasoning	• Connect the evidence to the claim • Should apply scientific theories	• Assess reasoning to see how well it connects the claim to the evidence
Engage in Argumentation	• Way to either prove or disprove something • Requires evidence to be proof	• Skills related to the listening role in argumentation: probing reasoning, eliciting details, …

This chapter has addressed the question: *How do the preservice elementary teachers make sense of the science practices while they are learning science content?* For most of the preservice teachers, the physics course was the first time they were asked to define and consider science practices explicitly. Throughout their discussions, most of the participants focused on the general aspects of each practice or sub-practice and did not go into the fine details. About the practices in general, the preservice teachers commented on the amount of overlap between the science practices and referenced the practices' connection to their understanding of the nature of science. The preservice teachers also speculated on the practices missing an element of curiosity as a driving force in science.

In every case, the main science practices had higher weighted knowledge LOS averages compared to the preservice teachers' engagement scores (See Table 5-1). It appears as though the preservice teachers could have understood the science practices better than they were able to engage in the practices as students. This could mean that the preservice teachers' knowledge of the practice facilitated their ability to engage in the practice rather than their knowledge of the practice being constructed through their engagement in the practice. It could also be an example of cognitive load, where their engagement scores could have been lower because their attention was divided among many things (e.g., learning new content, managing social interactions in their lab groups).

Based on their discussion about the practices, the preservice teachers demonstrated a generally good understanding of many of the overall purposes of the practices. For example, they made several connections to students' sensemaking through the sub-practices *Model "FOR"*, *Find Patterns*, and *Use Reasoning*. Many of the preservice teachers ignored the specific details of the sub-practices. This was especially evident in their discussion of the *Use Tools* and *Make Claims* sub-practices.

In the next chapter, I present the results related to the preservice teachers' use of the science practices in lesson planning and instruction which is a unique way to apply their knowledge and experience with science practices. Thus, chapter 6 turns to phase two of the study: the science methods class and student teaching.

Chapter 6 Preservice Elementary Teacher Use of the Science Practices in Teaching

In this chapter I present the findings related to the third research question and its sub-questions: *How do the preservice elementary teachers use the science practices in their lesson plans and enactments? How does that use change over time and from one context to another? How do the lesson plans and enactments showcase the sensemaking that the preservice elementary teachers have about the science practices?* These research questions get at the heart of what I am interested in this study. In the end, it is how the preservice teachers use the science practices with their future students that will make the difference in how children experience and learn science in the future.

To answer these research questions, I used lesson plans written by the focal preservice teachers during each phase of the study. Each focal preservice teacher wrote approximately five lesson plans during the physics course and two in the methods course; in addition, three of the student teaching preservice (STP) teachers wrote a series of short lesson plans making up a unit while they student taught. I coded each lesson plan to see which practices the participants used and then scored the lessons with the adjusted level of sophistication (LOS) rubrics. I also coded the videorecords of science teaching from the methods course and student teaching and compared those records to the corresponding lesson plan to see how much their planned teaching with the practices differed from their enacted teaching. Lastly, I used data from the interviews from each phase of the study to better understand what the preservice teachers thought about their use of the science practices in their teaching.

In this work, I characterize teaching knowledge using knowledge of content and teaching (KCT) and knowledge of content and students (KCS), subdomains of pedagogical content knowledge in the Content Knowledge for Teaching framework (Ball et al., 2008). KCT is defined as the knowledge of how the design of instruction intersects with content. For example, a preservice teacher could choose to have their students engage in Scientific Modeling in an investigation on atoms or they might choose to have them use the practice of Data Analysis & Mathematical Thinking to understand the phenomenon. Why they align a given practice with the phenomenon they are teaching is the essence of KCT. KCS represents the intersection of the preservice teachers' understanding of the practices and the knowledge of their students. For example, when teaching first grade students using Scientific Modeling, the participants might have them use a model of the Earth (a foam ball) and the Sun (a flashlight) to make sense of night and day. On the other hand, if they taught sixth grade students, they could have them develop models that predict how increasing an object's mass changes how the object accelerates. In reality, when the participants choose to use a particular science practice, the choice could involve both the content being taught and the students in the classroom. The preservice teachers showcase this knowledge (KCT and KCS), in part, in their lesson plans and engagement with students in science.

In the previous chapters I found that the focal preservice teachers engaged with the science practices near the novice level, with their performance being a little higher for practices they claimed to be more familiar with from past experiences (Chapter 4). Their common content knowledge (CCK) of the science practices was closer to the intermediate level and was more sophisticated than their engagement in every case (Chapter 5). To preview the results in this chapter, I show that the preservice teachers' use of the science practices in their lesson planning and enactments, or their KCT and KCS, differed from the physics course to the methods course and student teaching phases of the study (as evident within the constraints of this study). For most practices, they showed higher levels of sophistication in their teaching during the second phase of the study. These differences could have been influenced by the context of the teaching situations or to the additional instruction of the methods course.

In the following sections I present which practices the preservice teachers used in their planning and break down how the practices they used shifted over the study. I examine which practices they used when planning for a given subject matter. I then show the adjusted level of sophistication scores for the uses of the science practices in the lesson plans. I describe what these scores could mean and present a few different ways to interpret them. This includes looking at how the preservice teachers used each science practice during the study in their teaching and planning. I then look at how the use of the science practices in the enactments compares to their use in the corresponding lesson plans. Finally, I present a set of themes related to the preservice teachers' thinking and sensemaking about using science practices in teaching developed from discussions in the interviews.

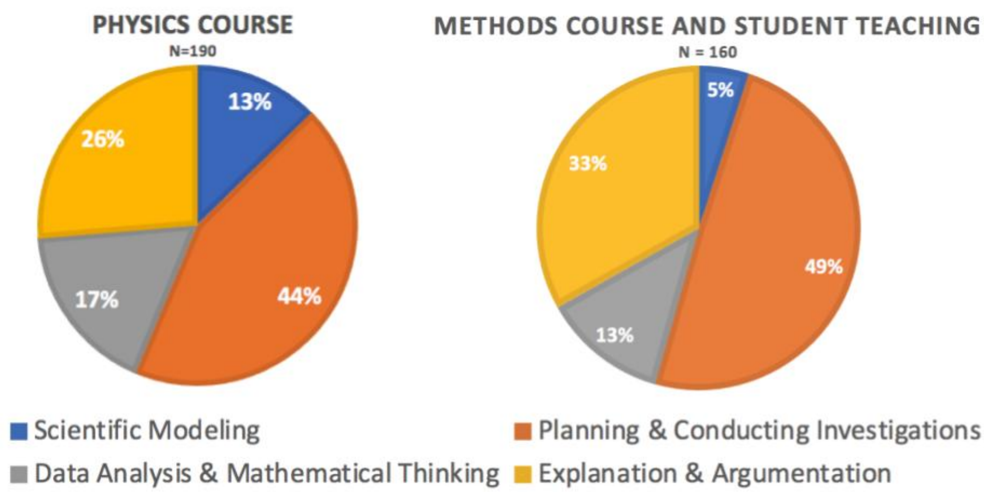
Preservice Teacher Use of Science Practices in Planning Over Time

From one phase to the next, the focal preservice teachers used a range of science practices in their lesson plans to help their students understand the natural world. Figure 6-1 shows which practices they included and how their use changed. In each phase, the preservice teachers primarily used Plan & Conduct Investigations (44% and 49%, respectively). In the physics course the other practices roughly shared the remainder of the distribution with Explanation & Argumentation (26%) making up a larger proportion than Data Analysis & Mathematical Thinking (17%) and Scientific Modeling (13%). In the Methods course and

Student Teaching, the proportion of Scientific Modeling (5%) was smaller than the other practices and the preservice teachers more frequently used Explanation & Argumentation (33%).

Figure 6-1

Distribution of Science Practices Used in Lesson Plans Across the Study

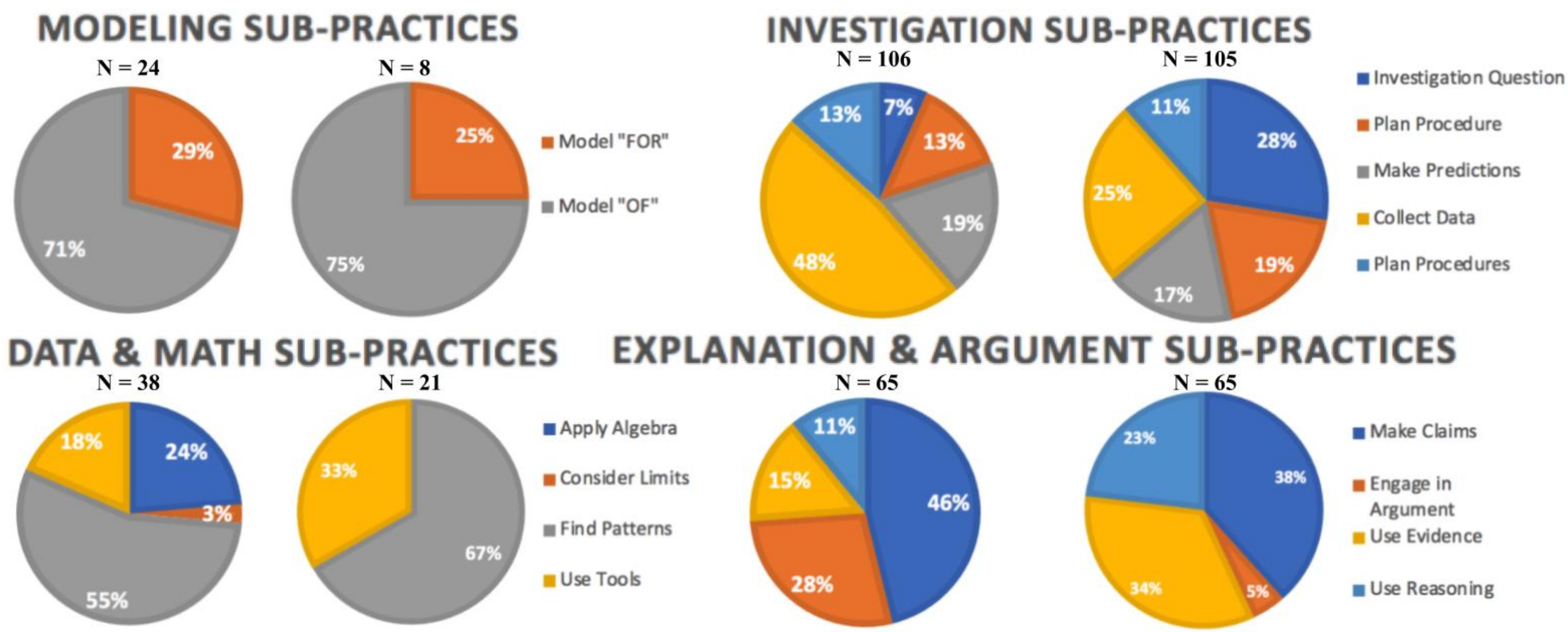


One way to make sense of this distribution could be to consider the preservice teachers' past experience with the practices and the context of the courses the participants were in at the time. For example, the greater use of Plan & Conduct Investigations in both spaces could be explained because many of their past experiences with the science practices included activities like collecting data and making predictions, which are prominent features of that practice. The methods course instructor also encouraged the preservice teachers to plan investigations for their lessons and they did a lot of work with the claim, evidence, and reasoning (CER) framework, which would help explain the prominence of Explanation & Argumentation in that phase. The fact that Scientific Modeling had the fewest uses in each phase could also reflect their inexperience with this practice. Several of the focal preservice teachers claimed to have never done any modeling prior to the physics class and this could have made them less likely to use it in their own teaching. One other contextual factor is that the science methods course does not focus on Scientific Modeling and the curriculum materials used to guide the preservice teachers planning did not include modeling either. This could account for the drop in Scientific Modeling across the two time frames (13% - 5%).

Figure 6-2 shows the distribution of the focal participants' use of the sub-practices in their lesson plans over the study. To highlight some of the notable differences, with Plan & Conduct Investigations, the participants used the same sub-practices in each period of the study, but the proportions were more balanced during the methods course and student teaching. Again, the methods course's focus on investigations seems apparent; the focal preservice teachers have a more balanced approach to the practice, which includes a greater focus on *Investigation Questions*. In Data Analysis & Mathematical Thinking, the participants used a greater variety of the sub-practices in the physics course. This could be because the subject matter used in the physics course lessons lent itself to sub-practices like *Apply Algebra*. In each phase the preservice teachers primarily used *Find Patterns*, which could be an indication of their emphasis on student sensemaking. With the practice of Explanation & Argumentation, the preservice teachers used *Engage in Argumentation* at higher frequency than their methods and student teaching lessons.

Figure 6-2

Distribution of Sub-Practices Used in Lesson Plans Across the Study.



*The physics course data is on the left and the science methods and student teaching data is on the right.

In summary, the proportion of which practices and sub-practices the participants used changed over the course of the study. These differences were likely due in part to elements of the context such as the subject matter and the target grade level of the lesson plans. The practices used in their lesson plans could have also been influenced by which practices the instructors emphasized in each phase of the study. For example, the methods course focused on Planning & Conducting Investigations and Explanation & Argumentation which might explain the distributions of their related sub-practices.

Unpacking Knowledge of Content and Teaching and Knowledge of Content and Students

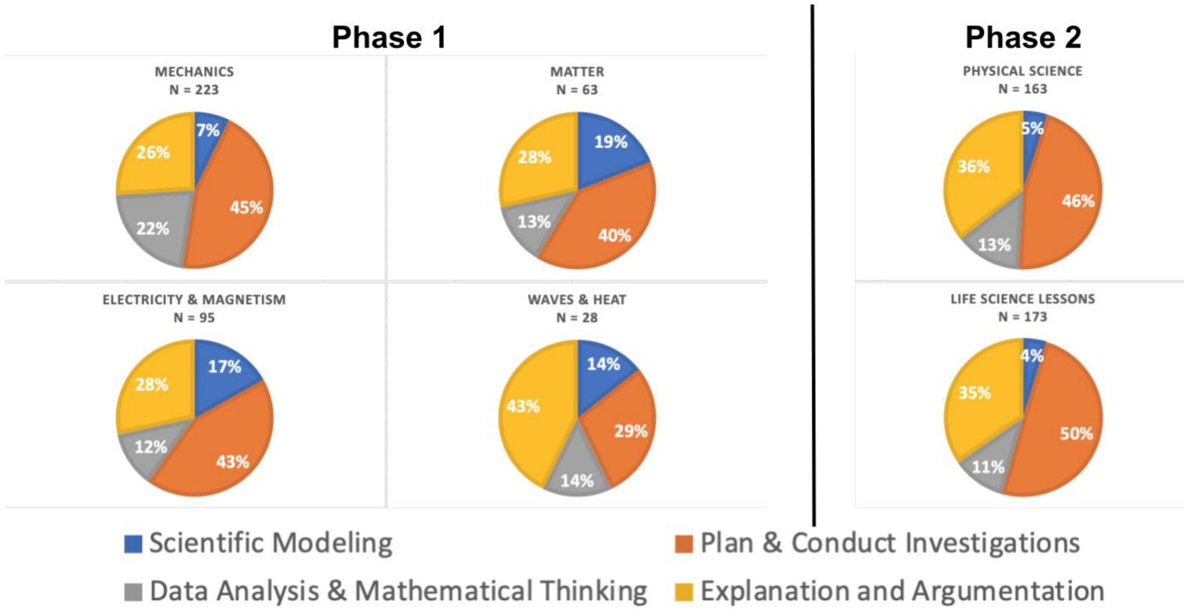
In the following sections, I unpack the data found in the lesson plans related to the preservice teachers' knowledge of content and teaching (KCT) and their knowledge of content and students (KCS). I also draw on several examples from the lesson plans to illustrate the findings. The data I used in each section only illuminates a portion of what the preservice teachers' knowledge could possibly be.

Knowledge of Content and Teaching

One way to interpret the participants' KCT is to look at which practices they use with the content they are teaching. Figure 6-3 displays how the participants' use of the science practices breaks down by subject matter for each phase of the study. Because the contexts of each phase are so different (e.g., phase 2 lessons were written for real students and in classrooms with real constraints), I chose not to compare the KCT of the participants from one phase to the other. Instead, I looked for patterns within each phase.

Figure 6-3

Distribution of the Uses of the Science Practices Separated by Phase of the Study and Subject Matter



I separated the physics lesson plan data by the focal subject matter of the course (Mechanics, Matter, Electricity & Magnetism, and Waves & Heat). While the lesson plan proportions from each subject matter do not match the participants' experiences from the original course (see Figure 4-1), there are similar patterns. For example, they used Scientific Modeling more frequently in the Matter and Electricity & Magnetism lesson plans. A lot of the content from those subjects is non-visible phenomena and, in those cases, Scientific Modeling is a good fit and could demonstrate sound KCT. Across each subject matter, the preservice teachers appear to lean on the practices that align with their past experience and that fit the Engage, Experience, and Explain and Argue (EEE+A) framework (see Kademian & Davis, 2020) of the lesson plan template. This template lends itself to investigation style lessons and provides a clear space for scientific explanations. The distributions showing which practices the preservice teachers used, could be more influenced by the lesson plan template than the participants' KCT. In other words, without the constraints and guidance of the template, the preservice teachers might have used different practices that better fit their understanding of the content or their planned learning goals for the students.

I was surprised by the comparison of the use of the practices in the phase two lesson plans. I separated these lessons into two groups, lessons that focused on physical science material (e.g., physics, Earth science, chemistry) and life science material (e.g., environmental science, biology). I expected there to be a noticeable difference between the two subject matters because of how different they are, but the participants used the practices with almost the same proportion for each subject matter. This could be more evidence showing the impact on planning with science practices that the lesson plan template has on instructional decisions. The participants planned the majority of the phase two lessons using the program's instructional planning template which emphasizes investigations and scientific explanations (the two dominant practices from that phase). The instructional planning template was more scaffolded than the lesson planning template used in the physics course, this could also account for part of the uniformity in use between the two subject matters.

Figure 6-3 gives one perspective of the preservice teachers' KCT. To see a clearer picture of the participants' KCT, Chapter 8 examines two cases to get into the details of the participants' lesson planning and science practice choices.

Knowledge of Content and Students

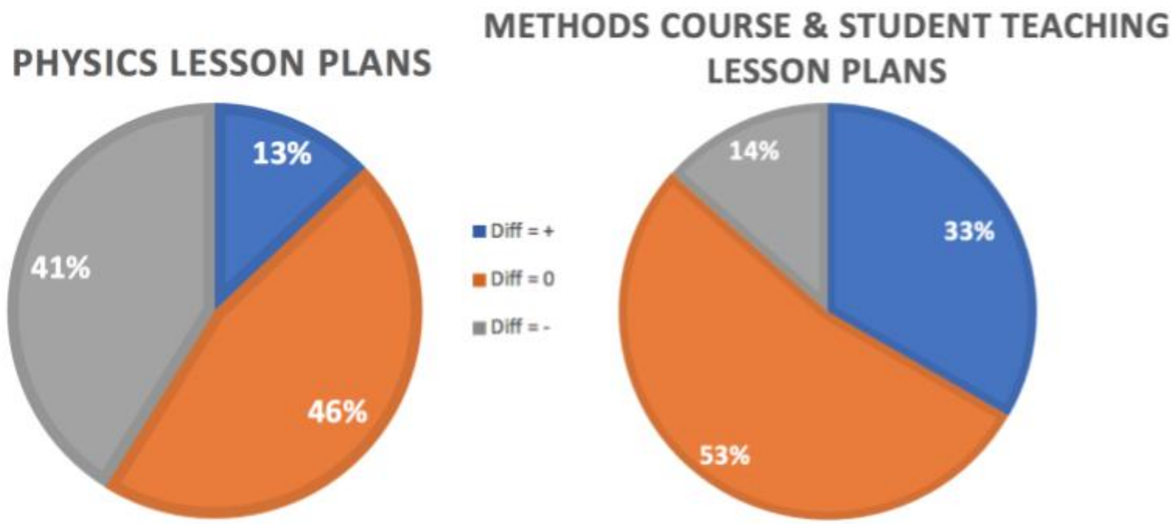
I used the LOS rubrics to evaluate how the preservice teachers used their knowledge of content and students (KCS). Students have many different characteristics that can influence instructional decisions (e.g., cultural or linguistic background, grade level, gender). This study focuses on the students' grade level. In the physics course, the participants planned lessons for imagined students and the only characteristic they clearly defined was their grade level. To remain consistent and due to insufficient data on the students, the phase two data also only conditions the KCS on the students' grade level.

Level of Sophistication Rubric Scores for the Science Practices Used in Lesson Plans

The level of sophistication (LOS) rubric scores assigned to the preservice teachers' KCS cannot be conceptualized in the same way as the engagement (Chapter 4) and common content knowledge (CCK) scores (Chapter 5). This is because the participants prepared lessons for particular grade levels. Students in first and second grade cannot be expected to engage in the science practices with the same sophistication as fifth and sixth graders. This is why *Appendix F* of the *Framework* (NRC, 2013) included grade level progressions for the practices. In building the LOS rubrics, I included the influence of the grade level progressions. Figure 6-4 shows the general distribution of how the participants' *use* of the practices in their lesson plans (the teaching LOS scores) compared to the target grade levels of the students. For example, if a participant planned a lesson for the target grade range 3rd - 5th, I would *expect* their uses of the science practices to be at the novice level (a score of 2). The rubric is organized around the grade bands of the NGSS in the following way: K-2nd (score of 1), 3rd-5th (2), 6th-8th (3), and 9th-12th (4). In a lesson plan for the grade level 3rd - 5th, if a participant used a sub-practice at the pre-novice level (a score of 1), the difference between their *use* (score 1) and the target grade level (score 2) would be negative. The negative difference (-) would indicate that the participants were likely underestimating the capabilities of their students. Likewise, if they used a practice at the intermediate or experienced level (a score of 3 or 4), the difference between their score and the target grade level would be positive. In that case, the positive difference (+) would indicate that they could have overestimated the capabilities of their students.

Figure 6-4

Distribution Showing the Difference Between the LOS Score of the Planned Use of the Practice Compared to the Grade Level of the Students



The results in Figure 6-4 show what percentage of the participants' uses of the practices in their lesson plans were above the target grade level (+), at the target grade level (0), or below the target grade level (-). A preliminary examination of the data suggests that there is a difference in how the participants used the science practices in their lessons from phase one to phase two. For example, during the physics class, the participants were more likely to use the practices below the target grade level of their students (41%) compared to the methods and student teaching lesson plans (14%). This could mean that the participants' physics lesson plans were more likely to underestimate the likely capabilities of their hypothetical students. In phase two of the study, on the other hand, their plans were more likely to overestimate the likely capabilities of their students.

To evaluate the preservice teachers' KCS and to be able to make limited comparisons among the KCS (this chapter), engagement (Chapter 4), and CCK (Chapter 5), I constructed an adjusted LOS rubric score for KCS that conditioned their knowledge based on the target grade level of the students. I qualified the participants' KCS using three levels: *strong, expected, or* *weak* (see Table 3-4). *Strong* scores indicate that at least 60% of the LOS scores were at the target grade level with no more than 30% above the grade level. *Expected* scores indicate that at least 40% of the LOS scores were at the target grade level with no more than 30% above the grade level. Finally, *weak* scores indicate that less than 40% of the LOS scores were at the target grade level. This characterization allows for flexibility in how a teacher engages children in the practices, acknowledging that not every engagement will be at exactly the "right" level, but providing an estimate of the overall match between plans and the likely or intended "levels" of the children's capabilities.

Table 6-1 presents the adjusted KCS scores, as well as the engagement and CCK scores from the previous chapters. The KCS scores, which only include the use of the practices in lesson plans, are separated into phase 1 (the physics course) and phase 2 (methods course and student teaching).

Table 6-1

Overall Distribution of the LOS Scores for the Engagement (Chapter 4), the CCK (Chapter 5), and the Adjusted Scores for the KCS

	Engagement (N=1725)	CCK (N=144)	KCS (N=345)
	Phase 1	Phase 1	Phase 1 - Phase 2
Scientific Modeling	1.92	2.52	Strong – Strong
Plan & Conduct Investigations	2.05	2.54	Expected – Expected
Data Analysis & Mathematical Thinking	2.11	2.91	Weak – Strong
Explanation & Argumentation	1.88	2.34	Expected – Strong

At the main practice level, the adjusted LOS scores for KCS show a change in use from phase 1 to phase 2. The participants' adjusted scores for Data Analysis & Mathematical Thinking and Explanation & Argumentation increased to the *strong* level. The scores for Scientific Modeling and Plan & Conduct Investigations stayed at the same level. These scores do not present a complete picture of the participants' KCS because they are only conditioned on the target grade level of the students. Future work could condition the evaluation of KCS on a broader range of student characteristics to create a more complete picture of this knowledge. The following section looks at each science practice in detail, giving the adjusted KCS scores for each sub-practice and providing examples of how the participants used the practices in their lesson plans.

Examples of the Participants' Use of the Science Practices in their Lesson Plans

The focal preservice teachers used the practices in different ways as they moved through their teacher preparation program. Depending on the practice, some of the differences could be attributed to context and others to the preservice teachers gaining skill and understanding. Each example displays varying levels of the participants' KCT and KCS.

Scientific Modeling. The focal preservice teachers had the highest adjusted LOS scores for KCS in Scientific Modeling. Table 6-2 shows how those scores break down for the two sub-practices used in the lesson plans. The preservice teachers also used Scientific Modeling the least in both phases of the study.

Table 6-2

Adjusted LOS Scores for the KCS of Scientific Modeling During the Physics Course and Methods Course / Student Teaching

	N	Phase 1	N	Phase 2
Scientific Modeling	24	*Strong*	7	*Strong*
Model "OF"	17	*Strong*	5	*Strong*
Model "FOR"	7	*Expected*	2	*Expected*

Of the two main sub-practices, the participants used *Model "OF"* more often in their lesson plans and at the *strong* level (i.e., with a high proportion of uses at the target grade level of their students). For example, in the physics course Angie planned to have her students work through a progression of models of the phases of matter. Coupling phases of matter and modeling displays sound KCT because of the invisible nature of the phenomenon at the molecular level. In the lesson, her students would start by drawing what they thought molecules looked like in different phases and after a little instruction they would then all stand up and use their bodies to model the different phases. As a gas, she expected them to "walk quickly or run if there is space (while keeping safe). As they carefully make contact with other students, they should walk or run in another direction. Have them spread around the entire space" (Angie_Phy_LP3). This model matched the grade level of her students by having them create a representation of a non-visible phenomenon. In the methods class, Heather used *Model "OF"* at the target grade level of her students by asking them to use a small sphere on a straw and flashlight to model the difference between night and day. She asked questions of her students like, "what do you think the straw represents?" (Heather_Mds_LPs) to help them reason about the model.

The focal preservice teachers used *Model "FOR"* less frequently. Of the two sub-practices, this type of modeling is more cognitively demanding (Passmore et al., 2014) and less familiar, which could account for the lower frequency. They scored in the *expected* range during both phases. To help the students understand electric fields, Brad planned to have them use a computer simulation modeling the fields around different charges to collect data on how fields change (Brad_Phy_LP5). During his student teaching, Justin planned to have his students collect data on the efficiency of windmill blades they designed in order to improve their models (Justin_ST_LP). Both of these uses of *Model "FOR"* had students collect data to either reason about the phenomenon or to revise the model. These examples showcase exemplary work for

Model "FOR" in both KCT and KCS that were not typical of the other participants for this sub-practice.

Plan & Conduct Investigations. The focal preservice teachers used Plan & Conduct Investigations the most throughout their lesson planning. Table 6-3 shows the adjusted LOS scores for the KCS of this practice during each phase of the study. Overall, the participants used this practice at the *expected* level but there was some fluctuation within the sub-practices. In this section, I highlight and share examples for the sub-practices *Plan Procedures* and *Make Predictions.* I chose these two sub-practices because the participants' use of them shifts between phases and in ways that possibly reveal differences in how the participants make sense of them.

Table 6-3

Adjusted LOS Scores for the KCS of Planning & Conducting Investigation During the Physics Course and Methods Course / Student Teaching

	N	Phase 1	N	Phase 2
Planning & Conduct Investigations	86	*Expected*	78	*Expected*
Collect Data	44	*Weak*	31	*Expected*
Plan Procedures	15	*Weak*	11	*Expected*
Make Predictions	19	*Strong*	18	*Expected*
Investigation Question	8	*Strong*	18	*Expected*

When the focal preservice teachers discussed their knowledge of *Plan Procedures* (presented in chapter 5), their opinions on who should do the work of planning (i.e., teachers or students) was split. Looking across how each of them used this practice in their lesson plans, the preservice teachers did the majority of the planning of the procedures themselves. Many of the lessons had specific details for what the students should do or how they should collect their data. For those who tried to share the planning with their students, they used strategies like giving the students roles within the lab (Angie_Phy_LP3), intentionally giving broad directions that allow for flexibility (Edith_Phy_LP2), use of questioning to build procedures as a class

(Brad_Mds_LPp), and modeling the procedure at the beginning (this was used by most participants in the methods lesson plans). As an example of what a trajectory of change for *Plan Procedures* could look like, I present a sequence of Angie's lessons. In the physics class, her lessons were primarily teacher directed. She used prepared lab sheets to guide her students' work and thinking, and later she introduced the use of different roles for each student to give them some autonomy over a portion of the lab. In both of her methods course lessons, Angie wrote out clear directions for how the investigations would proceed using teacher questioning as a way to keep the students on track and progressing towards the objective. For example, she planned to ask, "what is important to observe and how should we observe it?" (Angie_Mds_LPp). In this example, Angie shows how her questions give the students some choice in how to proceed with the lab. In her student teaching lessons, Angie made a shift to try a student directed investigation:

> Students will be discussing different variables that are in a habitat (ex: light vs dark, two different types of soil, cold vs war, same soil but one is wet soil vs dry). Students will choose one variable to test. Discuss why we only test one variable at a time. Then students will plan the investigation. (Angie_ST_LP)

She did not give any further explanations or expectations beyond this, but here she shows a shift to allow her students the chance to design their own experiment. This shift in Angie's use of *Plan Procedures* could be due to her working with and understanding real students, showcasing increased KCS. Not every preservice teachers' trajectory looked like this, but Angie's progress is a promising example of what could be possible. Another way to interpret the difference could be to look at her KCT. Angie claimed to be more confident with science topics that did not require as much mathematics. In this example, she was willing to give her students more autonomy in the lessons where her own content knowledge seemed stronger.

From the physics course to the methods course and student teaching, the preservice teachers shifted how they used *Make Predictions*. The adjusted LOS scores changed from *strong* to *expected*. This change seemed to be related to the peer teaching lessons. Several of the peer teaching lessons targeted the 2nd grade (pre-novice level) and the way the participants used predictions were above that level. In the physics course lesson plans, many of the predictions asked for simple statements of fact, such as, "students will begin by making initial predictions about which balloon is filled with the solid, liquid and gas" (Amber_Phy_LP4). These predictions were testable but did not take the more sophisticated step of asking students to provide content related reasoning. For most of the preservice teachers, their goal was to "get the students to begin thinking about the prior knowledge" (Edith_Phy_LP3) before they engaged with the phenomenon in the lab. In the methods class lesson plans, after instruction about the importance of justifying predictions, the participants included a request for reasoning with almost every prediction. As an example of a grade appropriate request, Morgan asked her students to:

> Talk to a partner and make a prediction about what you think will happen to the limp celery in the red water and clear water … Record those thoughts on your investigation sheet using words or pictures, then share with your partner what you already know about plants that makes you [think] that. (Morgan_Mds_LPp)

In this example, when Morgan asked for her students' justification, she situated it in relation to their prior knowledge and included a "pair-share" teaching move to help her students. For the younger grades (K-2), providing justifications can be too sophisticated a move if they are required to be content related rather than motivated by prior knowledge. Within the methods lesson plans, some of the preservice teachers used language that was unclear about how the prediction would be justified.

Data Analysis & Mathematical Thinking. The focal preservice teachers used Data Analysis & Mathematical Thinking in approximately the same proportion (~15%) across the phases of the study. However, the only sub-practices present in phase two were *Find Patterns* and *Use Tools*.

From one phase to the next, the adjusted LOS scores for the participants' KCS increased. One part of the context to keep in mind is the shift in science content from phase one to two. I required the preservice teachers to focus on physics content in their phase one lessons. Many of the lessons in phase two, from the peer teaching and field lesson plans, had a life science focus which tended to be less quantitative in nature. The change in subject matter would have required the preservice teachers to use their KCT in a different way. For example, although these lessons did not collect quantitative data, the participants would still need to include data analysis methods that matched the new content. Table 6-4 shows the breakdown of the adjusted LOS scores of the KCS in the lesson plans.

Table 6-4

LOS scores for the KCS of Data Analysis & Mathematical Thinking during the physics course and methods course / student teaching

	N	Phase 1	N	Phase 2
Data Analysis & Mathematical Thinking	35	*Weak*	21	*Strong*
Apply Algebra	7	*Expected*	-	-
Find Patterns	21	*Weak*	14	*Expected*
Use Tools	7	*Weak*	7	*Strong*

As a general use of *Find Patterns* across the study, the participants referenced using it to prepare evidence for scientific explanations. Their planning around this sub-practice shifted from the physics course to the methods course and increased in sophistication. In the physics course, many of the examples included general statements to have students find patterns, and gave no details about how they could do that. As an exception to this trend, in a lesson about buoyancy, Brad encouraged his students to "notice any patterns that they could turn into rules which govern the 'floatability' of an object" (Brad_Phy_LP3). In this example, Brad planned for his students to use their data to make sense of the phenomenon, which is the purpose of finding patterns. Emily did the same kind of work in her first lesson plan on Newton's Second Law, but her focus was on having the students find patterns in their graphs to "make the law in question more visible" (Emily_Phy_LP1). This example showcases Emily's KCT as she used the quantitative nature of the content and paired it with the construction of graphs to build understanding. In the methods course, many of the focal participants took their use of *Find Patterns* a step further. For example, in her peer teaching lesson, Edith planned to ask her students to share their data between groups for comparison before they decided on any general trends. Others made similar plans to have groups share data for the analysis or to collect all of the class data into one place for analysis. This collaborative work improved the use of the sub-practice without putting it beyond the target grade level of the students, an example of KCS.

The *Use Tools* sub-practice is another case where I found a clear difference across the phase one and phase two scores. During each phase of the study, the participants included tools like t-charts, several references to graphs, data tables, and bar-graphs for both quantitative and qualitative data. In some lessons, the use of tools contained several layers of analysis. For example, in physics, Angie planned to have her students video record the flight of a rubber band and then use computer software to analyze the motion in order to build velocity graphs which could be used to construct additional graphs related to the main variables of the investigation. This use of tools and technology was beyond the grade level of her target students (displaying weak KCS), but it aligned well with the content she was teaching (an application of KCT).

In the methods course, the participants discussed the use of graphs and charts as whole group board work. Some lessons differed because the teacher would construct the graph or chart for the students to use in their analysis. In these cases, the participant could have done this because of the grade level of the students (a decision motivated by KCS) or it could have to do with the amount of available teaching time (a constraint of the environment). For example, Morgan planned to move between the groups during an investigation, gathering their data and charting it for them in one main place on the board because the students were in the first grade and could not do this for themselves (Morgan_Mds_LPs). *Use Tools* was a sub-practice where the preservice teachers became more aware of the differences between the skill levels of different age groups. For example, in the case of Angie's lesson (during the physics course), the technology she planned to ask her students to use was a little advanced for the grade level she chose and many of the other participants made similar moves in their early lessons. The use of tools in the methods course and student teaching better matched the capabilities of the younger students. This could be because the preservice teachers knew their students after spending time observing them during their practicum. This could account for the group's higher KCS scores in the second phase.

Explanation & Argumentation. The preservice teachers used Explanation & Argumentation with the second highest frequency in both phases of the study. At the sub-practice level, they used *Make Claims* the most and supported many of these claims with the *Use Evidence* and *Use Reasoning* sub-practices. The participants did not have written evidence (in their lab sheets) of *Engage in Argumentation,* but it was present in their lesson plans. Table 6-5 shows the adjusted KCS rubric scores for the Explanation & Augmentation sub-practices. The participants' KCS (related to use of the practices in terms of student grade level) of *Use Evidence* stayed constant and *Make Claims* and *Use Reasoning* improved, from phase one to phase two. The participants used *Engage in Argumentation* more often in the physics lesson plans but used it more proficiently in the second phase, when present. In relation to KCT, I would argue that the practice of Explanation & Argumentation is not more or less appropriate for any given science subject matter. In this case, I would expect most lessons to include an element of explanation construction because this is a fundamental aspect of student sensemaking in science regardless of the given subject matter. In the following paragraphs, I highlight the basic features of the changes in *Use Evidence* and *Use Reasoning*. I also show how the focal preservice teachers used *Engage in Argumentation* in their physics lesson plans, which is a practice that is typically less evident in preservice teachers' lessons.

Table 6-5

Adjusted LOS Scores for the KCS of Explanation & Argumentation During the Physics Course and Methods Course / Student Teaching

	N	Phase 1	N	Phase 2
Explanation & Argumentation	63	*Expected*	65	*Strong*
Make Claims	29	*Expected*	25	*Strong*
Use Evidence	10	*Expected*	22	*Expected*
Use Reasoning	7	*Expected*	15	*Strong*
Engage in Argumentation	17	*Expected*	3	*Strong*

In the physics course, the participants talked about *Use Evidence* in a generic way, referencing it as a part of scientific explanations. They included data and findings as things that can be used as evidence. Going beyond the generic use, Emily said that students should use evidence to "construct their own meanings" (Emily_Phy_LP3). From phase one to two, the participants' KCS stayed at the *expected* level. With *Use Reasoning*, the preservice teachers mentioned using scientific principles to support claims several times in the physics class lessons but did not take the practice further than this.

The biggest difference between the way that they used each part of the claim, evidence, and reasoning framework in the methods course compared to the physics course was that they took a moment in the phase two lesson plan to teach their students about the practice rather than expecting them to just engage in it, showing an increase in their KCS. For example, Amber used a series of questions to help her students think about evidence: "do we have any evidence that supports this claim?, why does that evidence/data support the claim?, is there any more data that supports our claim?" (Amber_Mds_LPp). Jamie included, "I will explain that the patterns/trends we notice can also be called Evidence, and scientists collect this to make Claims" (Jamie_Mds_LPs), to teach her students about evidence. This shows a different aspect of KCS, it is more than just knowing how to use the science practices with your students based on their characteristics, but also teaching them about the practices themselves.

I found a similar pattern with *Use Reasoning*. Heather taught her students that reasoning is "a justification that shows why the data counts as evidence to support the claim and includes appropriate scientific principles" (Heather_Mds_LPp). Helping children understand what the science practices are and how to engage in them was a focus of the methods course instruction and is likely the reason why their KCS increased between the phases.

Typically, there is less evidence of argumentation in science lessons at the elementary level (Biggers et al., 2013). Despite this, argumentation appeared with a relatively high frequency in the physics lesson plans. The use of this sub-practice could have been a product of the discussions and presentations that occurred after the investigations in the physics class. In those discussions, I encouraged the preservice teachers to share their explanations and challenge each other's ideas. In the physics lesson plans, the participants mirrored this with their imagined students by asking them to share their claims and findings with each other and to have a chance to either "agree or disagree" with each other. Most uses of the sub-practice looked similar to this: "each group will then report out to the class what they discovered and have a chance to agree or disagree with the other groups findings" (Amber_Phy_LP1). A few went a little farther and asked their students to have an "active discussion based on their observations" (Heather_Phy_LP3). Brad had the most sophisticated use of this practice in his last physics lesson plan. He wrote,

> In this discussion have students engage in a friendly debate where they can agree or disagree with the claims of their classmates regarding the patterns they noticed in the lab. Have them practice refining their hypotheses and observations by challenging them to precisely identify any patterns they were observing. (Brad_Phy_LP5)

When Brad had his students refine their hypotheses, he pushed them toward the core purpose of argumentation, which is to refine and test claims against their peers' ideas and data. Amber used this practice in her two methods lesson plans, but it did not persist for any other participant. This could be due to actually needing to teach the lessons with children and they could have been nervous about conducting a "friendly debate" (which sounds good on paper) with real students. Lastly, argumentation was not a focus of the methods course, unlike the elements of the CER framework.

Summary of KCT and KCS with Regard to the Practices

In summary, the focal preservice teachers' use of the science practices in their planning showed differences in their KCT and KCS. These differences could be due to the new learning they gained in the methods course or to differences in the contexts between the phases of the study. They showed the most sophistication (related to KCS) with their use of modeling. This was especially true during the physics course when they had the most exposure to modeling. Their modeling lessons also aligned well with the subject matter (e.g., matter, electricity and magnetism) showing high KCT. With Plan & Conduct Investigations, the participants improved how they used *Plan Procedures* by beginning to share some of the responsibilities with their students over time, which better matched the target grade level of those lessons. This showed greater KCS as the preservice teachers increased the amount of agency of their students. In Data

Analysis & Mathematical Thinking, the preservice teachers used more quantitative skills during the physics lesson plans and transitioned to more qualitative methods in the phase two lessons because of the shift in subject matter. This indicated a well-developed KCT for this practice for the majority of the participants. Last, with Explanation & Argumentation, they included instruction for the elements of the CER framework during the second phase of the study. This could be because of the experiences they had in the methods course about needing to be explicit with the practices to teach equitably, showing an increase in their KCS.

Use of the Science Practices in Enactments

I used videorecords from each of the focal preservice teachers during the methods course and from the STP teachers during their student teaching to evaluate their enactments. To characterize the videorecords, I took a modified version of fieldnotes where I recorded which practices the participants used, how they used them, and what supports they used with their students. I drew on approximately 18 hours of videorecords from the 9 focal preservice teachers' methods course lessons and 2 hours from the STP teachers' student teaching lessons for this analysis.

The focal preservice teachers' use of the science practices in their lesson enactments closely matched the descriptions they wrote in their lesson plans. In several cases, the way they planned to use the practices was an exact match to what I saw in the recorded enactments. Table 6-6 shows how much, in terms of the LOS rubric scores, the enactments differed on average from the lesson plans. Each of the average differences were close to zero, with Plan & Conduct Investigations and Explanation & Argumentation being slightly less than zero (i.e., the use of the practice in the enactment was slightly less sophisticated on average than what was planned in the lesson), and Data Analysis & Mathematical Thinking being a little higher than zero (i.e., the enactment was slightly more sophisticated than the plan).

Table 6-6

Average Differences Between the LOS Scores of the Phase Two Enactments and the Associated Lesson Plans

	Average Difference
Scientific Modeling	0*
Plan & Conduct Investigations	-0.17
Data Analysis & Mathematical Thinking	0.28
Explanation & Argumentation	-0.06

*Only three comparable instances found within two lessons

Scientific Modeling. There were very few instances of scientific modeling in both the lesson plans and the enactments; only two lesson enactments included modeling.

Plan & Conduct Investigations. The focal preservice teachers used Plan & Conduct Investigations consistently across their lesson plans and enactments. These sub-practices made up the majority of their enactments, with most of the lesson time spent working on this practice. The preservice teachers showed the most consistency, in terms of where the practice appeared and how often, with the *Investigation Question* and *Make Predictions* sub-practices. These normally occurred at the beginning of the lesson and were done as a large group discussion where the students shared their predictions and reasoning as pairs and then with the whole class. In most cases, *Collect Data* brought the overall average of the enactments a little below the lesson plans. In their plans, the preservice teachers more carefully used written language to qualify the data collection as needing to be clear, accurate, and precise. Most enactments, though, did not reflect these reminders about the nature of data collection. While coding the enactments, I observed the sub-practice *Plan Procedures* more frequently than I did in the lesson plans. I found a difference with how the preservice teachers used this sub-practice between the enactments in the peer teaching lessons (when their peers acted like students) and the field lessons (when they taught children). In the field enactments, the preservice teachers took more control of the planning, giving very specific directions to the students or showing them how to do different parts of the investigation by modeling it beforehand. When teaching their peers, they experimented more with using questions to build the procedure together. This difference could be due to the "safe" nature of peer teaching where the preservice teachers are risking much less if the investigation goes awry; indeed, that is the very intent of the peer teaching experience.

Data Analysis and Mathematical Thinking. The sub-practices of Data Analysis and Mathematical Thinking scored slightly higher in the enactments than those in the lesson plans. This was primarily due to the *Find Patterns* sub-practice. In the lesson plans, it was unclear how much data would be available, what questions the focal preservice teachers would ask, and exactly how the groups would organize their data. I could clearly see these details in the video records and the details gave extra weight to this practice. I found a similar trend with the *Use Tools* sub-practice in the enactments. I could more easily identify the details of the tools (often in the form of graphic organizers) given to the students to analyze their data during the enactment.

Explanation & Argumentation. It was more difficult to code and find a difference for the Explanation & Argumentation sub-practices because, while most every lesson plan included scientific explanations, in several enactments, the preservice teachers ran out of time and truncated this portion of the lesson. In the peer teaching enactments this was less of a problem because the preservice teachers had a dedicated teaching section called "Explain and Argue" to practice these skills. In the field lessons and student teaching enactments, which were taught to children, the management of the class (time spent transitioning between activities or waiting for students) and the length of the pre-investigation discussions left little time at the end for the sensemaking work of constructing explanations let alone engaging in argumentation. In these engagements, the participants typically used *Make Claims* and *Use Evidence* together, but very few of the enactments reached the point of *Use Reasoning*. In the enactments, the class did most of this work in whole group discussions where the students shared their findings and used sentence starters to create statements.

Using Teaching Moves Across Practices. One element of the enactments that stood out in the videos was the influence of group work on how students engaged in the practices. The focal preservice teachers skillfully used the different dynamics of their classrooms to create rich engagement in sub-practices like *Make Predictions*, *Find Patterns*, and *Make Claims* to enhance the science sensemaking experiences of their students. Using teaching moves like "pair share", the participants helped their students discuss their thinking and reasoning within each of these sub-practices. That level of student engagement is difficult to capture in a lesson plan and the LOS rubric does not measure group uses of the practices well.

Preservice Teacher Sensemaking about Teaching and the Science Practices

The sections above detail how the focal preservice teachers used the science practices in their lesson plans and enactments to teach science content. In this section I used responses to interview questions to discover why the preservice teachers used the science practices in their lesson plans and what thinking motivated those decisions. Most of the data comes from responses to the interview protocol questions, "what role will the science practices play in your future teaching?", and "why was it important to include {insert practice or practices} in this lesson?". Over the course of the study, the participants' motivation stayed relatively constant. Table 6-7 shows the major themes developed from their responses. Across the phases of the study, the participants discussed each of these themes but not to the same degree.

Table 6-7

Themes Describing Why and How the Focal Preservice Teachers Used the Science Practices in Their Lessons

Theme	Description	Example
Build Student Understanding	The science practices are used to build student understanding of the science content central to the lesson	"The models and asking questions, observing, having them recording what they see … I think that's all huge to get their minds going and to understand" (Angie_Phy_Int)
Useful Framework/Tool	The science practices can be used as a tool to build and plan lesson plans, but they are not the primary objective of the lesson	"I think they are very important … and I think that they are a useful tool, that's how I would see them, I would see them as a useful tool" (Brad_Phy_Int)
Wide Engagement	All of the science practices should be spread out over a unit or series of lessons (not all forced into a single lesson)	"I would hope that my lessons are going to be built around the science practices and incorporating at least a couple science practices into each lesson to give students the opportunity to practice" (Edith_ST_Int)
Skills Beyond Science	The science practices are skills that students will use beyond their science classroom experiences (other subjects or general life skills)	"To help encourage them to find ways to apply these to all different aspects of their life, so they can see that not only do I think like this inside the laboratory, but it's a way of thinking and engaging with the world" (Justin_ST_Int)
Teach Practices Explicitly	The science practices should be explicitly taught to students as they use them.	"I notice in some classrooms, they are just up for everyone to see … I think that's really important with anything you're teaching … that the people in your room should know what you're doing" (Emma_Phy_Int)
Develop Scientific Skills	The science practices engage students in the work of science	"I think they are important to incorporate into your teaching though, as they develop strong scientific skills in students" (Amber_Phy_Lab24)

Build Student Understanding. From one phase to the next, the focal preservice teachers talked the most about using the practices to build student understanding. They used phrases like, “get their minds going” (Angie_Phy_Int) and “promote inquisitive learning” (Brad_Phy_Int) during the physics phase of study. In the second phase, they talked about “working through things and making connections” (Edith_Mds_Int) and “thinking critically … learning and acting on a practice” (Justin_ST_Int). They thought of the practices as a way to guide the students’ thinking. For example, they could have their students ask questions to motivate an investigation which would lead to analyzing data and explanation building. This process of working through the practices naturally could lead students to engage in sensemaking with building an explanation for the science content as the main goal.

Useful Framework/Tool. Seeing the science practices as a useful framework or tool was not mentioned by as many of the participants as the other themes. This theme is the idea that the science practices should not be the focus of any given lesson. Rather, they are more of a tool that teachers can use to feature the content they are teaching. Emily called them “tools to help” (Emily_Phy_Int) and Angie mentioned using them to “kind of focus the learning goals” (Angie_ST_Int) of her lesson. This idea positions the science practices as teaching strategies. While this is not a bad place to begin, the science practices should do more than this in a lesson. In addition to being a useful lesson planning tool, they should be seen as a way to engage students in authentic science as an essential part of the learning process, which is their intended purpose.

Wide Engagement. The preservice teachers believed that they should not try to force all of the science practices into one lesson. Instead, they thought it was important for their students to have a wide engagement with the science practices, experiencing each one over the course of a unit. In her physics lessons, Heather said that "focusing on a couple at a time I think would be really important" (Heather_Phy_Int). They wanted their students to get practice with the science practices and to build up skill over time. Despite their claim to widely engage their students with each of the science practices, the evidence from their lesson plans suggests that they used most frequently those practices that they had the most experience with. For example, use of Scientific Modeling and several of the sub-practices of Data Analysis & Mathematical Thinking faded out in their phase two lesson plans. Some of those lessons were stand-alone lessons and so should not attempt to include all of the practices, but the student teaching lesson plans were a series of short science lessons that comprised an entire unit. In these unit plans, some of the participants' use of the science practices did not include the majority of the practices. Wide engagement is a theme where their practice did not yet match their beliefs.

Skills Beyond Science. The focal participants discussed how the science practices are useful beyond the laboratory. Justin said, "I want to encourage using them not only in science, but in school on the whole" (Justin_Phy_Int). At the end of his student teaching, he wanted to "find ways to be able to apply these to all different aspects of [students'] life, so they can see that not only do I think like this inside the laboratory, but it's a way of thinking and engaging with the world" (Justin_ST_Int). Many of the other participants shared his view of finding use for the science practices in other subject areas. Specifically, they mentioned applying argumentation skills in English language arts and data analysis and algebra skills in mathematics. Because elementary teachers are trained in each subject area, they could have a unique perspective on the wide range of applications of the science practices. Finding these connections to other subject areas could help students practice these skills while doing other work, but the participants need to be careful not to lose the aspects of the practices that make them unique to science.

Teach Practices Explicitly. The focal preservice teachers frequently mentioned teaching the science practices explicitly in the post-physics course interview but only included this theme in the methods course and student teaching lessons. They described this theme as directly calling out the practices to the students. For example, in a lesson where the students would be modeling, the teacher could call that out by saying something like, "In today's investigation we will be constructing a model to …". There was a little disagreement between the opinions of the participants in this theme. The majority of their beliefs aligned with Morgan's comment:

> I think I see a lot of value in students knowing what the science practices are. I think it's very helpful in understanding what science is and what scientists do. And it makes science feel applicable to outside of the classroom life … I would like them to play a large role, whether it be very explicitly talking to students about, like, these are the science practices and these are the ones we're working on today. (Morgan_Phy_Int)

For this group, they wanted their students to know what they were doing and to make connections between that work and the work of scientists. Two of the other participants took a slightly different stance on this theme. Amber said, "I don't know if I'll explicitly use all of them … But I think they are a good basis to have when thinking about lesson plans … just so you do get that variety of learning" (Amber_Phy_Int). Amber and Justin did not necessarily disagree with explicitly teaching the science practices, but thought that if it happened, it should take second place to the content learning objectives of the lesson.

Develop Scientific Skills. The participants discussed *developing scientific skills* the least of all the themes, despite this being emphasized in the methods course. Brad said that as students engage in the practices, they will begin to develop "a complete understanding of the scientific process" (Brad_Phy_Int). Amber stressed the importance of developing "strong scientific skill in students" (Amber_Phy_Int), and Justin wanted his students to be "engaged in the work of actually doing science" (Justin_ST_Int). This theme gets at the heart of the science practices and their importance in science teaching, yet was least prominent among the preservice teachers' thinking.

Summary. As mentioned in the beginning of this section, the focal preservice teachers' ideas about why and how they used the science practices in their teaching changed very little over the study. The most frequently referenced theme was to *build student understanding* and the least was to *develop scientific skills*. Across the phases, no theme completely disappeared (although discussion, but not use of, *teach practices explicitly* waned from phase 1 to phase 2) and no new themes appeared. At this point in their teaching, the preservice teachers were still very new to thinking about teaching with the science practices and teaching science in general. This set of themes showcases their diversity and depth of thought about their teaching with science practices and it shows how deliberately they used the practices in their instruction.

Summary and Conclusion

Table 6-8 summarizes the use in teaching findings from each science practice, breaking them down by sub-practice. In each case, I use the table to highlight the preservice teachers' strengths of use in teaching and the areas where they can improve.

Table 6-8

Summary of Areas Where the Participants Have Displayed Strength in Teaching and Areas for Improvement

Sub-Practice	Areas of Teaching Strength	Areas of Improvement for Teaching
Scientific Modeling		
Model "OF"	• Used models to represent non-visible phenomenon	• Gave students few opportunities to develop models • Help students leverage models for explanations
Model "FOR"	• Used of simulations to collect data	• Help students use models to collect data, make predictions, and reason about phenomenon
Plan & Conduct Investigations		
Collect Data	• In phase 2 lessons, took opportunities to teach students how to collect clear, accurate, and objective data	• Help students to test accuracy of data and to compare outcomes to real world results
Plan Procedures	• When they shared the planning, they used these strategies: student roles, flexible directions, use of questioning, modeling procedures	• Did not often share the work of planning procedures with their students
Make Predictions	• Scaffolding provided to students encouraged testable predictions • Used predictions as a way to help students think about the concept and uncover prior knowledge	• Be more attentive to the grade level of the students and if their justification should come from prior knowledge or be theory driven
Investigation Question	• Questions directly addressed variables in the investigation	• Questions focused on changes in variables and less on the how and why of phenomena

		• Often provided the questions for the students, could increase students' agency by allowing them to build their own
Data Analysis & Mathematical Thinking		
Apply Algebra	• Used teacher provided equations to generate and test data	• Help students to create their own algorithms • Help students in analysis (calculate slopes, function fits)
Find Patterns	• Compared data between groups to find patterns • Organized data into larger class sets • Patterns to be used as evidence in explanations	• Help students compare predictions to patterns • Help students use mathematical representations to test data
Use Tools	• Use of a variety of tools in lessons (t-charts, graphs, data tables)	• Shift the use of the tool from the teacher (in large group) to the students
Explanation & Argumentation		
Make Claims	• Indicated that claims can answer the original investigation question • In phase 2, included sentence starters to aid students	• Help students build claims that account for all variables and that can predict outcomes
Use Evidence	• Taught students about what counts as evidence	• Help students to use multiple sources of evidence and to reference specific data to support claim
Use Reasoning	• Taught students that reasoning should connect evidence and claim • Taught students that reasoning should include scientific principles	• Help students to know which laws to use in their reasoning to support the claim
Engage in Argumentation	• Gave students opportunities to agree or disagree with each other's claims and debate their findings	• Help students to use argumentation, especially when planning lessons for real students

This chapter has attempted to answer the questions: *How do the preservice elementary teachers use the science practices in their lesson plans and enactments? How does that use change over time and from one context to another? How do the lesson plans and enactments showcase the sensemaking that the preservice elementary teachers have about the science practices?* The lesson plans used as data were the first science lesson plans that the participants have written and the recorded enactments were their first attempts at teaching science. The great majority of these lessons showcase exemplary attempts to engage students in authentic science practice.

The focal preservice teachers used the science practices in their lesson plans and enactments emphasizing Plan & Conduct Investigations while their use of Scientific Modeling decreased over time. At the sub-practice level, the preservice teachers used similar sub-practices from one part of the study to another although the distribution of the use changed from phase one to phase two. This was likely due to changes in context from one phase to the next. For example, the use of *Apply Algebra* disappeared as the subject matter changed from physics lessons to the methods and student teaching lessons. Many of the lessons from phase two were life science focused and did not have an emphasis on mathematics. This shift in sub-practices also displays the participants' KCT as they used sub-practices that better matched the content they were teaching at the time. In other cases, the difference was likely influenced by changes in their understanding. For example, the participants could have balanced their use of the sub-practices of Plan & Conduct Investigations better during the methods course where that practice was a central focus of the instruction, and they included justification for predictions after learning about that in the methods class.

In an attempt to unpack the KCT of the participants, I looked at which practices they used for a given subject matter. While there was some variation from one subject to the next in the physics course lesson plans, the phase two lesson plans showed almost no difference in which practices the preservice teachers used between the physical and life science lesson plans. Some of the differences in the physics lessons could be due to the participants' KCT (e.g., the Science Modeling lessons). The consistency of which practices the participants used could be due to the lesson planning template they used and to the emphasis on certain practices in the courses' instruction.

Looking at the adjusted LOS scores for the participants' KCS over the study shows improvement in their understanding of how to use the practices at different grade levels. This could point to the positive effects on teaching that can result from methods course instruction. It could also showcase how the participants' planning differed when they planned lesson for actual children rather than for imagined classes.

The LOS scores across the enactments and their corresponding lesson plans were not very different. The unique elements of the enactments that did stand out include: the group nature of working with the science practices in a classroom, the difference of teaching children compared to practicing with peers, and the limiting nature of real time constraints. The participants more proficiently supported data analysis and interpretation in their enactments than what they had shown in their lesson plans, but were less proficient at supporting data collection in the enactments. I found the group nature of working with the practices to be the clearest difference between the lesson plans and the enactments.

All of these findings display the complicated and intricate nature that is the work of teaching. Elementary science teachers teach science content that ranges from life science, Earth science, astronomy, physics, and more. They work with students from the ages of 5 up to 11 years old. They teach within time constraints and in competition with other subject matters. Each one of these contextual factors can impact the way the preservice teachers used the practices in their teaching. This chapter focused on the subject matter of the content and the grade level of the students. In the following chapter, I discuss the findings related to how the preservice teachers talk about the science practices and supporting student learning.

Chapter 7 Preservice Teachers' Connections Between Science Practice and Learning

In this chapter I present the findings related to the fourth research question: *How do the preservice teachers make sense of how their use of the science practices in instruction promotes student learning? How do these views change over time and from one instructional context to another?* For these questions, I used data taken from the interviews during each phase of the study. Each interview asked a variation of this question: how can engaging in the science practices help students learn? I organized the responses and then open coded them to find patterns and themes. This allowed me to see what the participants thought about learning and the practices and to make connections between the beginning of the study and the end.

In the previous chapter I looked at how the preservice teachers planned to use the science practices in their future teaching. The themes developed from that analysis (e.g., *Build Student Understanding, Skills Beyond Science, Develop Scientific Skills*) are closely related to how the preservice teachers connected learning to the science practices. Teaching and learning should go hand-in-hand, so I expected to see similarities between the answers to these questions. To preview the findings, in this analysis I found seven themes across the data corpus. Many of these appeared to be related to the given context of that phase of the study. For example, the theme *Equation Based Thinking* was only identified in the physics interviews and this could be because of how often we used Data Analysis & Mathematical Thinking during the course. The preservice teachers each believed that their view or understanding of the science practices changed from their time in the physics class to the end of their student teaching. Many of them connected these differences to their engagement in the science practices. In the end, the findings show a group of preservice elementary teachers who consider themselves well prepared and excited to use the science practices in their future classrooms.

In the following sections I outline the themes the focal preservice teachers discussed in their interviews. The themes illustrate how the participants' sensemaking connected learning with the science practices. I look at how those themes progressed from the beginning of the study to end. Last, I show how the student teaching preservice (STP) teachers saw their own understanding of the science practices change over the course of the study.

Connecting Learning and the Science Practices

I found several themes in the focal preservice teachers' discussion of student learning and the science practices. Table 7-1 and 7-2 include the themes from the two phases of the study. Only two themes persisted from the physics course to the methods and student teaching phase, namely, *Autonomy & Curiosity* and *Hands-on & Visible Science*. I found two new themes in the second phase, *Learning to Be Scientists*, and *Group Nature of Practice Work*. I only have interview data for the four STP teachers from the second phase of the study and this could have limited what patterns I saw in the data.

During the physics course, a time when the preservice teachers focused more on the content, the themes in the focal preservice teachers' talk (except *Multiple Avenues for Learning*) lined up with a given science practice. For example, *Autonomy & Curiosity* aligned with Plan & Conduct Investigations, and *Chance for Reflection* matched Explanation & Argumentation. I illuminate these connections below. The comments from the second phase of the study appeared to apply to the practices more generally, even within the themes that repeated. In the following sections I look at each of the themes and reflect on their use given the results from the previous chapters.

Table 7-1

Themes Describing How the Focal Preservice Teachers Connected Student Learning to the Science Practices During the Physics Course (Phase 1 of Study; n=9)

Theme	Description	Example
Autonomy & Curiosity	When students have the autonomy to plan and ask their own questions, driven by their curiosity, they will be more motivated to learn	"I think naturally they are curious about things in the world and how they are happening. So I think having them ask questions at the beginning and plan out how they are going to investigate something helps them learn" (Jamie_Phy_Int)
Hands-on & Visible Science	The science practices allow students to experience phenomena in a direct way rather than through secondhand sources	"I think by doing [the practices], the knowledge comes more solid in your mind. Because it's not just, like, your teacher telling you facts. You get to actually work with the science that you're trying to learn." (Morgan_Phy_Int)
Chance for Reflection	The Explanation & Argument practice makes time for students to reflect on what they have learned and make connections	"Providing time to have them create explanations for what they observed solidifies ideas in their head and understand things they are seeing in the world" (Jamie_Phy_Int)
Multiple Avenues for Learning	The science practices provide multiple ways of engaging with phenomenon, each resonating differently with the students	"I think as a whole, they provide different ways of learning. So, for some people, developing a model is going to help them … And then maybe for others talking about it and communicate it is going to help … Or doing the math … it just provides just a lot of different avenues for people to understand the content" (Amber_Phy_Int)
Equation Based Thinking	Using equations and ratios between variables to support and reinforce students' understanding of phenomenon	"I think clearly in numbers/units and find the experience of manipulating numbers and expressions reinforced my thinking very helpful" (Emily_Phy_Lab24)

Table 7-2

Themes Describing How the Student Teaching Preservice Teachers Connected Student Learning to the Science Practices During the Methods Course and Student Teaching (Phase 2 of Study; n=4)

Theme	Description	Example
Autonomy & Curiosity	When students have the autonomy to plan and ask their own questions, driven by their curiosity, they will be more motivated to learn	"As they go into an actual experience … they're actually doing it … already thinking about it and curious about it, they're gonna be a lot more likely to engage with it" (Justin_Mds_Int)
Hands-on & Visible Science	The science practices allow students to experience phenomena in a direct way rather than through secondhand sources	"Hands-on experiments and them being fully immersed and engaged in the science is the best way for them to learn, because I know if someone's talking at me, telling me and how to do it, and I don't get to experience it at all … it's gonna go in one ear and out the other" (Angie_Mds_Int)
Learning to Be Scientists	Students are not just learning science content, but science skills as well	"I think they're learning to be scientists when they practice [science skills]" (Brad_ST_Int)
Group Nature of Practice Work	When students work together with the practices, they can learn more	"Especially if you share and talk about it as a group, you can learn from each other … I think it's good for them" (Angie_ST_Int)

Autonomy & Curiosity. During the physics course, the focal preservice teachers connected *Autonomy & Curiosity* closely with the science practice Plan & Conduct Investigations. Specifically, they mentioned connections to the sub-practices *Plan Procedures* and *Investigation Question*. They believed that when students have the freedom to plan and ask their own questions, they will be more motivated to learn and will remember the content better. Jamie said that,

> naturally [students] are curious about things in the world and how they are happening, so I think having them ask questions at the beginning and plan out how they are going to investigate something helps them learn so they'll be naturally engaged (Jamie_Phy_Int)

At the end of the physics class, Angie commented that, "it was frustrating sometimes but ... it helped me learn the most because you weren't sitting there just telling me what to do and how it worked. Like we actually had to figure it out and really think" (Angie_Phy_Int). She saw the benefit of doing the work herself, in the end she said, "I feel like you learn more when it's independent instead of spoon-fed … to make those discoveries on their own … it would have more of an impact on their learning" (Angie_ST_Int). Her lesson planning showed a similar progression from teacher-led to experimenting with student-designed experiments.

The idea of students' natural curiosity persisted into the second phase. Justin said the practices are for, "wondering curiosity, to help students be more engaged and interested as they go into an actual experience" (Justin_Mds_Int). Jamie and Justin assigned the element of curiosity to the students. In chapter 5, when I asked the preservice teachers to describe the science practices in general, they said that the way the practices were written left out the element of student curiosity. Throughout the study, they held onto the idea that curiosity in science is an important element and motivator.

Hands-on & Visible Science. The participants referenced *Hands-on & Visible Science* as a learning theme with the highest frequency. During the physics phase, they made several connections between this theme and Scientific Modeling. For example, in a lesson on waves and how they propagate, Angie said, “when you showed us the pictures [images of transverse and longitudinal waves] ... we couldn't really see it, and then you showed us how they moved [animated models and slow motion video data]. We didn't really understand it until you showed us the model” (Angie_Phy_Int). Amber discussed it this way, “I felt that a model was a way to show them something that was a little more abstract. That they might have trouble grasping. I thought a model was a good way to help understanding of the content” (Amber_Phy_Int). In each of these cases, and in other comments, it was important for the students to see and handle something to take their learning to the next level.

While the idea of *Hands-on & Visible Science* persisted through the study, the references to modeling did not continue into the methods and student teaching phase. Their comments transitioned to apply to the practices in general, for example Brad said, “when they're not doing the science themselves, it makes it difficult to understand” (Brad_Mds_Int), or in Edith’s comment, “they're not just being lectured at ... But instead, they're like working through the science practices” (Edith_Mds_Int). The disappearance of modeling in these comments could be connected to how modeling seemed to also drop out of their lesson plans. The participants had little experience with Scientific Modeling prior to the physics class and its lack of persistence could be because they have had little engagement with it over the course of their education. In the end, the participants continued to hold to the idea that in order to learn science, students need to be engaged in doing science.

Chance for Reflection. The preservice teachers only directly mentioned *Chance for Reflection* during the Physics course. They tied this theme directly to Explanation & Argumentation. Brad said that, "reasoning is a good way to connect what they've already learned to what they're currently learning and I think it connects those two ideas really well" (Brad_Phy_Int). Heather described her experience in physics this way:

> I was forced to answer, like, why I did something and what about it was right and in a lot of other classes prior to physics, I had just been asked to write an answer ... so coming to this class and having to like explain why my answer was the way it was, was really helpful just in the learning process (Heather_Phy_Int)

Heather's moments of reflecting on her work came when she wrote Claim, Evidence, and Reasoning (CER) statements for the labs in physics. Taking the extra steps to stop and make connections between what she was claiming and her data made a difference for her learning. Angie also said, "constructing explanations was a good way for me to write down and/or check to make sure I know the material" (Angie_Phy_L24). Although the STP teachers did not mention *Chance for Reflection* during the phase two interviews, they continued to use the CER framework extensively in their lesson plans, showing that they still recognized reflection as an important part of the learning process.

Multiple Avenues for Learning. In the physics class, the preservice teachers saw the science practices as a way to reach different types of learners. Amber said,

> as a whole, they provide different ways of learning. So, for some people, developing a model is going to help them understand the investigation ... Or doing the math behind the physics might help them understand better. So, I think it just provides just a lot of different avenues for people to understand the content (Amber_Phy_Int)

Emily also said that, "you can support ways of thinking using several of [the practices]" (Emily_Phy_Int). Both of these comments hint at a "learning styles" like interpretation of the science practices. For example, they mentioned that some students were good at the math parts of physics and others preferred the communication practices. Their argument was that as they used a wide variety of the practices, similar to the teaching goal *Wide Engagement* from chapter 6, they would have a better chance of reaching the preferred learning mode of each of their students. This theme did not appear in the second phase of the study, and one possible explanation for this could be that the methods course and other parts of the program challenged the idea of "learning styles" (e.g., Willingham et al., 2015).

Equation Based Thinking. The last theme from the physics course was *Equation Based Thinking.* This theme leans a little on the previous theme, *Multiple Avenues for Learning*, because several participants said something similar to, "I think clearly in numbers/units and find the experience of manipulating numbers and expressions reinforced my thinking" (Emily_Phy_L24). These participants saw this type of learning as a "learning style" that they were particularly good at. Others said that just being able to "see what each piece of the equation actually is" (Amber_Phy_Int) helped them learn or view the content in a different way. This was not the case for every participant, Angie said that, "the hindrance was the math stuff because I'm not good at it, and I've never done it before. Like, that part was hard for me" (Angie_Phy_Int). Later, she did acknowledge that although she did not like it, it was probably a good thing for her to have the experience. Aside from Angie, the other participants appreciated the different thinking required of them by the mathematics found in physics. This was reflected in their high LOS scores for knowledge (CCK) in Data Analysis & Mathematical Thinking.

Learning to Be Scientists. The STP teachers introduced *Learning to Be Scientists* during the methods and student teaching phase of the study. This theme is closely related to the *Develop Scientific Skills* teaching goal from Chapter 6. Brad said, "I think they're learning to be scientists when they practice observations" (Brad_ST_Int). Brad understood that as he engaged his students in the practices, they were gaining the skills that scientists use to do their work. Edith added to this saying, "go a bit further than just having students experience it … specific practices are needed to learn science and build those skills" (Edith_ST_Int). The idea here is that the students did not just learn content, but they learned to do the work of scientists at the same time.

Group Nature of Practice Work. Because the preservice teachers worked with actual students, they saw the benefit of the *Group Nature of Practice Work.* This theme is related to the influence of the group work in the videorecords of the participants' teaching, as discussed in Chapter 6. The preservice teachers leveraged the group work inherent in sub-practices like *Make Predictions*, *Find Patterns*, and *Make Claims*. In their teaching, they noticed how powerful of a learning tool that working in groups can be. Angie said, "especially if you share and talk about it as a group, you can learn from each other" (Angie_ST_Int).

Summary. The focal preservice teachers made sophisticated connections between student learning and engaging in science practices. They linked their early themes directly to specific science practices and broadened their perspective for the themes towards the end of the study. They also made connections to the situated nature of the science practices by linking learning with them to developing science skills. They saw the value of the science practices in helping students through different stages of the learning process.

Preservice Teachers' Impressions of Change Over Time in their Thinking

In the last interview I had with the STP teachers, I asked them how their knowledge and understanding of the science practices changed since the beginning of the physics course to the time of the interview. For Angie, Brad, and Edith this was a two-year time period and for Justin, it was one year. Their answers varied a little but included one common idea. The overall impetus for the changes they saw in their own understanding came from the experiences they had with the science practices both in the physics and methods courses. Angie said, "especially [the physics] class, that's the most engaged I've ever been in science in my life … you taught those ... practices so that definitely changed my view on how to teach science" (Angie_ST_Int). Brad said that the "multiple exposures" helped him see a difference in how to teach with the science practices, both in the physics course and the methods course. Edith said, "I guess all those experiences really helped give a clear idea of how to incorporate these into teaching science … before I even had those classes, I hadn't ever heard of the science practices" (Edith_ST_Int). In each of these comments the STP teachers reflected on the importance of their experiences (engaging in and teaching with) with the science practices and seeing a different way to teach and learn science.

Angie discussed how she sees the science practices as strengths and that before, she knew things like the practices were important, but now she knows why they are and how to apply them in her teaching. Edith had a similar experience, she said, "those experiences in those classes helped open my eyes to see how you can incorporate these into your science teaching" (Edith_ST_Int). Justin described his experience as a complete turnaround in how he viewed science teaching. In the beginning he thought of teaching science as "the notion or kind of conception that it is like history … where you just have to memorize a bunch of dates" (Justin_ST_Int). Through his experiences in the program, this evolved into him seeing

> the value of doing things in science, so not just learning some things for the sake of learning it, but for the sake of understanding and using science as a way of getting you to think critically about the world and engaging with it. (Justin_ST_Int)

Brad described his transformation as in the beginning he would try to fit or force the practices into the activities he wanted the students to do. Now, this has been reversed and he uses the practices or the skills he wants his students to gain to guide what activities he has them do in the lesson plans. In Brad's example, his priority shifted, the science practices started to take a front row position in his planning and the goals he had for his students rather than being secondary or an afterthought. He said, "how can I design [teaching] around these science practices to help students become more well rounded science learners?" (Brad_ST_Int).

In each case, rather than talking about how their understanding of individual practices changed over time, they discussed how their view of science teaching changed. The preservice teachers' experiences with the science practices likely motivated these changes. It is an example of how important it is to engage preservice teachers in science practice not only as teachers using them in lessons, but as students, engaging in the practices themselves. In the end, this is the kind of change that I was hoping to see, not that the preservice teachers could define every practice well, but that the way they viewed engaging students in science had shifted to a view situated in authentic science practice.

Conclusion

This chapter attempted to answer the questions: *How do the preservice teachers make sense of how their use of the science practices in instruction promotes student learning? and, how do these views change over time and from one instructional context to another?* To answer these questions, I asked each preservice teacher how they thought student learning connected to the science practices in each interview.

To understand the preservice teachers' sensemaking about the practices and learning I developed a set of themes from their interview responses. The themes *Autonomy & Curiosity* and *Hands-on & Visible Science* persisted through the study. These themes foreground the participants' desire to highlight the connection between the work of science and curiosity.

Curiosity is what motivates science questions and working with the phenomenon in a "hands-on" way, through science practice, can generate new understanding and learning.

In the physics course, the preservice teachers discussed the themes *Chance for Reflection*, *Multiple Avenues for Learning*, and *Equation Based Thinking*. They used these themes to connect learning to the science practices by showing how practices like Explanation & Argumentation allowed students to reflect on their work through frameworks like CER, and how Data Analysis & Mathematical Thinking can offer students a unique way to think about phenomena and make connections between variables.

The STP teachers introduced the themes *Learning to Be Scientists* and *Group Nature of Practice Work* in the second phase. They believed that the science practices offered students a way to learn the work of scientists. They also saw that certain practices allowed students to learn from each other if used in group settings. These themes fit the context of the second phase because the participants taught their lessons to actual students rather than just preparing lesson plans for possible future students.

When asked about how their understanding of the science practices changed over time, the STP teachers universally agreed that their many experiences engaging with the science practices, as students and as teachers, during the program made the difference for their learning. Their view of the practices changed in different ways but each description could be linked to how they taught with the practices. Each of these teachers planned to continue to use the science practices as the mode of science learning for their students. In the following chapter, I present the cases of two of the focal participants to illustrate their journey with a given science practice over the course of the study.

Chapter 8 Case Studies of Prior Experience

In this chapter I selected two of the participants to use as case studies. The cases illuminate and allow me to compare the differences these individuals experienced as they engaged in the science practices and made choices about them in their teaching. Each case represents a different perspective and shows the possible growth of each participant over time. I drew on data from each phase of the study to build a comprehensive picture of the participants' progress.

I chose Angie and Brad as my two cases. They each took physics with the Winter 2018 group and worked as lab partners during the majority of the course. This means that during the physics course, they had similar experiences during their investigations, but recorded them differently in their lab sheet (as shown by the different level of sophistication (LOS) rubric scores for each lab). They also entered the physics course having had opposite prior experiences with the science practices. Brad was a science concentrator in the elementary program and in addition to taking more science coursework, he explained his experiences as including work with investigations and the science practices. Angie concentrated in English language arts and described her past science experiences as being activity based (e.g., making slime) or focused on note taking. This positioned Brad as beginning the study with "extensive" prior experience and Angie as "minimal". In the second phase of the study, while the demographics of the schools they taught in were very similar, they taught different grade levels. Angie's 2nd grade class fell into the pre-novice LOS level and Brad's 4th grade class fell in the novice level. In other words, Brad’s uses of the science practices should have been more sophisticated than Angie’s in their phase two lesson plans as they taught students with different ability levels.

Considering their backgrounds, Brad represented the case of a well-positioned beginner in the physics course and Angie was the case of a minimally-positioned beginner. The previous chapters show the results of the participants as a whole and they attempt to give a general interpretation of the preservice teachers’ experiences and sensemaking throughout the study. In this chapter, I show the progression of these two cases, make comparisons between them, and give possible interpretations of their experiences throughout the study.

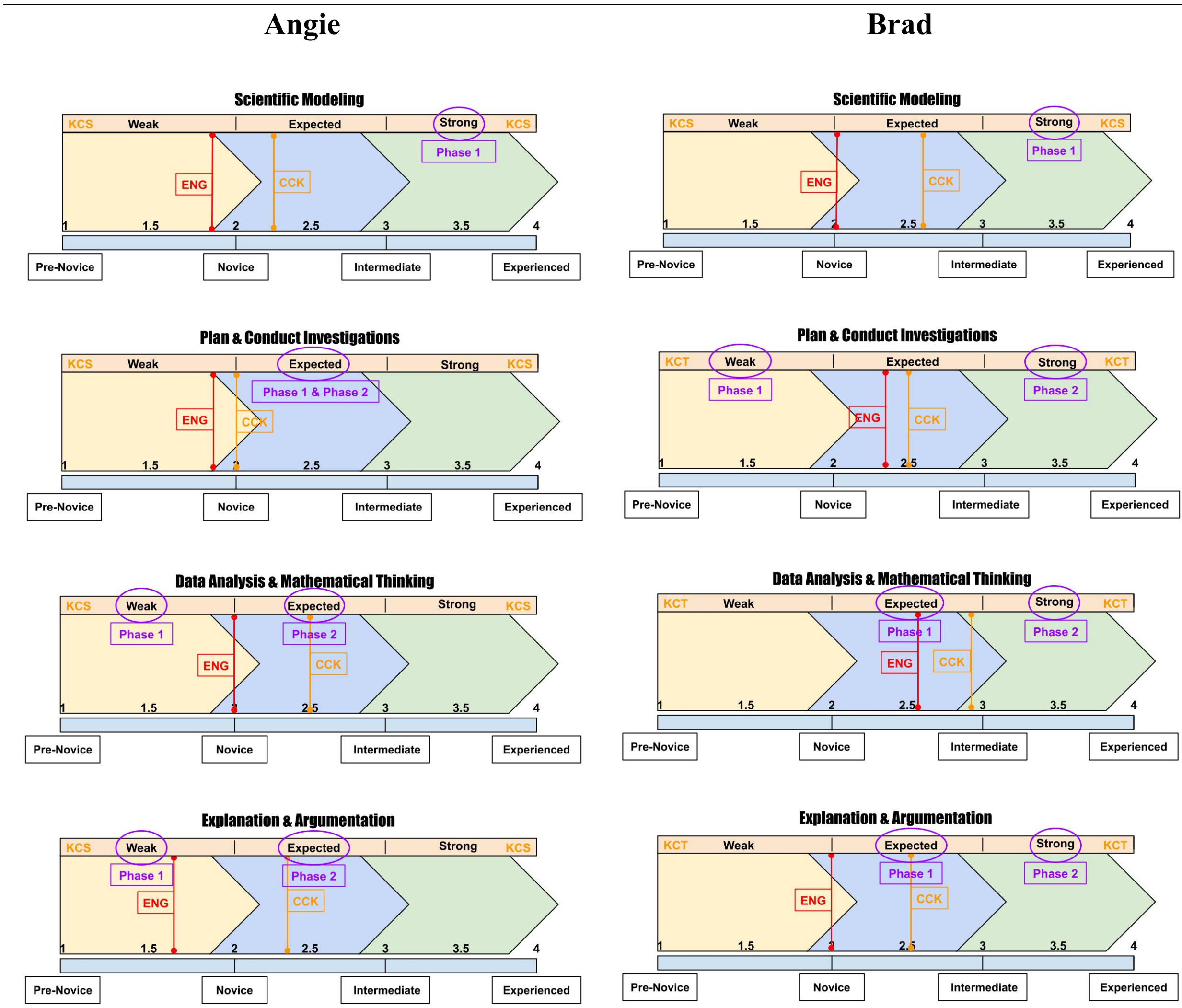
In the following sections I introduce a level of sophistication continuum as a way to see each focus of the study in one figure. I present the continuums of each science practice and give a general interpretation of patterns found between Angie and Brad’s performance as a way to set a background for further discussion. Next, I look at a specific science practice to show examples highlighting how Angie and Brad’s engagement, knowledge, and use of this practice in their teaching compared to one another and how it seemed to change over the time. I also speculate as to what might have been the reasons for the differences I found in their results.

Level of Sophistication Continuums

One way to interpret Angie and Brad’s experience with the practices during the study is to look at the results of each major element of the study (engagement – Chapter 4, common content knowledge (CCK) – Chapter 5, and knowledge of content and students (KCS) – Chapter 6). To do this, I constructed a continuum that displays the average LOS for the engagement and CCK from pre-novice to experienced. Imposed on this is also the adjusted LOS rating for KCS from weak to strong. Figure 8-1 presents this continuum for each science practice, comparing Angie and Brad’s averages side by side.

Figure 8-1

Level of Sophistication Continuums for Angie and Brad Across Each Science Practice



Looking at general patterns that are true for both Angie and Brad, they both engaged with each practice at a lower level compared to their knowledge (CCK) of the practice at the time. The difference between their engagement and CCK scores for Plan & Conduct Investigations is noticeably smaller than the differences in the other practices. One explanation for this could be that because they were more familiar with this practice (from past experiences), they could better apply their knowledge (or CCK) in their engagement. Similarly, the large difference between

CCK and engagement in Explanation & Argumentation and Scientific Modeling could be due to their lack of prior experience with those practices prior to the physics class.

Furthermore, for each practice, except Scientific Modeling (which neither of them used in the second phase of the study), they both show improvement in KCS from phase 1 to phase 2. Angie's KCT for Plan & Conduct Investigations was a little better in the second phase of the study but it was still within the expected range. These general trends give an overall and averaged picture of how these participants progressed through the study. The continuums show that Brad's prior experience likely gave him an advantage with the science practices, but both Angie and Brad made progress (as shown in the KCS scores) moving toward more sophisticated science teaching. The next section highlights one of the focal science practices of the study to show examples of their thinking and progress through the study.

An Exploration of Data Analysis and Mathematical Thinking

Looking across the continuums in Figure 8-1, both Angie and Brad scored their highest knowledge (CCK) and engagement LOS averages in Data Analysis & Mathematical Thinking. For Brad's case, the exploration of this practice serves as a way to highlight what strong participation looks like for a preservice teacher who is motivated to engage in science and science teaching (evidenced by his selection of science as a concentration). Angie provides a contrast to Brad's example because she was intimidated by the mathematics portion of physics despite this being her highest scoring practice.

After the physics course, Angie described her experience with mathematics and science this way,

> I never really did too much with math. I just don't think I went that far or went to take those classes … The math part and computing stuff, I never really used it until this class … But after this class I see why it's important … But for me, it's just not the route that I'm going. Since I've never done it. I probably would just take that off if it were me. But

> after this class, I definitely see why it's important to have. And people like [Brad], who are really good at it, and it just comes naturally … it's important to him but for me, it wasn't. (Angie_Phy_Int)

Despite her not appreciating Data Analysis & Mathematical Thinking as much as the other practices, she could have been undervaluing her own expertise or growth in the practice. This is because by the end of the physics course, she showed her highest engagement and CCK with this practice, compared to the others.

Examples of Common Content Knowledge

Brad described this practice as “underrated or undervalued” (Brad_Phy_Int). He believed that data analysis was a skill that would serve students in all aspects of their lives and that it would be important for him to help students develop critical thinking skills in mathematics. He said, “mathematical reasoning skills are quite important in understanding science because they allow us to easily identify and record certain patterns” (Brad_Phy_Lab2). In this quote, Brad could be taking for granted his own skill with mathematics because the patterns he could identify “easily”, might not have been interpreted in the same way by others. As mentioned above, Angie considered possibly removing the practice. This attitude seemed to be driven by her lack of prior experience with integrating math and science. One way to explain Angie’s high performance with this practice, despite her reluctance, could be because she and Brad worked as lab partners. In this group setting, she could have gained more knowledge and skill as she learned from her peer.

Angie and Brad both appreciated the technology aspect of the *Use Tools* sub-practice. In some of the physics investigations, the class used video analysis software and computer graphing tools to aid in the analysis process. In Brad’s description of the software, he focused on the time it saved and how it “increases the precision of the results” (Brad_Phy_Lab3). Angie thought the software was “helpful, very easy to use, and super fun” (Angie_Phy_Lab3). She was also concerned with using technology like this with younger students who might need the experience of making the plots by hand rather than skipping straight to the analysis. These responses showcase the level that Angie and Brad thought about this practice. Brad focused on the accuracy of the data while Angie appreciated how easy it was to use and that it made the analysis more fun. Angie also considered how the software might impact her future students. This pattern held true for the other sub-practices; Brad’s comments tended to focus on the utility of the practice and Angie described her experience, connecting it to particular aspects of a given investigation.

Brad had well developed CCK for this practice. He understood the mathematical principles behind the data analysis and could use mathematical reasoning to make connections between his data and the phenomenon he studied. In the beginning Angie struggled with these tasks and relied on Brad’s expertise in their lab work. Her CCK was still in the early stages of development. With sub-practices like *Use Tools,* where the tool alleviated some of the tedium of plotting (like the graphing software used in the physics course), Angie was also able to make connections and engage in the sensemaking work of the practice, developing her CCK along the way.

Examples of Engagement

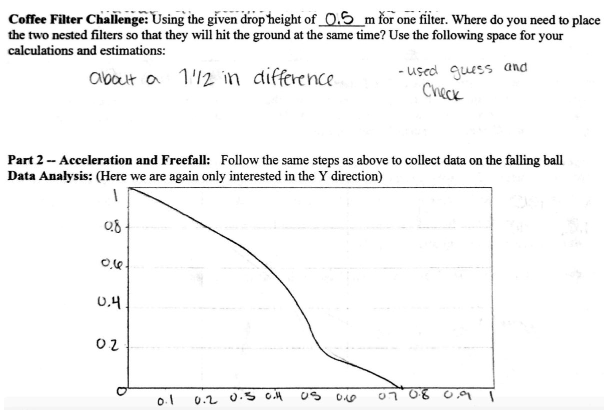
To understand how Angie and Brad engaged in Data Analysis & Mathematical Thinking, I compared their engagement in *Apply Algebra* (from one time period), and *Use Tools* (from two time periods). The first instance comes from Lab 3, which took place in the second week of the physics course. In Lab 3 the students learned about velocity and acceleration by taking videos of falling objects (coffee filters and balls) and using video analysis software to track the motion of the falling objects. The second example comes from Lab 9. In this investigation, the students designed and built carts powered by rubber bands where they needed to take several measurements and make comparisons between different quantities.

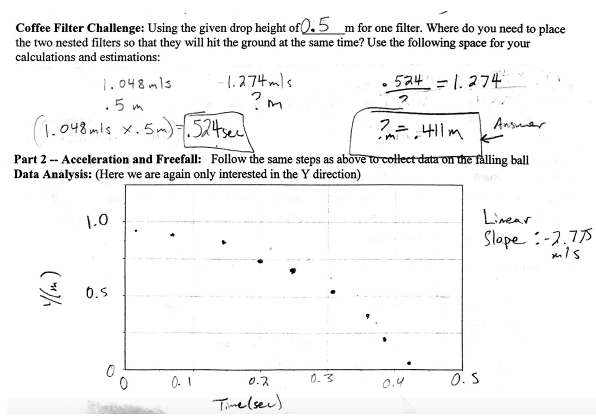
Figure 8-2 shows Angie and Brad's engagement in *Apply Algebra* and *Use Tools* for two investigations. In Lab 3, the Coffee Filter Challenge was an example of *Apply Algebra*. The preservice teachers were supposed to take data they collected in an earlier part of the investigation, use that data to construct an algebraic relationship, and answer a testable question. In Brad's example, he selected the correct quantities from his above data tables (not visible in figure) but incorrectly assembled them into a mathematical expression. If he tested his result, he would have found that the distance he calculated was incorrect. Although he came to an incorrect conclusion, Brad's efforts scored in the "Intermediate" range on the LOS rubric because he constructed his own mathematical relationship. In this example, Angie circumvented the *Apply Algebra* nature of the question (likely due to her aversion of mathematics) and tested several different heights until she found the one that worked using what she referred to as the "guess and check" method. In this case, Angie received no score for *Apply Algebra*, because she found another route to the solution.

Figure 8-2

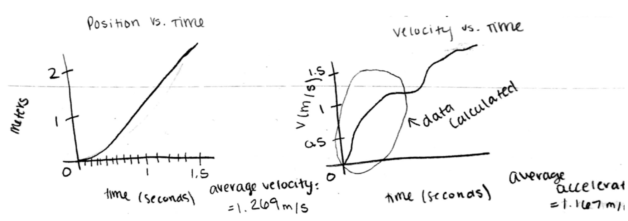
Comparison of Angie and Brad's Engagement in Apply Algebra and Use Tools

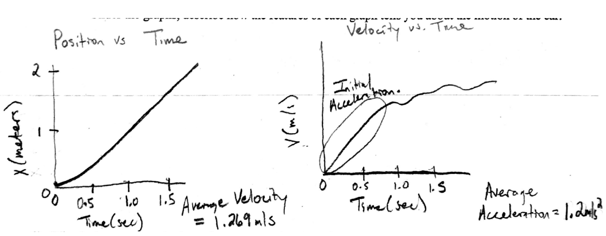
Angie	**Brad**
Lab 3	Lab 3





Lab 9	Lab 9





Looking at the graphs from Lab 3 shows a difference in how Angie and Brad engaged in *Use Tools*. In Angie's first graph, she does not show the individual data points, but rather displays the general curve found in the data. She did not indicate which quantities she measured or their units and so received a lower sophistication score for this engagement. From the beginning of the course, Brad labeled his axes, showing both the measured quantity and the corresponding units. Brad also included pertinent information from the graphs like the slope (although he does not indicate which region of the curve the slope came from). The example from Lab 9 shows a difference in the engagement for Angie, while Brad's level of sophistication did not change. Angie showed a large difference in her level of sophistication. In Lab 9, she included the quantities, units, and relevant slopes for each graph. Her shift in engagement in this sub-practice could be due to the feedback she received from me on her lab reports, or they are more likely due to her interactions with Brad and learning from his example over time.

One way to interpret these examples is to compare Angie and Brad's prior experiences with the science practices and their attitudes about using math with science. In the beginning Angie engaged in these sub-practices at the pre-novice level or avoided the practice. Towards the middle of the course, after several experiences with *Use Tools*, Angie's level of sophistication improved. It could be that Brad's sophistication did not change over this time because he already had many experiences building graphs in his past and these opportunities were not enough to push him to a higher level. It could also be the case, that without having someone in his group (or the class, he often showed the highest engagement in this practice compared to the other participants in the study) who engaged at a higher level than him, he had no one (other than feedback from me) to guide him to higher levels of engagement.

This example also presents an opportunity to show the role that content can play with the practices. Labs 3 and 9 both come from the mechanics portion of the course. The mechanics content (kinematics, forces, momentum, and energy) fits well into the Data Analysis & Mathematical Thinking practice because of the ease of collecting quantitative data. In fact, the phenomena are often understood by evaluating the slopes and relationships found in graphical representations of data. For example, acceleration can be found and understood by looking at the slopes of velocity versus time graphs (as seen in the Lab 9 graphs). Angie's hesitancy to engage in the mathematical reasoning parts of the investigations could have hindered her ability to learn the phenomena and also could have limited her CCK of the practice as well.

Examples of Knowledge of Content and Teaching and Knowledge of Content and Students

Examining Angie and Brad's knowledge of content and teaching (KCT), or which science practices they connect to the content they are teaching, reveals a similar pattern as seen in the previous sections. In Angie's physics lesson plans, she used Data Analysis & Mathematical Thinking in 7% of her uses of the practices compared to Brad's 21%. This is a reflection of Angie's comment from her physics interview where she claimed to have never used it before physics and that it was not important to her at the time. Brad's use of Data Analysis & Mathematical Thinking aligned well with the quantitative nature of the data he planned for his students to collect in his lessons and showcases his KCT. In Angie's case, her inexperience with the practice and reluctance to use it in lessons displays a limited KCT.

In the second phase of the study Angie and Brad primarily planned life science lessons. While these lessons tend to use data that is not quantitative in nature, both Angie and Brad used Data Analysis & Mathematical Thinking in 10% of their uses of the overall practices. Although life science lessons can be less quantitative in nature, students can collect qualitative data that they need to analyze, and Angie and Brad proficiently used the practice in these cases. For example, in a lesson on stems and celery stalks, Angie collected her students' observations and record them on the board to help them better find patterns and trends between the stems. In a lesson where students modeled animal blubber and insulation, Brad planned to have them build data tables where they could organize their qualitative observations to make comparisons with other groups. Each of these examples shows a high level of KCT as the preservice teachers appropriately used analysis tools with the qualitative data they asked students to collect. In Angie's case, when she planned to use qualitative data, she showed stronger KCT with this practice, while Brad was able to do so with either type of data.

Over the study, Angie's knowledge of content and students (KCS) in Data Analysis & Mathematical Thinking improved from weak to expected and Brad's improved from expected to strong. This means that by the end of the study, they each aligned their use of this science practice more closely with the grade level expectations of the students they taught. Angie's student teaching placement was with second grade students. Most of the data analysis she planned involved her collecting the class observations in whole group discussions and organizing those on the board for her students. Then the students would look for patterns together in the data she organized for them. In Brad's peer teaching lesson, he planned for his students to use their data to construct graphs, look for patterns in their own data, and then compare their trends and graphs with other groups. In a more sophisticated move, he also asked his students to compare the results to their initial predictions as a part of the analysis. These tasks aligned well with the older students he taught.

Summary and Conclusion

In this analysis, I have presented Angie and Brad as two cases. Angie represents the case of a minimally-positioned beginner and Brad was the well-positioned beginner. They each entered the physics course having had different prior experiences with the science practices and this was especially true of Data Analysis & Mathematical Thinking. In Angie's case, her past experiences with mathematics could have started her with a negative disposition. On the other hand, Brad enjoyed the mathematical side of science and was a main contributor to the *Equation Based Thinking* learning theme from Chapter 7.

In the beginning, Angie and Brad engaged in Data Analysis & Mathematical thinking very differently. Over time in the physics course, Brad's engagement stayed at the intermediate level, but Angie's improved as she had opportunities to use mathematics in science and to analyze quantitative data. One other possible reason for Angie's improvement is her being in the same lab group as more advanced others. She and Brad worked closely together in the physics course and he could help her engage at a higher level. In Brad's case, there wasn't an "advanced other" for him to work closely with to push him to the next level. While he did receive feedback on his work, this appeared not to be enough to push him beyond his current engagement.

Angie and Brad also used Data Analysis & Mathematical Thinking differently in their teaching. Brad planned lessons to include opportunities for his students to engage with quantitative and qualitative data. He appropriately matched the skill level of the analysis with the grade level of his students and by the end of the study his KCS in this practice was strong. Angie seemed to avoid this practice in her lesson plans, especially when the content fit better with quantitative data sources. In her phase two lessons, when she taught content supported by qualitative data, her use of the practice in teaching improved. For example, she organized the data on the board for the students to look for patterns in whole group discussions. She also provided the students with graphic organizers to help them keep track of their data, using short phrases or by drawing pictures.

Angie's case shows that despite finding improvement in her engagement in the more quantitative aspects of data analysis, she still hesitated or avoided using these skills in her early and later lesson plans. This hesitancy could indicate a lack of KCT on her part and because she never used any of these sub-practices with quantitative data in her later lessons, it was not possible to interpret that aspect of her KCS. Brad's engagement with quantitative data was the highest among the participants. He also used a lot of quantitative data analysis in his physics lessons displaying high KCT because the content aligned well with the sub-practices he chose. In some of these lessons, it is likely that because his knowledge of the practice (CCK) was so well established that his planned uses of the practice exceeded the target grade level of his students, showing an “expected” rather than “strong” KCS. After his methods course, Brad was better able to match his expectations with the grade level of the students. This is an instance where high CCK negatively influenced KCS, meaning that it is not enough to just know the content well, but having a knowledge of his students would have helped him plan better. It could be that because he was planning for a fictitious group of students, that lack of real context allowed his high CCK to plan beyond the students’ ability.

In summary, the prior experiences of these preservice teachers seemed to play an important role in their development as teachers. Although Angie and Brad ended up working together in the same lab group by chance, this appeared to have a positive effect on her knowledge of the practice and engagement. It also appears as though when these participants had a high CCK for a practice, they were more likely to also have high KCT. When working with content that they are comfortable with (in this case either quantitative or qualitative data), they can also display high levels of KCS when they are teaching in real contexts. While this chapter presented a focus on one of the science practices, this general trend appeared to be true across the science practices when they also had relatively high engagement. In the following chapter, I connect the findings from Chapters 4 through 8 with the literature, as well as the illuminating contributions the study makes to the field.

Chapter 9 Discussion and Implications

It has been nine years since the National Research Council released the *Framework* for the Next Generation Science Standards (NGSS) (National Research Council, 2012). This framework made clear the relationship between content standards, the practices of science, and science teaching pedagogy. Through the performance expectations, the NGSS integrated science content, science practice, and crosscutting concepts, giving science educators a map to follow when planning and teaching science lessons. A critical part of that map includes using the science practices in conjunction with disciplinary core ideas and crosscutting concepts to better understand the natural world (NRC, 2012). Research done before and at the time of the *Framework*'s release indicates that with their current understanding and tools, teachers were ill prepared to immediately take up the new mode of instruction (Davis et al., 2006; Trygstad et al., 2013). Since that time, while improvements have been made, engagement in the practices of science in elementary classrooms is not prevalent (Banilower et al., 2018; Plumley, 2019).

Using the science practices to introduce content and build student understanding requires complex thinking and reasoning skills (Tekkumru-Kisa et al., 2015). These skills take time to develop and the process can begin as early as the preservice teachers' content courses if those spaces can be leveraged to build a coherent contextual discourse through the program (Thompson et al., 2013). Opportunities to learn science practices are rare (Stroupe, 2015), and research has shown that just taking one methods course is not enough to cover the breadth and depth of what it means to teach science (Akerson et al., 2006). Often, constraints within a program do not allow for additional science methods courses which can make the task of building the curriculum, content, and practices of single methods course programs daunting.

This work is made easier when the teacher educators are well informed about the possible knowledge and experiences their preservice teachers have had (Ricketts, 2014). This study begins to address this understanding by looking at the knowledge and experiences preservice teachers had with the science practices before, during, and after a physics content course. Along with the work of others (Bismack, 2019; Hanuscin & Zangori, 2016; van Driel et al., 2014; Schneider & Plasman, 2011), this study begins to address important gaps in research by (a) characterizing the experiences of a group of preservice teachers with the science practices prior to their teacher education experiences and in one content course and (b) examining how preservice teachers could develop knowledge of the science practices over time and how that knowledge is connected to their teaching.

This chapter discusses the findings from this study and connects them to current literature. I begin by looking at the focal preservice teachers' experiences and knowledge over time for each practice and then for practices as a whole. I then use the level of sophistication continuums (introduced in Chapter 8) to showcase the participants' experiences with the practices, giving a visual representation of how each facet of the study (engagement, common content knowledge (CCK), and knowledge of content and students (KCS)) can be compared. I also discuss the situated nature of the science practices and how the participants progressed as they moved towards entering the community of science teachers. Last, I examine the theoretical, methodological and teacher educator implications highlighted by this work.

Building Knowledge and Experience with the Science Practices Over Time

This study followed a group of preservice elementary teachers from a physics content course, into a science teaching methods course, and through their student teaching experience. Over this time, I collected data on how they engaged in, made sense of, and used the science practices both in the role of students and teachers. The results presented about the participants' engagement (Chapter 4) and CCK (Chapter 5) are an assessment of these aspects from their time in the physics course and does not show change over the time of the study. Even within the physics course, the participants' engagement in the practices did not show statistically significant changes over time. However, some participants made progress in their engagement over the length of the course on an individual basis (e.g., Angie with Data Analysis & Mathematical Thinking). This could be due to the differences in the content from the beginning to end (e.g., starting with mechanics and ending with waves and heat) or it could indicate that significant changes in engagement happen over longer periods of time. The participants' KCS (Chapter 6) did show changes from phase one to phase two. In some instances, I found that the preservice teachers' KCS seemed to improve due to the additional instruction and support of the methods course (e.g., Explanation & Argumentation was a focus of the methods course). In other cases, I speculated that the changes in KCS could be due to factors related to the context of the teaching environments (e.g., teaching real students in the practicum and student teaching placements during phase two rather than preparing lesson for imagined ones). Shifts in the content being taught also could have brought out differences in the participants' knowledge of content and teaching (KCT) (e.g., changes in how the participants used Data Analysis & Mathematical Thinking due to many of the phase two lessons being based on life science lessons). The following sections look at each of the science practices individually and synthesize the findings across the chapters.

Scientific Modeling

Out of all the practices, the preservice teachers claimed to have had the least experience with Scientific Modeling prior to taking physics. Despite this, at the end of the physics course, their engagement in and knowledge (CCK) of modeling was near the averages of the other practices. The participants infrequently used modeling in their teaching. This aligns with current trends in elementary classrooms nationwide (Plumley, 2019). When they did teach with modeling, they used it with sophistication in both phases of the study. They more often engaged in and used *Model "OF"* in their teaching. They understood that this element of modeling helps students to connect phenomena to the real world and makes abstract concepts visible. In fact, making concepts visible was a major modeling theme for the preservice teachers. Other studies, where preservice teachers did not have a content course focused on science practice, found that preservice elementary teachers often struggled with these concepts (Bismack et al., 2020; Ricketts, 2014). In fact, they have shown that preservice elementary teachers may struggle with understanding Scientific Modeling and its purpose (Kenyon et al., 2011; Ricketts, 2014).

The focal preservice teachers in this study understood that, in general, the purpose of modeling is to help students make sense of phenomena and that all models have limitations (Lehrer & Schauble, 2000; Passmore et al., 2014). Beyond this, they did not discuss more specific and practical uses for modeling such as generating explanations, collecting data, or showing relationships, which is typical (Justi & Gilbert, 2002; Ricketts, 2014). The few times they used modeling in their teaching, the participants did so at a sophistication level matching their students' grade level and often these uses mirrored activities they had done in physics or their other teacher preparation coursework.

While the preservice teachers' KCS for Scientific Modeling was strong in each phase of the study, their infrequent use of modeling could imply a hesitancy to use modeling in their instruction. This could possibly indicate low KCT, meaning that without having had more experiences using modeling as students within different subject matters, the participants may not have been able to connect the new content to Scientific Modeling. Some of the lack of modeling could be attributed to the contexts of the teaching situations (e.g., the methods course intentionally omitted a deep perusal of modeling due to time constraints in the course, the curriculum material did not suggest modeling as a practice), but it could also be a reflection of their general inexperience with modeling (Banilower et al., 2018; Davis et al., 2006; Trygstad et al., 2013). Having many direct experiences with modeling in the physics course could be the reason why their CCK was stronger compared to preservice teachers from other studies who did not take a practice-oriented content course (Ricketts, 2014). This suggests that further experiences with modeling would likely continue to improve their CCK and could possibly lead to better KCT. Likewise, more experience teaching with modeling would most likely increase how often they use it in their teaching and lesson plans.

Plan & Conduct Investigations

In contrast to Scientific Modeling, Plan & Conduct Investigations was the practice the preservice teachers claimed to have had the most prior experience with. This practice made up just over a quarter of their opportunities to engage in the physics class and the participants used it the most in their lesson plans throughout the study. Having had the most experience with investigations prior to the physics course may not have been to their advantage. For example, if those experiences taught the preservice teachers poor habits (e.g., making predictions without justifications, or collecting data without multiple trials) their poor apprenticeship of observation (Lortie, 1975) would need to be corrected. For example, when comparing a similar group of preservice elementary teachers (Bismack, 2019) to the ones in this study, there is a difference in how their knowledge of investigations ranks among the other practices. Bismack (2019) found that her participants had the poorest content knowledge related to conducting investigations, and the participants in this study had CCK scores for Plan & Conduct Investigations in the middle of the practices. The difference in the knowledge raking of this practice for these two groups could be the focus on science practice experiences of the physics course (which the earlier group did not have).

Despite their greater familiarity with Plan & Conduct Investigations, the participants did not show improvement in their KCS for the practice as a whole. Their adjusted KCS score remained at the *expected* level throughout the study. In contrast, their KCS for each other practice ended at the *strong* level. This could be another case of the preservice teachers falling back on teaching patterns that they have more experience with rather than experimenting with their new experiences (Windschitl, 2003).

At a smaller grain size, the preservice teachers had less experience with the sub-practice *Plan Procedures*. As shown in Chapter 5, their understanding of this practice split the participants into two groups. The first group held that, especially for students in the younger grades, teachers should do the majority of the planning. They feared that because of the students' inexperience, they might not learn as much as they need to. The second group believed that students are capable of planning their own investigations and that teachers are responsible for putting scaffolds in place to support them in that work. This difference in beliefs is common among preservice teachers (Bennion et al., 2020; Haefner & Zembal-Saul, 2004; Shim & Ryu, 2017). Preservice teachers who had success with this sub-practice learned to share the planning with their students. Research shows that, although this work is complex, students who have proper support can effectively engage in this practice and develop these skills over time (Duschl & Bybee, 2014; Kirschner et al., 2006). The participants in this study found that assigning roles to their students, using broad directions that allow for flexibility, the use of questioning, and modeling some procedures helped them engage their students in planning. For example, Angie asked her students different questions during investigations to give them agency over how to proceed with their investigations. Each move towards shifting responsibilities to the students could help make them epistemic agents (Ko & Krist, 2019; Stroupe, 2014) or it could give them the responsibility to build and shape their knowledge. Traditionally, the teacher is the only one who acts as an epistemic agent but the *Framework* shows a pattern to shift that responsibility.

The preservice teachers also made progress with *Make Predictions*. At the end of the physics course, in their CCK, the participants confused the terms predictions and hypotheses, often using them interchangeably. One way to tease apart the difference is that hypotheses are built from existing theories and predictions are made from past experiences. While all predictions require some form of justification (Bybee, 2011), the source of the justification can shift how sophisticated the use is. For example, the grade level progressions in *Appendix F* of the *Framework* (NRC, 2013) asks for young students to support their predictions with prior knowledge (this could be past experiences or knowledge they have from other classes). This can shift when looking at the upper grades and the *Framework* uses the term hypothesis connected to justifications sourced from current theories and relevant content instead of past experience. The preservice teachers never made that final differentiation when discussing predictions. In their lesson planning, the participants used *Make Predictions* frequently, but only consistently included the justification aspect after the methods course. Other studies have shown that both preservice teachers and students can make predictions (Arias et al., 2016; Lee & Butler, 2003), but often struggle to justify them (McNeill, 2009; Ricketts, 2014; Sandoval & Reiser, 2004). This work adds to the argument that in addition to helping preservice teachers include justification, they need to consider the age of their students and the source of the justification (García-Carmona et al., 2017; Oh, 2010).

Data Analysis & Mathematical Thinking

The preservice teachers claimed to have the second highest past experience with Data Analysis & Mathematical Thinking. It appears as though this past experience was closer to the descriptions of the sub-practices found in the *Framework* because by the end of the physics course the participants had the highest LOS scores in both engagement and CCK for this practice. Most of the preservice teachers saw strong connections between math and physics (e.g., Bursal & Paznokas, 2006) and believed that having math skills enhanced their ability to do science. Although they engaged in the practice well and understood the overall purpose, in their physics lesson plans they displayed weak KCS. In other words, the preservice teachers left out many of the details of how students can analyze data or asked their students to work beyond their grade level ability. This behavior is typical in elementary science lesson planning (e.g., Zangori et al., 2013). For the methods course and student teaching lessons, this changed to a strong level of sophistication. This could be an instance where the content of the lessons (or the participants' KCT) came into conflict with their KCS. For example, in the physics course, some of the participants used *Apply Algebra* in a way that aligned with the subject matter, but was above the target grade level of the students because they used it in a similar way to their physics experiences (e.g., to calculate the slopes of position versus time graphs with young grades). In the methods course and student teaching lessons, the participants were likely more aware of their students' capabilities because they spent time with them each week (this would have improved their KCS). The content of many of these lessons was also life science and this shift away from quantitative data could have aligned better with their KCT. For example, in Angie's case study presented in Chapter 8, she saw an improvement in her KCS when the content (life science and qualitative data collection) matched her KCT. In the phase two lessons, the participants planned the majority of their uses of Data Analysis & Mathematical Thinking at the target grade level of the students.

Using mathematical thinking to *Find Patterns* can be difficult for preservice teachers (Bowen & Roth, 2005), but with additional support and practice they could make improvement in this area (Bennion et al., 2020; Rivet & Ingber, 2017). As the preservice teachers enacted their lessons, they supported their students in this practice by leveraging group work. Having students compare data between groups or to share general trends in whole group discussion made a difference in the overall engagement of the class. Using teaching moves in this way enhanced the effectiveness of the practice (Bismack, 2019). While the participants could do more to understand and use the specific mechanics of the practice (e.g., finding trend lines, plotting different types of data) (Bowen & Roth, 2005; Ricketts, 2014), they understood the overall purpose of the practice. This purpose is to make sense of the data in a way that allows students to build evidence-based claims (Rivet & Ingber, 2017).

Explanation & Argumentation

The participants struggled the most with Explanation & Argumentation in the physics course. They had the lowest engagement and CCK sophistication for this practice. In part, they struggled because the claim, evidence, and reasoning (CER) framework (McNeill & Martin, 2011) was a new tool for them and writing explanations is frequently left out in traditional science spaces (Biggers et al., 2013; Plumley, 2019). Over their time with the physics course, they became more comfortable with the framework and it also appeared in several of their last lesson plans. Leveraging the CER framework could be what allowed them to push their Explanation & Argumentation KCS sophistication to the *expected* level. The participants used the CER framework in their lesson plans more skillfully after their methods course. The methods course gave them instruction in the use of the framework and provided opportunities to use it in teaching. The participants' improvement in Explanation & Argumentation could be seen as evidence of the effectiveness of methods course instruction on future teaching as seen in other research on preservice teacher education (Arias, 2015; Bismack, 2019; Kademian & Davis, 2018).

In the physics lesson plans, the preservice teachers included *Engage in Argumentation*. This is often an overlooked aspect of the science practices in school classrooms (Biggers et al., 2013; Bricker & Bell, 2008; Plumley, 2019). Participants planned to have their students share their claims in small groups and to either agree or disagree with the evidence presented by the other groups. Brad described his plans as a "friendly debate" (Brad_Phy_LP5). Some of the participants wanted to leverage the arguments as tools to refine their students' claims which is an advanced use of this practice often not seen in classrooms (Berland & Reiser, 2011). The high frequency of argumentation in these lesson plans could be mirroring the lesson format the preservice teachers experienced in the physics course. Most of the physics labs ended with a 15 to 20 minute time period where I asked the groups to share their claims and resolve any differences in evidence or data in their analysis. This sub-practice did not persist into the phase two lesson plans, with the exception of Amber's two methods course lessons. To capitalize on the strengths the preservice teachers developed during the physics class, the methods class could have provided more opportunity for them to learn about and practice engaging in argumentation and supporting argumentative discourse.

The preservice teachers showed sophistication in their CCK for *Use Reasoning*, showing a strong understanding of the sub-practice relative to the other CER elements. While other studies have found opposite trends (e.g., Bismack et al., 2020 for preservice teachers, Berland & Reiser, 2011 for students), the participants as a whole could define the main elements of reasoning (e.g., connecting evidence and claims, using theories to support claims) (McNeill et al., 2006; McNeill & Martin, 2011). Knowing the component parts of reasoning is not new (Bennion et al., 2020), the difference is in how preservice teachers use reasoning in their teaching. In this way, the participants aligned more closely with past studies. In many of their lesson plans, they included reasoning as a part of the CER framework. However, during the enactments, the reasoning portion was often left out due to time constraints or the difficulty of this element (Bennion et al., 2020; Bismack, 2019).

Summary

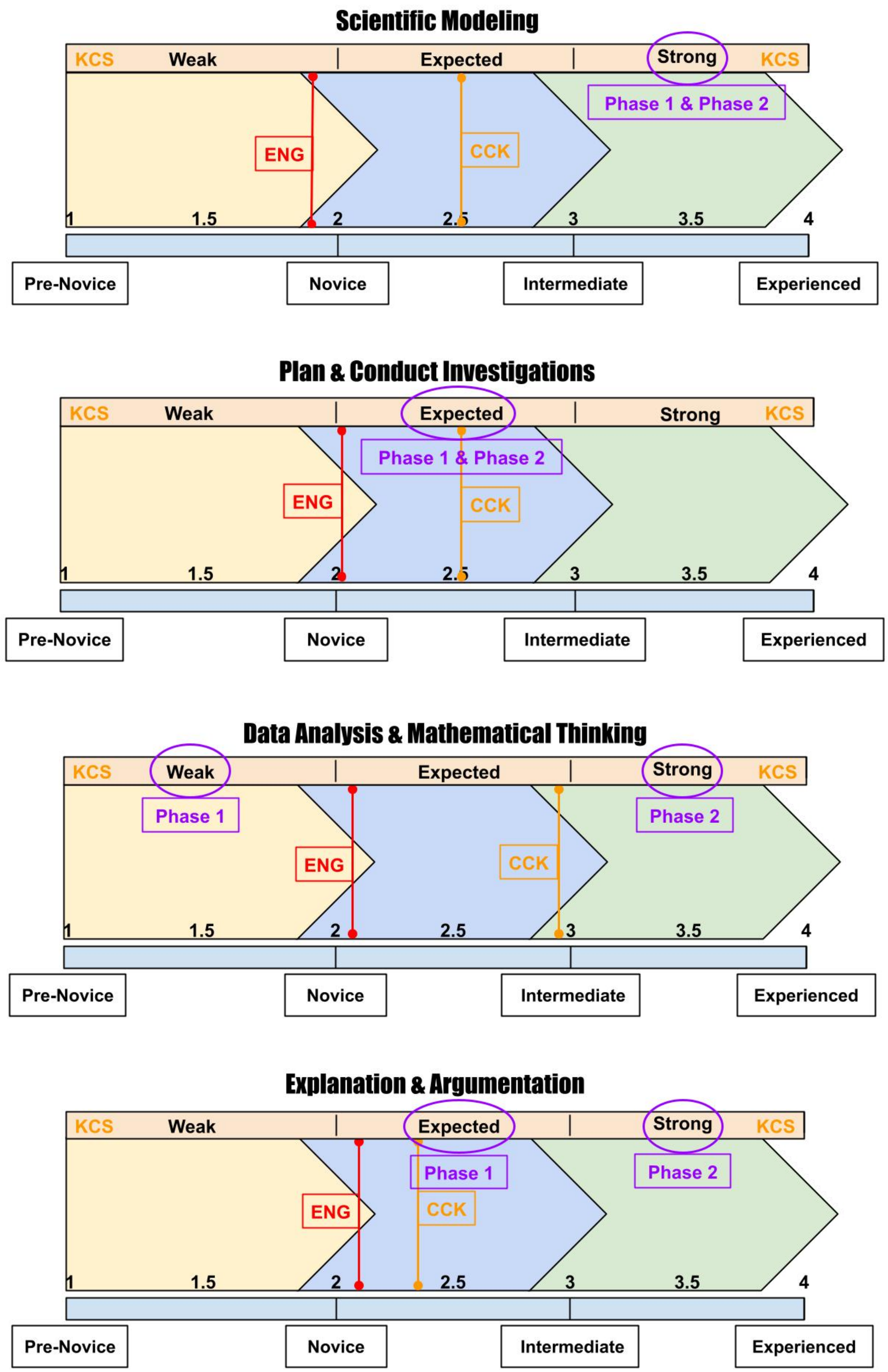
The participants used the science practices with varying degrees of sophistication, both as students and in their lesson plans. At times, their sophistication could have been bolstered by what they had learned in their program (e.g., improvement in Explanation & Argumentation KCS after the methods course). In other cases, elements of the different context seemed to change how they used the practices in planning (e.g., changes in Data Analysis & Mathematical Thinking when the subject matter was not as math reliant). In the final averages, with each practice except Plan & Conduct Investigations, the preservice teachers displayed strong KCS and often thoughtfully included several of the sub-practices in their science teaching.

Level of Sophistication Continuums

As a way to visually represent and compare each focus of this study (engagement, CCK, and KCS), I developed the level of sophistication continuums (see Figure 9-1). The continuums represent the LOS rubric scores from pre-novice to experienced, with the adjusted LOS scores for KCS across the top of each continuum. The engagement is indicated by a red line, the CCK by an orange line, and the adjusted KCS is circled in purple. These continuums show the averages of each participant over the entire study and give a zoomed-out view of the findings (in contrast, the continuums in Chapter 8 show data for individual participants).

Figure 9-1

Level of Sophistication Continuums Displaying the Engagement, CCK, and KCS for Each Science Practice (averaged across n=9 focal participants)



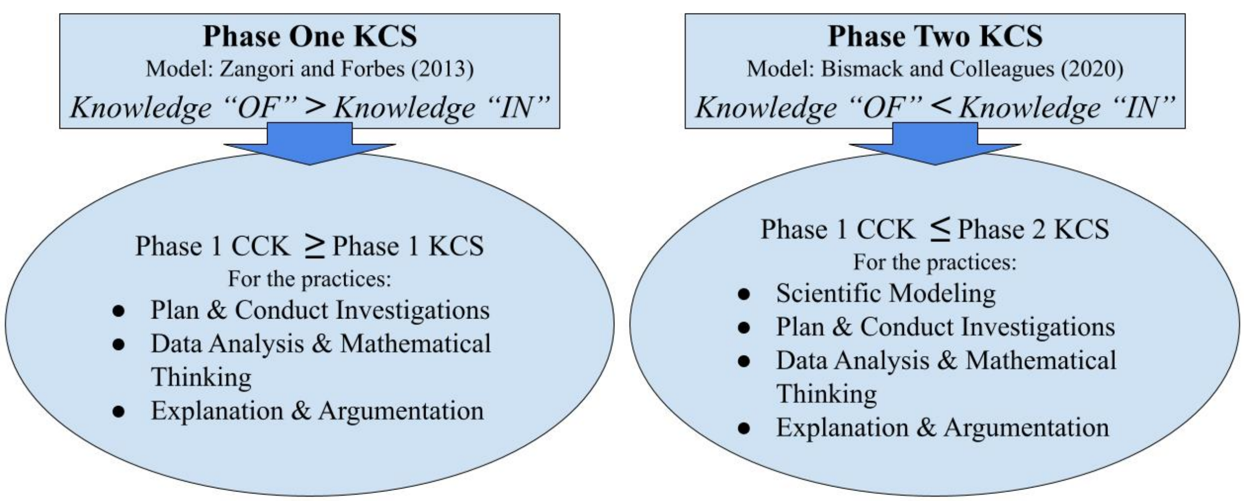
Looking at the science practices as a whole, the participants engaged with the practices, on average, near the novice level (LOS score 2). At the time of the physics class, the practices were new to many of the preservice teachers and the data shows some of their first interactions with each practice. Their CCK or understanding of each practice was higher than the engagement for each practice. In each case, the participants' CCK averaged between the novice (2) and intermediate (3) levels. I measured the engagement and CCK scores only at the time of the physics course. From these continuums, it appears as though the participants' engagement in the practice was not constrained by their knowledge of the practice. For each practice, they likely understood it at a higher level than they engaged in it. The lower engagement scores could be evidence of a cognitive load issue. For example, during an investigation, when the participants are balancing different real time concerns (e.g., working with a science practice, group dynamics, wrestling with new content), the added load could be constraining their efforts with the practice. Chapter 4 presented possible evidence of this where the data showed statistically significant drops in performance with certain practices when the content was challenging.

One possible way to interpret the KCS scores is to use Zangori and Forbes' (2013) framework of knowledge "for" practice versus knowledge "in" practice. They found, when working with constructing scientific explanations, that novice teachers had a stronger knowledge "of" the practice (similar to CCK) compared to their knowledge "in" practice (similar to KCS). During phase one, the preservice teachers' KCS scores averaged either at the same level or lower than their CCK holding true to the pattern found by Zangori and Forbes (2013) (with the exception of Scientific Modeling). While I did not collect data for or make an assessment of the focal preservice teachers' CCK at the end of the study, comparing their phase two teaching (KCS) scores to their phase one CCK scores shows the opposite pattern for each of the practices.

This aligns with the results of Bismack and colleagues' (2020) recent study with a similar group of preservice elementary teachers. In that study, the researchers claimed that the preservice teachers were able to teach with the practices at a more sophisticated level than their current understanding because they leveraged teaching tools and practices learned during their methods course to bridge the gap. This could have been the case for the participants in this study as well. For example, the preservice teachers leveraged in class group dynamics (a skill taught during the methods course) to improve the sophistication of their use "in" practice during the enactments. Figure 9-2 shows how the KCS scores from each phase of this study could align with the two different models of knowledge "of" versus knowledge "in" practice. The figure also shows which practices from the given phase align with the featured model.

Figure 9-2

Comparison of Knowledge "OF" (CCK) and Knowledge "IN" (KCS) During different Phases of the Study



Situated Learning and the Science Practices

One of the primary purposes of using the science practices is to situate science learning within authentic activity (Brown et al., 1989). The physics course followed this model using legitimate peripheral participation (Lave & Wenger, 1991) to introduce the preservice teachers to the science practices. This is where learners move towards mastery of knowledge and skill in a community by engaging in the practices of the community. In the physics course, the preservice teachers stood on the periphery of two different communities: science, and science teaching. While the goal was not to bring them fully into the community of scientists, it was important to help the participants get a glimpse of what work in that community is like. This knowledge cannot be "transmitted" to teachers; instead, learning like this emerges from their own activity (Korthagen, 2010). On their journey to enter the science teaching community, the participants had many "oldtimers" (Lave, 1991) to help them along the way (e.g., myself in the physics course, methods instructor, mentor teachers). The preservice teachers had opportunities to engage in the work of the community as they wrote lesson plans throughout the study, engaged in peer teaching, and evaluated student work. Evidence of their progress towards full participation in this community can be seen in the improvement of their KCS sophistication in the LOS continuums. By the end of the study the participants made excellent progress and were "well-started beginners" (Avraamidou & Zembal-Saul, 2010; Davis & Boerst, 2014) as they moved on from student teaching to begin their elementary teaching careers. Brad's case from Chapter 8 exemplified this transition towards full participation in the science teaching community with regard to Data Analysis & Mathematical Thinking. In the beginning, Brad's high CCK possibly interfered with how he planned to use the practice with his students. In his phase two lessons, after learning more pedagogy and having a better understanding of his students, his KCS improved to the "strong" level.

Implications and Contributions

Findings from this study provide insights into how aspects of teachers' knowledge are connected and how this work has added to our understanding of this knowledge. I have organized the implications of this study into three sections: theoretical, methodological, and implications for teacher educators.

Theoretical Implications

This study used the framework of content knowledge for teaching developed by Ball and colleagues (2008) to situate the preservice teachers' knowledge of the science practices. This framework divides teacher knowledge into two categories: subject matter knowledge and pedagogical content knowledge. Within these subdomains, I focused on common content knowledge (CCK), knowledge of content and teaching (KCT), and knowledge of content and students (KCS). In most studies of teachers' CCK (e.g., Donna & Hick, 2017; Nixon et al., 2019), the authors focus on content (e.g., conservation of energy, carbon cycle, life cycle of stars). CCK is more than just the theories and laws developed by scientists, it is also an understanding of the practices that developed the knowledge. This study adds to what is known about preservice teachers' understanding of practices in several different ways as described above (Bismack, 2019; Ricketts, 2014). For example, the study illuminates the need to help preservice teachers differentiate how to use justifications and predictions based on the grade level of their students, or to help them include the skills related to the listener's role in argumentation (see Table 5-6 for full overview).

This study also adds to our understanding of preservice teachers' use of the science practices in teaching. In Chapters 6 and 7, I presented two lists of themes that emerged from discussing how teaching and learning connect to the science practices during the interviews from each phase of the study. First, I presented themes related to how and why the preservice teachers used the practices in their teaching (e.g., *build student understanding*, *useful framework/tool*, *skills beyond science*). For example, when using the science practices as a *useful framework/tool* for lesson planning, they seemed to be treating them like a set of curriculum materials. In a way, the science practices can provide a map of what science teaching could look like in their classrooms (Roseman & Koppal, 2008). The preservice teachers likely applied their KCT as they aligned which practices to use with the content they taught and they used their KCS as they determined how sophisticated the engagement needed to be.

Second, I found themes in how the participants connected student learning to the science practices (e.g., *autonomy & curiosity*, *chance for reflection*, *learning to be scientists*). Each of these themes is an important element of the preservice teachers' KCT and KCS because they can help the participants to make decisions about which practices to use and how to use those practices in their teaching. For example, when planning a life science lesson, a preservice teacher might draw on the theme of *wide engagement* and so will make sure to include a wide range of science practices throughout the unit (engaging their KCT in the process). They could also think about using the practices in a way to build on students' autonomy and curiosity, or epistemic agency (Stroupe, 2014), by giving them more agency in the planning portion of the lesson (engaging their KCS in this decision).

The case studies in Chapter 8 show how CCK, KCT, and KCS were connected for Angie and Brad. In their cases, Angie and Brad's KCT appeared to be constrained (or bolstered) by their CCK. For example, Brad's in-depth knowledge of Data Analysis & Mathematical Thinking (i.e., CCK) allowed him to better align the practice with the content he chose to teach (an aspect of KCT), while Angie had the opposite experience in her physics course lesson plans. Similarly, without the pedagogy learned in the methods course, Brad's high CCK could have influenced him to plan beyond the skill level of his students in his physics lesson plans (indicating a lower KCS). He and Angie were able to improve their KCS scores after their experiences in the methods course and when working with real students in their practicum placements.

The LOS continuums also imply connections between CCK and KCS. Research shows that these knowledge categories are connected (Ball et al., 2008; Bismack, 2019; van Driel et al., 2014). The continuums imply that when the preservice teachers used the practices in the physics course lessons (prior to their explicitly learning science teaching pedagogy), their use of the science practices was less sophisticated than how they used them after their methods course. This could be additional evidence of the importance of pedagogical content knowledge (of which KCS and KCT are subdomains) and its connection to science practices in addition to standard content knowledge. This is another indicator that CCK or an understanding of how the practices work is not enough to produce desired results in instruction which is a fundamental tenet of pedagogical content knowledge (Shulman, 1986).

Methodological Implications

Measuring levels of sophistication can be complicated work. There are many different variables that changed how the participants engaged in or used the science practices in their teaching. When I looked for changes in the LOS engagement scores over the physics course using an ANOVA, I found that the difference in the scores for each practice from the beginning of the study to the end were not statistically significant. Despite all of the practice the participants had with each practice over the semester, they still engaged with the practices in a similar manner as when they started. On an individual basis, some participants (e.g., Angie with Data Analysis & Mathematical Thinking) did show some improvement in their engagement. This group trend could imply that in order to see significant change in how people engage in the science practices, that more time is needed for them to practice. Also, to push their limits with the practices, they may need an "advanced other" in their group to help lead them to higher engagement as was the case with Angie. Looking at the design of the science practices, K-12 students are intended to take years to develop skill and progress in sophistication (NRC, 2013).

Measuring sophistication in teaching over time can also be problematic. This is especially true for preservice teachers where the contexts in which they plan lessons during the program and student teaching is constantly changing. I could not directly compare the differences in LOS rubric scores for KCS from one phase of the study to the next, or between one preservice teacher and another without making an adjustment. The subject matter of their science lessons (e.g., momentum, sound waves, plant life cycles, animal classification), available resources (e.g., technology, lab equipment), and the age of the students varied so much that to take an unadjusted measurement using the LOS rubric was problematic. To compensate for this, in this study, I used the grade level of the students to normalize the scores. This improved my ability to make comparisons but did not account for each possible variation. For example, if a teacher planned to use the science practices at the pre-novice level for a group of first graders, that would indicate strong KCS because the use of the practice would align with the ability level of the students. In contrast, if they used the practices in the same way with a class of sixth graders, that would indicate weak KCS. Building mechanisms to directly control for variations like this is a contribution of this study, but further work is needed to fully address this issue.

When comparing how the participants used the science practices in their enactments and their lesson plans, I found the two modes to be mostly closely matched. On average, the enactment scores were slightly lower than the sophistication I found in the lesson plans. This could be another reflection of the preservice teachers' knowledge "*of*" practice being higher than their knowledge "*in*" practice (Zangori & Forbes, 2013) as well as a representation of the gap that sometimes exists between beliefs and practice (Abell & Bryan, 1997; Davis et al., 2006). The participants' use of Data Analysis & Mathematical Thinking was a case where this trend did not hold. They displayed higher sophistication in their enactment than they did in the original lesson plan. For this practice, the participants leveraged small group work to enhance the student's engagement in ways that were not evident in the lesson plans.

Implications for Teacher Educators

Teacher educators should consider the types of experiences their preservice teachers have had with the science practices prior to enrolling in their methods courses. Each individual will have had varied experiences, but recent studies show that in many cases their training is inadequate to fully engage in reform-based science teaching (Demir & Abell, 2010; Gillies & Nichols, 2015). It is also not enough to just read and discuss what the science practices are (Capps & Crawford, 2013; Newman et al., 2004). Preservice teachers need to engage in the practices as students first and then experience using them as teachers in low-risk situations like peer teaching (Bennion et al., 2020; Korthagen, 2010; Ricketts, 2014).

Teacher educators should help their preservice teachers build their understanding of the practices by explicitly calling out the practices during their engagement in order to help them begin to translate it into their teaching (Grossman et al., 2009; Hanuscin & Zangori, 2016). Preservice teachers may not realize which practices they are engaging in during an activity, so without explicitly showing them those practices, they wouldn't know to build it into their own lessons. For example, Justin pointed out in the middle of the physics course that he had no idea what scientists really do, so he could not make comparisons between his work and theirs.

Making those connections explicit for preservice teachers could help them do the same for their future students. This could also help them develop their CCK which could lead to higher KCT and KCS.

To assist teacher educators in deciding what aspects of the practices they could focus on during their methods courses, I would refer them to the areas for improvement listed in the tables at the end of Chapters 4 through 6 (Tables 4-7, 5-6, and 6-8). For example, with Plan & Conduct Investigations, they could engage their preservice teachers in investigations that require them to grapple with the details of planning (e.g., number of trials, controlled variables, which tools to use), make predictions with justifications rooted in theory, and take time to evaluate and revise their investigation questions. In addition, constructing and using scientific models is a large part of the work that scientists do, but preservice teachers have few opportunities to engage in this practice. The participants in this study had more opportunities to engage in modeling during the physics course than the other practices. In addition to that engagement, they could still use more opportunities to design their own models and then use those models for specific purposes (e.g., data collection, explanation building). Although they did not use it often in their teaching, when they did, it was at a strong level of sophistication. I attribute this to their experiences with modeling during physics. Preservice teachers likely need more experience with this important practice especially engaging in constructing models (Passmore et al., 2017; Ricketts, 2014). The methods class could and perhaps should, for example, build on the strengths developed in the physics class to extend the preservice teachers' expertise around scientific modeling.

The last implication in this section is the positive effect that content courses could have on the future teaching outcomes of preservice teachers if they are included in the contextual discourses of the teacher education program (Thompson et al., 2013). The more teacher educators can do to align the tools, language, and experiences the preservice teachers have as they progress through their program, the better prepared they will be to deal with the challenges of their classrooms. In the physics course, I aligned the lesson planning template with the one used in the overall program (EEE+A framework), the equity leverage points (a framework used to help the preservice teachers consider equity in their teaching) (Tupper et al., 2017), a focus on NGSS, and the use of other science practice related frameworks like the CER framework for scientific explanations. In addition, elementary teacher education programs face the dilemma of training teachers across all subject areas while still allowing their students to graduate in a reasonable amount of time. Because of this, most programs only have one science methods course. Often this is not enough to produce lasting results (Akerson et al., 2006). This is another reason to leverage content courses. In this physics course, the preservice teachers engaged in the science practices as students in an explicit way every time the course met. While the main objective of the course was to teach science content, the way that content was taught impacted the participants' future teaching. For example, having already learned with and used the CER framework in their lesson plans, the participants were able to build on that foundation in the methods course. They also experienced a lot of quantitative data analysis in the physics course, which could have prepared those who taught the energy lesson in their methods course peer teaching experience. In addition, within many of the lesson plans, the preservice teachers attempted to use similar approaches to the labs and practices they experienced in the physics course. For example, when teaching about the phases of matter, Angie used the same modeling designs as she did in physics. Without those experiences, or if the physics course had been designed more traditionally, the preservice teachers likely would have had a less rich base of experiences to build their own lessons from.

Limitations and Next Steps

This study investigated the engagement, knowledge, and use of the science practices of a group of preservice elementary teachers. The overall aim of the study was to increase the understanding researchers and teacher educators have about preservice teachers and the science practices as a whole. One of the limitations of this study was the size and selection of the sample. I did not randomly generate the sample and size of the sample was small. Because of this, the results of the study are not generally applicable although they do provide an example of what is possible under given conditions. For example, the cases in Chapter 8 show what the trajectory of two preservice teachers could look like given their prior experience with the practices. Further work could be done using the LOS rubric to evaluate preservice teacher use and knowledge of the science practices with groups of preservice or novice teachers with different backgrounds or from a more widely represented sample.

While I tested and adjusted the LOS rubric through rounds of inter-rater reliability (see chapter 3), the rubric has its own constraints. At its base, I designed the rubric from the grade level progressions and student expectations found in the *Framework* (NRC, 2012). I originally intended to use the rubric to quantify the how sophisticatedly the preservice teachers engaged in the science practices. As I moved forward in my research, I applied the rubric to the preservice teachers' knowledge (CCK) and to their teaching with the practices (KCS). I found that the use of the rubric in those spaces was a little restricted. This was especially true when I was evaluating the videorecord enactments. The rubric did not have a way to capture certain aspects of the teachers' pedagogy (like using the practices in small groups). Future work should focus on adapting the LOS rubrics and expanding their uses to include broader contexts.

One area I intend to continue to study is how teacher educators can help preservice teachers to engage with the practices at higher levels. In this study, I wanted to see where the preservice teachers' skills were at the time they took the physics course. While certain labs did have scaffolding to help the participants engage at a higher level than they might have on their own, most labs left the participants with enough agency to work at their own level. I am interested to see what kinds of scaffolding or group arrangements could help push the preservice teachers out of their comfort zones with the practices as they engaged in them. In a scenario like this, where the participants engaged in the practices beyond their comfort zones, what influence would that then have on their knowledge and future teaching?

Conclusion

The way that preservice teachers learn science matters. Not only can it impact the content they eventually learn, but it likely impacts how they understand the processes of building knowledge in science. How they interpret the way knowledge is constructed in science could influence how they teach science to their students. In the end, this is what science teacher education is trying to guide and improve. Whether it is in the context of a science content classroom or a teaching methods course, educators have a responsibility to build knowledge in authentic ways and to help their preservice teachers to aspire to do the same. Brad understood it this way,

> what's important … looking at the science practices, so not just like, teaching science the way that I think it should be done. But the way that the rest of the scientific community thinks that should be done (Brad_ST_Int)

In his last interview, Brad showed that he was beginning to understand his responsibility as a science teacher and that how he teaches is much more than a personal preference.

This work adds to the field's knowledge of preservice elementary teachers and the science practices by studying a wide range of science practices and their sub-practices, and by observing the preservice teachers over a long period of time. Tracking them from a science content course, to the science teaching methods course, and through their student teaching can give a more holistic view of what experiences they have had and how their teaching with the practices could develop over time. It also highlights the challenges of doing research over a time when the context of the study shifts drastically from one phase to the others.

The participants in this study are not a generalizable case, but they do represent a case of what could be possible. These preservice elementary teachers were excited to teach science and they planned to do it in authentic ways (this already sets them apart from many of their peers). While they still had areas to improve in, they were a representation of "well-started beginners" (Avraamidou & Zembal-Saul, 2010; Davis & Boerst, 2014), and this study highlights the importance of giving preservice elementary teachers the opportunity to engage in the science practices in authentic ways both as students and as teachers.

Appendices

Appendix A: A Description of the Course Labs with the Target Science Practices

Lab	Description	Target Science Practices
Lab 1	Introduce science investigations and explanations through a lab where the preservice teachers study bubble planes and bubble lines (shapes made by bubbles on the interior of 3D geometric shapes).	Investigations Explain & Argue
Lab 2	Explore inertia by the means of an oscillatory device that vibrates horizontally. Varying the amount of mass in the device, the preservice teachers will measure differences in period.	Investigations Explain & Argue
Lab 3	Study velocity and acceleration using computer software to analyze the motion of videos of falling objects that the preservice teachers have recorded.	Modeling Data & Math
Lab 4	Investigate Newton's second law by collecting data on the acceleration of paper rockets of variable mass. Slow motion videos of rockets are recorded and then analyzed with computer software.	Investigation Data & Math
Lab 5	Study impulse and momentum by prototyping models of a device designed to protect a chip from being crushed by a falling mass. Force and time data are recorded with the aid of sensors and software.	Modeling
Lab 6	Investigate conservation of momentum by video recording collisions of air carts with varying amounts of mass. Computer software is used to analyze the videos and provide data analysis.	Data & Math Explain & Argue
Lab 7	Study gravitational and kinetic energy through the construction of a roller coaster. Gravitational and kinetic energy is compared at several points.	Modeling
Lab 8	Investigate a popper (a small hemispherical piece of rubber) that jumps up into the air when inverted. Preservice teachers design and carry out an experiment that will allow them to determine the original amount of energy in the popper.	Investigation

Lab 9	Devise a way to build and power a toy car with rubber bands. Preservice teachers will collect data on their cars and quantify several of its physical features and abilities.	Modeling Investigation
Lab 10	Collect data and use the density equation to compare the densities of several different objects. Float test are done on the objects afterwards to look for patterns among the numbers.	Data & Math Explain & Argue
Lab 11	Investigate Bernoulli's Law with a tank of water. The velocity of a jet of water is measured as the depth of water in the tank changes.	Investigation Explain & Argue
Lab 12	Model solids, liquids, and gasses in several different ways. Limitations of each model are discussed.	Modeling
Lab 13	Explore atoms with the use of online simulations. Preservice teachers develop rules that govern the structure of stable atoms and isotopes.	Modeling Data & Math
Lab 14	Investigate of static electricity by the means of various experiments (furs and rods, Van de Graff generator, pith balls, …).	Investigation Explain & Argue
Lab 15	Investigate the components of a battery. Preservice teachers need to design and carry out an experiment that will test each element of the battery.	Modeling Explain & Argue
Lab 16	Investigate simple circuits (battery, bulb, wire). Discussion on electrical safety.	Investigation
Lab 17	Investigate Ohm's law with complicated circuits (multiple bulbs and batteries).	Investigation Explain & Argue
Lab 18	Investigate magnetism and model magnetic fields with various arrangements and types of magnets.	Investigation Modeling
Lab 18	Build "buzzer" circuits as preservice teachers investigate the combination of electricity and magnetism (missed this lab in 2019 year)	Investigation
Lab 19	Build models of motors and generators and use them to collect data.	Modeling
Lab 20	Build speakers and microphones. Investigation of alternating current and its applications as well as sound production.	Investigation Modeling

Lab 21	Investigate sound with a pipe of variable length and a set of tuning forks to find connections between the resonance frequency pipe length.	Investigation Explain & Argue
Lab 22	Investigate the physical properties of waves with the use of a vibrating cord at variable frequencies and other implements.	Investigation Explain & Argue
Lab 23	Use models of different wave forms to collect data on wave propagation. Use the principle of diffraction to measure wavelength of light.	Modeling Data & Math
Lab 24	Study calorimetry by mixing different proportions of water at different temperatures. Preservice teachers will use their data to develop a mathematical model.	Modeling Data & Math
Lab 25	Use a model of a room to collect data on the mechanisms of heat transfer.	Investigation Modeling

Appendix B: List of Post Lab Questions

Related to Scientific Models:

L1Q1 - Did today's activity relate more to scientific modeling or was it more of a scientific investigation? Why?

L5Q2- What does a scientific model look like to you? Can it have different forms? What is the purpose of a model?

L6Q2- Were any of today's experiments a space where you felt you were either developing or using a model? How would you define a scientific model?

L7Q2- The roller coasters we built in class today could be considered models of actual roller coasters. Do you think this is an example of a scientific model? Why or why not?

L10Q2- In the activity where you built a boat out of foil, what are the limitations of this type of model?

L12Q1- How can a model be used to support a scientific explanation?

L12Q2- What is the purpose of scientific modeling?

L12Q3- What should a model in science be able to do? How do you know what the limitations of a model are?

L13Q2- In what ways can computer programs be models?

L17Q2- Coloring your circuits, and looking at them with steps diagram from the high voltage to the low is a form of modeling. What are the advantages and disadvantages of this type of model?

L18Q1- Is the electromagnet we built in class today a model? Why or why not?

L21Q2- Can a model be used to collect meaningful data? Why or why not?
What would this type of model look like?

Related to Plan & Conduct Investigations:

L1Q1- Did today's activity relate more to scientific modeling or was it more of a scientific investigation? Why?

L4Q2- In a lab like the rocket lab, how much scaffolding do you think students need to learn the science principles that the teacher is trying to teach? (None (pure open-ended inquiry) ………. A lot (cookbook style lab write report))

L4Q3- What can a science teacher do to help their students develop meaningful investigation questions? Why are these questions important?

L5Q1- Did the single pringle challenge feel like a science investigation or was it something else? Why?

L6Q3- From what you understand of the term "scientific investigation", do you think any or all of today's mini-labs could fit into that space? Why or why not?

L7Q3- Why did your group choose the method they used to find the velocity at the end of the track? Would you rather have been told how to find it? What are the advantages to finding your own way?

L8Q1- When your group was investigating the popper, how did you decide what course of action to follow?

L9Q3- Was today's lab a scientific investigation? Why or why not?

L11Q1- With scientific investigations, how student lead vs. teacher lead do they need to be in order to be effective? Why?

L15Q1- What is the difference (or is there a difference) between asking regular questions and asking a question in a science context? (Think about your lab with the coke battery)

L15Q2- How is a prediction different than a hypothesis?

L17Q3- What types of data/evidence did we collect in today's lab? Was there data we didn't collect that could have helped you more?

L21Q1- When your students are doing a science investigation, what are some of the safety and ethical considerations you need to make as a teacher? Why is this important?

L22Q3- Lasers can be dangerous to use in a classroom. Would you use a tool like this with elementary students? What kind of safety precautions would you put in place?

Related to Data Analysis & Mathematical Thinking:

L2Q1- In what ways did collecting data in the lab help you to understand mass and inertia?

L2Q2- How well do you trust the conclusions you found and the graph you built to predict the mass of different objects? Why?

L2Q3- How important are mathematical reasoning skills in being able to do and understand science?

L3Q1- What are the advantages (or disadvantages) of using graphs to analyze the results we get during a science lab?

L3Q2- What advantages do you think using technology like Logger Pro could have for students? Is this something you could see yourself using in your own classroom? Why?

L3Q3- Do you think that using software like Logger Pro to make graphs takes away from the students' learning? Would it be better for them to just do everything by hand?

L7Q1- With a topic like energy and its conservation, we could easily leave the math out. What advantages or disadvantages are there with having the students learn the mathematical reasoning as well?

L8Q2- In any of today's experiments, did your group decide to make a graph to analyze the results? Why or why not?

L9Q2- Today's questions involved doing a lot of math. Would you consider question like these engaging in mathematical reasoning? Or was it something different? Why?

L10Q1- How is observational data different than quantitative (numeric) data? Is one type of data more valid than the other?

L13Q1- One of the science practices is using mathematical and computational thinking, did you feel like you engaged in that practice during today's activities? Why or why not?

L16Q2- Often in science we talk about conceptual understanding and mathematical understanding of a phenomenon. Is one more important than the other? Why or why not?

L17Q1- In today's lab, we have ignored the mathematical equations that support what is going on in a circuit. Do you think you would understand the topic better if also took time to work out the math? Why or why not?

L18Q2- Did any of the tasks in today's labs require you to engage in mathematical or computational thinking? Why or why not?

L22Q1- Is it useful to compare classroom lab results against real world values like we did in today's lab? Why or why not?

L22Q2- How important is it to keep track of your units when you are doing this kind of work in science? Why or why not?

Related to Explanation & Argumentation:

L4Q1- Is the CER framework a useful tool for building scientific explanations and arguments? Why or why not?

L5Q3- Would the CER framework of "Claim, Evidence, and Reasoning" work well with a lab like the single pringle challenge? Why or why not?

L8Q3- When presenting your results about the rubber bands, if another group challenged your findings, how would go about defending your results?

L9Q1- Could you write a scientific explanation for the what we did in class today? Why or why not?

L10Q3- How can writing scientific explanations help students learn?

L11Q2- We have had several chances to use the CER framework in class up to this point. Do you think it is a useful frame for building explanations, or should teachers give their students more freedom in how they express themselves in science?

L12Q1- How can a model be used to support a scientific explanation?

L14Q2- What is it that makes a student's explanation of something scientific? Is there more to it than what is just in the CER framework? Why or why not?

L15Q3- What qualifies as evidence when you are trying to support a scientific explanation?

L16Q1- When working with CER framework for building scientific explanations, what is the reasoning part of the framework and how important is it? Explain your thoughts?

L18Q3- Let's imagine that you are in class and one of your peers said that they were able to cut their permanent magnet in half to separate the North part from the South part. How would you engage in a productive argument with this student? What would you say?

General Questions About the Practices:

L6Q1- Which of the following scientific practices do you feel like you engaged in today? Why?
Asking questions
Developing and using models
Planning and carrying out investigations
Analyzing and interpreting data
Using mathematics and computational thinking
Constructing explanations
Engaging in argument from evidence
Obtaining, evaluating, and communicating information

L11Q3- The science practices as defined by NGSS are specific in what has been laid out. Do you think these practices do a good job of capturing the actual nature of science? Why or why not? Do you think they are missing anything?
Asking questions
Developing and using models
Planning and carrying out investigations
Analyzing and interpreting data
Using mathematics and computational thinking
Constructing explanations
Engaging in argument from evidence
Obtaining, evaluating, and communicating information

L13Q3- In today's last activity we took a shortcut with the fake atoms to approximate something that astronomers do. Do you think taking shortcuts like this distorts the view students have of what actual scientists do? Are activities like this helpful in the long run? Explain your reasoning.

L19Q1- Which of the following science practices, if any, do you think was the most salient in today's lab. Explain your reasoning:
Asking questions
Developing and using models
Planning and carrying out investigations
Analyzing and interpreting data
Using mathematics and computational thinking
Constructing explanations
Engaging in argument from evidence
Obtaining, evaluating, and communicating information

Appendix C: Example of Lab Sheet

Name: ____ Date: _____/_____/______

Lab 2 -- Mass on a Stick

Pre Lab Questions:

1) What is the difference between an object's mass and an object's weight?

2) Pretend that you and a giant bulldozer are standing on the surface of the international space station. If the bulldozer is truly weightless, could you pick it up? What would be different?

3) Let's say that you wanted to throw the bulldozer away from the space station, what would happen to both you and the bulldozer if you tried this? Why?

Part 1 -- Demo with the Mystery Masses:

Under the influence of Earth's gravity, it is easy to tell which of the objects has the most mass.

1) How can each of these blocks have a different mass when they are basically the same size?

2) Draw a picture that would illustrate your point at the atomic level.

3) In the absence of gravity, how could you tell which block had the most mass?

Part 2 -- Mass on a Stick Lab:

Draw a picture of a the lab apparatus and label all of the parts, also note the on the diagram how the different variables will be measured.

Investigation Question:

Prediction:

Data Collection:

Graph and Data Analysis:

Scientific Explanation:

Post-lab Reflection:

1) In what ways did collecting data in the lab help you to understand mass and inertia?

2) How well do you trust the conclusions you found and the graph you built to predict the mass of different objects? Why?

3) How important are mathematical reasoning skills in being able to do and understand science?

Appendix D: Post-Physics Course Interview Protocol

Intro: My project is trying to better understand how preservice elementary teachers, like yourself, develop their knowledge and use of the science practices. So, I'm going to ask you some questions about your experiences in our physics class. The interview should take no more than 15 minutes. If there are any questions that you don't want to talk about, that's fine, you can just say so and there are no right answers to these questions. Do you have any questions for me?

1) Thinking back to physics 420, were there any of laboratory experiences were more meaningful to you? Why is that?
   a) Which science practices do you remember being central to that lab?
   b) How did you engage in the [above mentioned practice(s)]?

2) In your ideal lesson plan, you mentioned having your students [insert science practice]. Why was it important to include this practice in your ideal lesson? How does this practice help students learn?

3) In your lesson plan [pull out reference lesson plan] you had your students engage in [reference one of the practices in the lesson]. Why was it important to include this practice in this lab?
   a) How do you envision your future students engaging in this practice?
   b) How does this practice connect to the other practices [state other practices in lesson] included in your lesson plan?

4) What experiences did you have with the science practices before taking this course, if any?
   a) How were those experiences helpful to you in navigating this course? Your learning of science?
   b) If they mention the scientific method… how similar and different

5) How can engaging in the science practices help students learn?

6) What role will the science practices play in your future science teaching?

7) If you had the chance to change the science practices in anyway, how could you make them more useful for you as a teacher?

8) Do you think it is important for students to learn about the science practices by themselves, outside of using them in labs and to learn content?

9) Do you have any questions for me? Or is there anything else I should know about your thinking about the science practices?

Appendix E: Post-Methods Course Interview Protocol

The interview is meant to be an open-ended conversation where the preservice teacher will be given the chance to tell their story and elaborate on the experiences they had in the science methods course. Not all of the question will be asked to each interviewee. The selection of questions will depend on the relevant materials available.

1) In what ways did you engage with the science practices in your science methods course (e.g., lesson plans, peer teaching, field placement)?

2) In what ways did the work we did in physics 420, with the science practices, support (or not) your learning in the science methods course?

3) In your small-scale teaching experience, you had your students engage in [name relevant practices].
    a) Why was it important for your students do this activity in this way?
    b) How did it help them learn?
    c) How well did these practices work together?
    d) Could you have included a different practice? Which one? Why?

4) In your full-scale teaching experience, your students engaged in these two practices (name relevant practices).
    a) Why did you choose to use these practices together?
    b) Was your students' experience with the practices what you thought it would be? Why or why not?
    c) Looking back, would change anything about how you used the science practices? Why?

5) What role will the science practices play in your student teaching?

6) In general, how do you think engaging in the science practices can help (or not) students learn?

7) Do you have any questions for me? Or is there anything else I should know about your thinking about the science practices?

Appendix F: Student Teaching Interview Protocol

The interview is meant to be an open-ended conversation where the preservice teacher will be given the chance to tell their story and elaborate on the experiences they had while teaching science. Not all of the question will be asked to each interviewee. The selection of questions will depend on the relevant materials available.

<u>Pre-conversation:</u>

… Ask about how they are doing? … Do they still have a roll in the teaching? …

If They Taught a Lesson

1) How did you decide on which science practices to include in this lesson? [*List of practices I found in lesson for reference*]
    a) Why did you choose to use ____ and ____ practices together?

2) …Ask about specific science practices and sub-practices evident in the lesson…
    a) How did engaging in these practices help the students learn?
        i) How did the combination of these practices help students learn?
    b) What would you do differently (if anything) if given another chance to teach this particular part of the lesson? [only for the enacted lessons]

If They Didn't get the Chance to Teach

1) Tell me about the science that you were planning on teaching?

… Transition into the think aloud on the lesson plan

Think Aloud on Lesson Plan

-Pick two sections of the lesson plan to highlight and read through-
(I am choosing this based on the science practices I found in the lesson, specifically I want to highlight area where the students are engaging the practice and how that will happen, and why it is important)

Ask about:

- why they chose a particular practice(s) (why the combination)
- how does the preservice teacher define/understand the above practice?
- how they envision students will engage in the practice
    - What experience do the students already have with this practice and what scaffolding do you think they will need?
- how that engagement could promote student learning

3) In general, how do you think engaging in the science practices can help (or not) students learn?

4) What role will the science practices play in your future science teaching?

5) How do you think your understanding of the science practices has changed since the physics course?

    a) What do you think caused your change in thinking?

6) Do you have any questions for me? Or is there anything I can help you with?

Appendix G: Physics Lesson Planning Template

Student Name:	
Title of Lesson Plan:	
Grade Level:	

Lesson Objective:
NGSS Alignment: Disciplinary Core Idea: Cross Cutting Concept: http://ngss.nsta.org/CrosscuttingConceptsFull.aspx Science Practices: http://ngss.nsta.org/PracticesFull.aspx
Materials:

Equity Leverage Points:

I will:

- select and support science experiences and contexts with care by…
- introduce and use scientific language carefully by…
- make scientific practices and content explicit by…
- support meaningful participation by all students by...

Explain the science content of your lesson at the college level: (100-150 words)

Explain how the science practices you chose above will help the students to learn the objective: (Give specific examples from your lesson of how you think this would work.)

Lesson Plan: (Within each of the lesson plan segments, you can format your lesson however you would like. Please detail what your expectations are for the students)

Engage: (How will you initially engage the students in the lesson? How will you find out what they already know? ...)
Experience: (What exactly will your students do to meet the lesson objective? What questions could they ask? What data could they collect? …)
Explain & Argue: (This is the sensemaking part of the lesson. How will the students make sense of the things they have learned? Will they have the chance to explain and defend their interpretations? …)

Appendix H: Instructional Planning Template (from methods course)

INSTRUCTIONAL PLANNING TEMPLATE

Please complete this version of the template. However, please also see the guidance provided in the "annotated version" of this document, found starting on page 4 of this file. This will help you develop a high-quality science lesson plan oriented to the EEE framework.

Overview and Context

Your name(s):	
Grade level and school:	
Title of lesson/activity:	
Teaching date(s) and time(s):	
Estimated time for lesson/activity:	
Overview of lesson:	
Context of lesson:	
Sources:	

Learning Goals and Assessments

Connections Standards (GLCEs and NGSS performance expectation)		
Michigan GLCE that is targeted by this lesson (may be broader than the lesson):		
NGSS performance expectation that is targeted be this lesson (may be broader than the lesson):		
My three dimension statement for this lesson (should include a disciplinary core idea, a practice, and a cross cutting concept, and should be aligned with your C-E-R statement).		
Learning Goals (1-2 in each)	Type of Assessment	Connection to activities
SCIENCE CONTENT / DISCIPLINARY CORE IDEAS Students will be able to…		
SCIENTIFIC PRACTICES Students will be able to…		
CROSSCUTTING CONCEPTS (likely the reasoning piece of your C-E-R statement)		

Students will be able to…		

CLAIM-EVIDENCE- REASONING STATEMENT
I think ___________ (claim). I think this because I've seen or done ______________ (evidence 1), _________ (evidence 2), ______________ (evidence 3). *as appropriate [see annotation below]:* The science idea or principle that helps me explain this is _______ (reasoning). This helps me use my evidence to support my claim because _____.

Connections to the Big Idea and Big Questions

Describing how the content of this lesson fits in with the larger picture/big ideas of the unit	
Big Idea Question – this question should connect to the big ideas of the unit – this may be broader than the lesson	
Investigation Question – this question should directly connected to what students are investigating in the lesson and also connect to the big idea	

Attending to the Learners

Anticipating student ideas including alternative ideas, misconceptions, and prior knowledge **(be sure to check the MSTA misconceptions lists and benchmarks!!):**	
Making the content accessible to all students:	

Instructional Sequence

Materials:	

Instructional Sequence: Engage Element

Time	Steps Describing What the Teacher and Students Will Do	Notes and Reminders (including management considerations)
Key aspects of the Engage Element:		
Key questions (and anticipated student responses) I will ask students to elicit their initital ideas about the phenomenon are:		

Instructional Sequence: Experience Element

Time	Steps Describing What the Teacher and Students Will Do	Notes and Reminders (including management considerations)
Key aspects of the Experience Element:		
The key pieces of data I hope students notice are… These key pieces of data can use used as evidence to answer the investigation question because…		
Key questions (and anticipated student responses) I will ask students as they collect data:		

Instructional Sequence: Explain Element

Time	Steps Describing What the Teacher and Students Will Do	Notes and Reminders (including management considerations)
Key aspects of the Explain Element:		
Key pieces of evidence I need to elicit from students during this discussion are…..		
Key questions (and anticipated student responses) I plan to ask students as we have our group discussion:		

Reflection on Planning

Learning goal for self:	
Preparing to teach this lesson:	

Appendix I: Scientific Modeling Level of Sophistication Rubric

Level of Sophistication -- SP2 Modeling

L1 → "pre-novice" L2 → "novice" L3 → "intermediate" L4 → "experienced"

Model "OF"

<table>
<tr><td>Level 1 Sophistication</td><td>Level 2 Sophistication</td><td>Level 3 Sophistication (includes 1 - 2 element)</td><td>Level 4 Sophistication (includes 3 or 4 elements)</td></tr>
<tr><td rowspan="2">Develop a simple model to represent an object or phenomena. No attempt is made to connect to real-world aspects.</td><td rowspan="2">Develop a model to describe a scientific principle that links aspects of the physical / diagrammatic model to the real-world phenomenon</td><td colspan="2">Must include:
Develop or use a model of a phenomenon that embodies the "how" or "why" the phenomenon occurs</td></tr>
<tr><td colspan="2">Could include:
Develop a model of a system to represent an abstract or non-visible phenomenon
Develop a model of a system or phenomenon that highlights the relationship between elements of the model.
Develop a representation / model that is used to support a scientific explanation</td></tr>
</table>

Model "FOR"

<table>
<tr><td>Level 1 Sophistication (includes 1 element)</td><td>Level 2 Sophistication (includes 2 or 3 elements)</td><td>Level 3 Sophistication (at least one)</td><td>Level 4 Sophistication</td></tr>
<tr><td colspan="2">Develop a model:
to show relationships or patterns in data
to make predictions about phenomena
to generate data</td><td>Use a model to reason about phenomenon (focused on analysis)
Modeling includes an iterative or revision element
Use of modeling focuses on changes in variables</td><td>Develop a model that is used to reason with and about phenomena to develop a scientific explanation</td></tr>
</table>

Identify Models and Limitations

Level 1 Sophistication	Level 2 Sophistication (at least one)	Level 3 Sophistication	Level 4 Sophistication (at least one)
• **Distinguish** between a model and the phenomenon or object	• **Compare models** to find common features and differences • **Identify general limitations** of a model	• **Identify specific content related limitations** of a model	• Evaluate a model in order **to make revisions** • Compare two different models of the same phenomenon **to make revisions**

Appendix J: Plan & Conduct Investigations Level of Sophistication Rubric

Level of Sophistication -- SP3 Plan & Conduct Investigations

L1 → "pre-novice" L2 → "novice" L3 → "intermediate" L4 → "experienced"

Investigation Question

Level 1 Sophistication (at least one)	Level 2 Sophistication (at least one)	Level 3 Sophistication	Level 4 Sophistication
ure of question is more about facts and definitions		Nature of question is about the *how/why* of phenomenon	
• Ask or identify question that can be answered by investigation • Question is of a **Yes or No nature** or simple answer	• Asks questions about what would happen **if a variable changed** or compares two variables • Question **asks only for** empirical evidence	• Question asks about the **how/why** of the phenomenon	• **Evaluate question** to determine if it is relevant and testable

Make Predictions

Level 1 Sophistication	Level 2 Sophistication	Level 3 Sophistication (includes 1 element)	Level 4 Sophistication (includes both elements)
• Make prediction based on prior experience (**statement or fact**)	• Make a prediction **that is testable**	• Prediction includes content related **justification or rationale** • Prediction establishes a relationship between the **dependent and independent variables**	

Plan Procedures

Level 1 Sophistication (includes 1-2 elements)	Level 2 Sophistication (includes 3-4 elements)	Level 3 Sophistication (includes 1-2 elements)	Level 4 Sophistication (includes 3-5 elements)
• Plan **with guidance** from Teacher • Consider **number of trials** • Evaluate appropriate **methods or tools** • Plan investigation where **variables are controlled**		• Plan **individually** or collaboratively (little to no teacher direction) • Consider how measurements will be recorded and **how much data is needed** for claim and reliability • **Evaluate** experimental design and **accuracy** of method • Identify **independent and dependent variables.** • Consider **safety and ethical implications** (environment, social, ..)	

Collect Data

<table>
<tr><td>Level 1 Sophistication</td><td>Level 2 Sophistication (includes 1-2 elements)</td><td>Level 3 Sophistication (includes 3-4 elements)</td><td>Level 4 Sophistication</td></tr>
<tr><td>Produce data (observations or measurements) -- no order to the data collected</td><td colspan="2">Quantitative Data
Data is clear (units)
Data is accurate (precision, multiple trials)
Data collection includes multiple dependent variables
Data is sufficient (enough data points to make accurate claim)
Qualitative Data
Data is clear (neat and specific)
Data is accurate (recording only what is viewed)
Data is objective (no inferences)
Data is complete (including all parts)</td><td>Test/Consider the accuracy of the data collected*
*can also change a score of 2 to a 3</td></tr>
</table>

Appendix K: Data Analysis & Mathematical Thinking Level of Sophistication Rubric

Level of Sophistication -- Data & Mathematical Thinking

L1 → "pre-novice" L2 → "novice" L3 → "intermediate" L4 → "experienced"

Find Patterns

<table>
<tr><td>Level 1 Sophistication
(at least one)</td><td>Level 2 Sophistication
(includes 1-2 elements)</td><td>Level 3 Sophistication
(includes 3-5 elements)</td><td>Level 4 Sophistication</td></tr>
<tr><td>• Use observations to describe patterns or relationships (no work done beyond data set)
• Recognizes a pattern but does not connect to phenomenon</td><td colspan="2">• Analyze data to find evidence for phenomena (look for use of data in evidence statement)
• Organize simple data sets (bar charts, venn diagrams, graphs, ...)to reveal patterns
• Use mathematical representations (equations, slope, proportions, ...) to aid analysis
• Compare predictions to patterns seen in data
• Compare and contrast different sets of data</td><td>• Test the outcomes of patterns against the real world*

*can also change a score of 2 to 3</td></tr>
</table>

Use Tools

<table>
<tr><td>Level 1 Sophistication</td><td>Level 2 Sophistication
(includes 1-2 elements)</td><td>Level 3 Sophistication
(includes 3 elements)</td><td>Level 4 Sophistication
(includes 4-5 elements)</td></tr>
<tr><td>• Represent data using simple graphs or representations. (no clear purpose for tool)</td><td colspan="3">• Represent data in tables, graphical displays, or diagrams to reveal patterns
• Use tools to identify linear, non-linear, or spatial relationships
• Use digital tools to test or analyze results (e.g., computer based visuals, word maps, Venn diagrams, mathematical simulations)
• Use the tool to reason about phenomenon.
• Revise computational models or other tool used to work with the phenomena based on results</td></tr>
</table>

Apply Algebra

Level 1 Sophistication	Level 2 Sophistication	Level 3 Sophistication (includes 1-2 elements)	Level 4 Sophistication (includes 3-4 elements)

• NA	• Use **instructor provided algebraic relationships** between data to generate new data	• Apply concepts of basic statistics or simple algebra **to characterize data** • Apply algebra (**function fits, slope,** ..) and stats to analyze data to **support claims** • **Create algorithms** to solve problems or define patterns • Apply **ratios and unit conversions** in complicated measurement problems

Consider Limitations

Level 1 Sophistication	Level 2 Sophistication	Level 3 Sophistication (includes 1 element)	Level 4 Sophistication (includes both elements)
• NA	• NA	• Consider the limitations of data analysis • Use limitations to seek to improve precision	

Appendix L: Explanation & Argumentation Level of Sophistication Rubric

Level of Sophistication -- Explain & Argue

L1 → “pre-novice” L2 → “novice” L3 → “intermediate” L4 → “experienced”

Construct an Explanation (Make Claim)

<table>
<tr><td>Level 1 Sophistication</td><td>Level 2 Sophistication (includes 1 element)</td><td>Level 3 Sophistication (includes 2-3 elements)</td><td>Level 4 Sophistication (includes 4-5 elements)</td></tr>
<tr><td>• Construct an account of natural phenomenon (“definition”, What is… ?)</td><td colspan="3">• Construct an explanation of observed relationships (Why does … ?)
• Explanation accounts for controls or all variables
• Construct an explanation that can predict outcomes
• Construct an explanation using models or representations
• Make and defend a quantitative / qualitative claim regarding the relationship between variables or the natural world.</td></tr>
</table>

Use Evidence

<table>
<tr><td>Level 1 Sophistication</td><td>Level 2 Sophistication (includes 1 element)</td><td>Level 3 Sophistication (includes 2 elements)</td><td>Level 4 Sophistication (includes 3-4 elements)</td></tr>
<tr><td>• Use generic reference to observations or data as evidence (... our data shows that…)</td><td colspan="3">• Use evidence in the form of patterns found in analysis
• Evidence makes specific references to the data
• Evidence fits the aspects of the phenomena related to the investigation
• Use valid evidence obtained from multiple sources (including own experiments, models, theories, simulations, peer review)</td></tr>
</table>

Use Reasoning

<table>
<tr><td>Level 1 Sophistication</td><td>Level 2 Sophistication (includes 1 element)</td><td>Level 3 Sophistication (includes 2 elements)</td><td>Level 4 Sophistication (includes 3-4 elements)</td></tr>
<tr><td>• Attempt to use theory/laws with no clear connection (or incorrect connection) to claim or evidence
• Unsupported attempt at reasoning</td><td colspan="3">• Apply theory/law with clear and correct connection to claim and evidence
• Use reasoning to show why the data is adequate for explanation
• Use reasoning to link evidence to the claim
• Reasoning assesses how well explanation is supported</td></tr>
</table>

Engage in Argumentation

Level 1 Sophistication	Level 2 Sophistication	Level 3 Sophistication (includes 1 element)	Level 4 Sophistication (includes 2-3 elements)
NA	• **Listen actively to arguments** to indicate agreement or to retell main points	Respectfully provide and receive critiques: • that **elicit pertinent elaboration and detail** • by **probing reasoning and evidence** • by **challenging ideas and conclusions**	

Identify/Evaluate Arguments

Level 1 Sophistication	Level 2 Sophistication (includes 1-2 element)	Level 3 Sophistication (includes 3-4 elements)	Level 4 Sophistication
• Identify if arguments are supported by evidence	• **Refine argument** based on evaluated evidence. • **Compare and critique two arguments** on the same topic. • Distinguish among **facts, reasoning based on findings, and speculation** in explanation. • Determine **additional information** required to **resolve contradictions.**		• Compare and evaluate competing arguments **in light of currently accepted explanations**, new evidence, limitations, constraints, and ethical issues. *can change a score of 2 to a 3

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