Learning to Teach Elementary Students to Construct Evidence-Based Claims of Natural Phenomena

by

Anna Maria Arias

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Educational Studies)
in the University of Michigan
2015

Doctoral Committee:

Associate Professor Elizabeth A. Davis, Chair
Assistant Professor Leah A. Bricker
Professor Jean P. Krisch
Professor Annemarie S. Palincsar

DEDICATION

To all of the teachers in my life, especially my parents and grandparents.

From you, I have learned that *"*They can take away everything, but they cannot take away your education.*"*

En el nombre del Padre, y del Hijo, y del Espíritu Santo.

ACKNOWLEDGEMENTS

I want to acknowledge the many people who supported me throughout my graduate studies and in my work on this dissertation. First, I thank my advisor and committee chair, Betsy Davis, for her guidance and mentorship. You have served as a wonderful role model for how to be a science education researcher and teacher educator. I cannot list all the ways and times I have felt grateful to have you as a mentor throughout this process. Thank you for sharing with me your wisdom, integrity, and vision for science education. I would also like to thank the members of my committee, Annemarie Palincsar, Leah Bricker, and Jean Krisch, for sharing their expertise, insights, and thoughtful feedback. Your guidance helped me develop this dissertation and learn to be a scholar. I am so thankful to have had the opportunity to learn from each of you.

I extend my gratitude to the students, interns, teachers, and teacher educators involved in this study. To the interns in the study, especially Ms. Atkin, Ms. Kelly, Ms. Michaels, Ms. Schuster, and Mr. Cruise, thank you for sharing your experiences and thinking with me. I have learned so much from you. To the many teacher educators involved in this study, thank you for your dedication to education and learning. Having the opportunity to witness your teaching practice inspired me to become a better teacher educator. I also acknowledge the University of Michigan School of Education, Rackham Graduate School, English Language Institute, and Marj Wexler for supporting this research and the writing and editing of the dissertation.

I want to thank all of my friends who have been my teachers, colleagues, supporters, and guides. Thank you to my fellow teachers, especially Katie (Hesmond) Riehman; you pushed me to want to study teaching. I extend my gratitude to my fellow science education researchers who helped me think about this work in new ways. I thank Sarah Fick for demonstrating how to complete a dissertation and then helping me finish mine. I thank Amber Bismack for being my first collaborator in studying science education, John-Carlos Marino for help in collecting the data and thinking about elementary teachers, and Sylvie Kademian for her support in the conceptualization and analysis of this study. My colleagues at the School of Education became my friends and provided hope and encouragement. In particular, Diana Sherman and Rachel Snider helped me think deeply about teacher education and kept me smiling in the process. I also thank Matthew Pauly for his patient ear, constant encouragement, and hopeful smile.

Finally, I thank my family, who always supported me along the way. My parents encouraged me to love learning, work diligently, and follow my heart to serve others. You gave me the strength and belief to do my best. My grandparents showed me the importance of hard work, faith, and education. My brothers were my first "students" when we played together. Thank you for supporting me in my dreams. To my entire family, thank you for teaching me how to share, listen, and care for others. In sum, I am so blessed by the people in my life and for the opportunity to know and learn from all of them.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ABSTRACT

Engaging in science practices integrated with content facilitates deeper learning of science and is called for by new reforms. Supporting this science learning requires complex teaching that is not common in U.S. classrooms. Given this complexity, beginning elementary teachers need support in learning to engage students in science practices such as constructing evidence-based claims about natural phenomena. A practice-based approach to teacher education, focused on making teaching practice core to professional learning, has been suggested to support beginning teacher development. This approach has shown potential in supporting secondary science teachers' learning, yet little is known about how it might support preservice elementary teachers' learning over time.

This dissertation addresses this gap by investigating the change in preservice teachers' teaching practices and knowledge for supporting elementary students in constructing evidence-based claims during a practice-based elementary teacher education program. Using longitudinal qualitative methodology, this study drew on video-records, lesson plans, class assignments, and surveys from one cohort of 54 interns enrolled in a two-year coherent practice-based teacher education program. A subset of five focal interns was followed closely throughout the program.

The preservice teachers grew in their ability to support elementary students to construct evidence-based claims incrementally by adding components of the teaching practice over time. Specifically, the teachers typically developed the ability to support students to analyze data earlier than they developed the ability to support students to justify their claims. However, they faced challenges during student teaching in consistently supporting students to construct evidence-based claims. These challenges may be due to the removal of scaffolding in the face of the complexity of fulltime teaching.

The findings highlight the potential of a coherent practice-based approach to teacher education. For example, the preservice teachers seemed to draw on courses from across the program in developing their teaching practice. These findings also provide new insights into how teachers learn a teaching practice over time and the factors that influence this learning, such as tools for planning science lessons. The analyses underscore the need for development of and research on tools and scaffolds that might continue to support beginning teaching over time.

CHAPTER 1

INTRODUCTION

Engaging students in science practices integrated with science content facilitates deeper learning of science and is called for in new reforms. One example of a science practice is constructing evidence-based claims of natural phenomena. This practice involves both the identification of claims based on patterns and relationships revealed through analysis of the data, and the justification of claims with evidence and reasoning (National Research Council, 2012). Elementary students are capable of constructing evidence-based claims of natural phenomena, but students struggle with aspects of this science practice. For example, students often struggle to justify their claims with sufficient evidence or reasoning (e.g., Songer & Gotwals, 2012). These struggles suggest that students need support to learn to construct evidence-based claims, yet providing this support is complex and atypical in U.S. classrooms (Banilower et al., 2013).

In providing support for constructing evidence-based claims of natural phenomena, teachers face many challenges. Specifically, teachers may not have the knowledge, abilities, beliefs, and teaching practices required for supporting their students. Teachers' probable lack of prior experience with this type of learning as students themselves in the U.S. educational system can make it difficult for them to envision this work (cf. Lortie, 1975). Beginning elementary teachers, in particular, face additional challenges, as they are responsible for teaching multiple subjects and must develop deep knowledge and practices across multiple disciplines (e.g., Appleton, 2007). Despite the need for elementary teachers to learn to teach content from a range of disciplines, there is a lack of emphasis on science in U.S. elementary classrooms compared with other subjects (e.g., mathematics, language arts). This lack of emphasis can reduce beginning teachers' opportunities to learn to teach science. Thus, beginning elementary teachers need support to learn how to facilitate the vision of science learning in new reforms, including supporting students to construct evidence-based claims. This highlights the importance of understanding how teachers might develop this teaching practice and corresponding knowledge to engage students in constructing evidence-based claims over time, a process about which little is known. This dissertation attempts to help fill this gap through exploring how new teachers learn to do this work in a practice-based approach to teacher education.

To support teachers in learning to teach, a practice-based approach that emphasizes doing the work of teaching along with developing knowledge for teaching has been suggested. A practice-based approach draws on pedagogies of professional teaching practice (e.g., representing the practice through discussing video-records or lesson plans of exemplary teaching) (Grossman, Compton, et al., 2009). These pedagogies of professional practice facilitate learning of a set of high-leverage practices (e.g., the practice of supporting students to construct evidence-based claims) and the corresponding knowledge for teaching. This approach to teacher education has shown potential to support secondary science teachers' learning over several years (Thompson, Windschitl, & Braaten, 2013). Studies have considered how this approach might support elementary teachers in the context of one science course, yet none have explored how a practice-based approach could facilitate elementary teachers' learning over time in a coherent extended learning experience. In addition, more information is needed on how individual elementary teachers, with their specific experiences, knowledge, and orientations, might develop their teaching practice throughout such a coherent practice-based teacher education program.

To address these gaps in the literature, this dissertation aims to further the field's understanding of how preservice teachers' practice and knowledge for teaching elementary science changes over the course of a coherent two-year practice-based elementary teacher education program. Focusing on one science teaching practice, *supporting students to construct evidence-based claims of natural phenomena*, this study considers how a cohort of 54 preservice teachers (called interns in this study) learned this teaching practice and associated knowledge over two years. The study also examines the pathways of individual interns' learning during the two years. Use of a longitudinal qualitative methodology allows for close analysis of how a practice-based approach might support the development of a teaching practice over time. This close analysis also enables a description of the pathways teachers might take in learning to facilitate students to engage in science practices integrated with science content.

I frame this dissertation with the following analytic questions: With regard to supporting elementary students to construct evidence-based claims about natural phenomena,

(1) How do the interns' practice and corresponding knowledge change over time in a practice-based teacher education program? Specifically, I ask,

> What characterizes the science knowledge for teaching, teaching moves, and quality of support in the interns' planning for and enactment of the teaching practice at particular time points in the program? How do these aspects of the interns' teaching practice and knowledge change over time?

(2) How do interns describe how and why their knowledge and practice for supporting students to construct evidence-based claims changed over time? Specifically, I ask,

How do the interns describe the changes in their science knowledge for teaching, teaching moves, and quality of support for this teaching practice?

How do the interns describe why these aspects of their teaching practice and knowledge change over time?

I decompose the teaching of supporting students to construct evidence-based claims into the subpractices of (1) analyzing data to reveal patterns and relationships and (2) justifying their claims with evidence and reasoning. I examine the entire cohort's teaching subpractices and knowledge for supporting students to construct evidence-based claims at several time points in the program. The analysis of the entire cohort's teaching practice and knowledge across these time points enabled a description of the change over time. I also examine several subcases by following closely a set of interns from the cohort (called focal interns) by selecting purposefully five interns to represent a possible range of knowledge, practice, and experiences that interns may have in the program (Miles, Huberman, & Saldana, 2014). Data sources include course assignments, program-level surveys and assessments, and video-records of enactments of lessons during student teaching with approximately 300 lesson plans and 20 hours of video. The focal interns participated in several interviews during their second year in the program. These interviews focused on how interns describe their learning of teaching practice and knowledge.

The analyses suggest that preservice teachers grew in their ability to support elementary students to construct evidence-based claims incrementally by adding components of the teaching practice over time. Specifically, the teachers typically developed the ability to support students to identify patterns in the data earlier than they developed the ability to support students to justify their claims. However, they faced challenges during student teaching in consistently supporting students to construct evidence-based claims. The individual trajectories of the focal interns also varied, and this variation seemed connected to the different experiences of the interns prior to and during the teacher education program.

Findings from this study extend and refine the field's understanding of how elementary science teachers learn over time. The study makes theoretical contributions to understanding learning to teach elementary science as practice integrated with content, extending other studies that illuminate the complexity of the teaching called for by new reforms (Erduran et al., 2004; McNeill, 2011; NGSS Lead States, 2013; Thompson et al., 2013). Describing the change in knowledge and teaching practice across two years in a coherent, practice-based program highlights the possible pathways for learning to teach and what challenges may exist in learning to teach. This can provide additional empirical evidence for the hypotheses and theories for supporting preservice teachers' learning as suggested by a practice-based approach (e.g., Ball & Forzani, 2009; Grossman, Compton, et al., 2009). The study has methodological implications for how to study the learning of teaching practice over time in a practice-based program. Finally, these findings also have implications for informing the design of learning opportunities for teachers to facilitate the improvement of their education and their students.

In Chapter 2, I present a review of the literature on supporting elementary students' engagement in science, elementary teachers' learning to support science learning, and the practice-based approach to teacher education. I elaborate on the sociocultural and situated perspective used in this dissertation. Chapter 3 describes the study design and methods used. This chapter outlines the context, participants, methods, and analysis used for the dissertation. Chapters 4, 5, 6, and 7 describe the findings from the analyses. In particular, Chapter 4 examines the entire cohort's learning in the subpractice of supporting students to analyze the data to reveal patterns and relationships, whereas Chapter 5 focuses on the subpractice of supporting students to construct claims justified by evidence and reasoning. In Chapter 6, I consider the change in the cohort's knowledge for teaching this science practice. In Chapter 7, I describe the trajectory of the individual focal interns. Chapter 8 discusses these findings in light of the research and provides implications of the study.

CHAPTER 2

LITERATURE REVIEW AND THEORETICAL FRAMEWORK

This chapter describes the theoretical frames and empirical research that inform this dissertation. I begin by defining *practice* to provide clarity for my use of this word in science and teaching throughout the dissertation. Then, I review the literature in science education and teacher education to highlight the challenges of learning to teach elementary science in the context of the Next Generation Science Standards (National Research Council, 2012; NGSS Lead States, 2013). I also outline how this dissertation defines the teaching practice of supporting students to construct evidence-based claims of natural phenomena by drawing on the empirical and theoretical literature. Next, this chapter focuses on practice-based teacher education and its possibility to support preservice teacher learning. Finally, I provide my theoretical framework of how people learn, drawing on a sociocultural and situated cognition perspective.

What is Practice?

This study uses an understanding of science as practice and teaching as practice. Because the word *practice* is used in many contexts with different meanings, I begin by defining how I use the word *practice* in this dissertation. I draw on Lampert's (2010b) four meanings of *practice*. First, Lampert (2010b) explains how practice is often conceived as "that which contrasts with theory" (p. 3), with a definition of "the active practical aspect considered in contrast to or as the realization of the theoretical aspect'" (Oxford English Dictionary as cited in

Lampert, 2010b, p. 3). In contrast to this view that practice opposes theory, practice and theory can be seen as intertwined in an "adaptive expertise" that allows for the use of "theory-in-action" (Hammerness et al., 2005; Schön, 1983). In this view, rather than positioning practice in opposition to theory, theory informs practice and practice informs theory in such a way that the practitioner draws on both practice and theory in the actions they take (Shulman, 1998). My research takes the view that theory and practice are intertwined in the work of learning, teaching, and "doing science." Given this view, I will not regularly refer to practice as contrasting to theory in this manner.

A second meaning of *practice* is as in "a collection of practices." Lampert (2010b) draws on the definition from the Oxford English Dictionary of "a habitual way or mode of acting; a habit, custom; something done constantly or usually; a habitual action" (p. 5). When a professional does certain tasks regularly to perform his work, these tasks can be called a collection of practices (Lampert, 2001, 2010b). I use this definition of *practice* to describe a collection of practices that teachers engage in, and to describe the collection of practices enacted by scientists.

Third, Lampert (2010b) considers the verb "to practice" in the context of learning to teach. Drawing on a definition of *practice* as "the doing of something repeatedly or continuously by way of study; the exercise in any art, handicraft, and so forth, for the purpose with the result of attaining proficiency" (Oxford English Dictionary in Lampert, 2010, p. 26), this meaning has the synonyms of "to rehearse" or "to train." For example, a group of prospective teachers may role-play as a teacher many times when learning to elicit student ideas (Ball, Sleep, Boerst, & Bass, 2009; Grossman, Compton, et al., 2009) or children may repeatedly engage in observations of an aquarium to learn how to make scientific observations and to understand more about the interactions in the aquarium.

The fourth meaning Lampert provides is "the carrying on or exercise of a profession or occupations" (p. 9). Lampert draws on Cook and Brown's (1999) definition of practice as "the coordinated activities of individuals and groups in doing their 'real work' as it is informed by a particular organizational or group context" (p. 386 as cited in Lampert, 2010b). The nature of the profession or practice is culturally defined by working with others to consider common problems as they share, define, and accomplish the goals of the work in a community of practice (Grossman, Wineburg, & Woolworth, 2001; Lampert, 2010b; Wilson & Berne, 1999). This fourth meaning is used throughout this dissertation as I consider how learners move toward becoming a member of a community of practice, such as the practice of teaching or practice of science. Table 2-1 provides Lampert's second, third, and fourth meanings of practice with examples from teacher education and science education.

Table 2-1: Lampert's Second, Third, and Fourth Meanings of Practice with Examples from Teacher Education and Science Education

	Lampert's Meaning of Practice	Learning Teaching Examples	Learning Science Examples
2	A collection of practices	A set of high leverage practices used in teaching such as eliciting student ideas and explaining content	A set of science practices used to discover and communicate about natural phenomena such as constructing evidence-based claims and collecting and analyzing data
3	To practice: to rehearse; doing something repeatedly to study it	A beginning teacher rehearses a lesson in front of peers; a novice teacher repeatedly works on explaining science content in appropriate ways.	A graduate student rehearses what she will share in a presentation; an elementary students repeatedly works on constructing evidence-based claims.
4	The carrying on of a profession	The profession of teaching	The community of biologists

Learning Elementary Science as Practice Integrated with Content

This section describes my theoretical understanding of science as practice, including learning through integrating the practices of science with the content ideas of science as called for by new reforms. This section focuses on a particular science practice (Lampert's second definition) by considering how scientists engage in the practice of evidence-based claims and how science education describes the goals for elementary students to engage in constructing evidence-based claims of natural phenomena. Finally, I describe the abilities and challenges of elementary students to meet these goals and the support that can be provided to do this work.

Science as Practice: New Goals for Science Education

> Science is both a body of knowledge that represents current understanding of natural systems, and the process whereby that body of knowledge has been established is being continually extended, refined, and revised. Both elements are essential: one cannot make progress in science without an understanding of both. (National Research Council, 2007, p. 26)

This quote defines science as the human endeavor of trying to understand and explain natural phenomena in the world. As time has progressed, people involved in science are able to "account for a wider range of natural phenomena or to account with greater precision for some of those previously known" (T. S. Kuhn, 1996, p. 66) as they seek an objective understanding of the world that results from work in a particular time and place (Pickering, 1995). One engaging in science needs an understanding of this body of knowledge to extend, refine, and revise this knowledge (NRC, 2007), including the disciplinary core ideas and cross-cutting concepts of science (NGSS Lead States, 2013; NRC, 2012). However, engaging in science also involves participation in the process of establishing this knowledge (NRC, 2007), which I view as participation in the culture of science practices.

Viewing the process of science as active participation in science practices pushes against the perspective of science as a single, lock-step method completed in a rigid, orderly fashion. Rather, this view of science highlights both the social aspect of making sense of natural phenomena and the iterative, interconnected nature of the practices used by the scientific community (Latour, 1999; Longino, 2002; Pickering, 1995; Rudolph, 2000; Schwab, 1962). For example, to investigate the changes in a forest, a multi-person team with different expertise may come together. This team uses the tools and representations of their professions to make sense of the data. They engage in practices such as data collection, representing data, constructing explanations, and posing new questions in an iterative process (e.g., they might return to collect more data after initial theorizing of ideas) (Latour, 1999). At the same time, communication and discussion of one's work allows the team to engage in the practice of argumentation with other scientists, where multiple perspectives and views exist and are considered (Latour, 1999; Schwab, 1962). This engagement in the practices of science facilitates adding to, refining, or revising the science community's understanding of forests (Latour, 1999; NRC 2007). In this example, we see the social nature of science as the individuals interact with one another and use tools to co-construct meaning (Vygotsky, 1978). Likewise, the example shows the interconnected, recursive nature of scientific practices, where science involves iteratively returning to different science practices throughout the process of trying to understand a phenomenon (Bell, Bricker, Tzou, Lee, & Van Horne, 2012; Latour, 1999; NRC, 2007, 2012; Windschitl, Thompson, & Braaten, 2008).

New reform documents underscore the importance of having students learn the practice of science integrated with science content. Although a vision of facilitating students' learning of the processes of science in K-12 classrooms is not new (Dewey, 1900; Schwab, 1962), this new reform underscores active participation in the practices of science (NGSS Lead States, 2013; NRC, 2012). This new reform chooses to use the word *practice* instead of *skills* "to emphasize that engaging in scientific investigation requires not only skill but also knowledge that is specific to the each practice" (NRC, 2007, p. 40). The new reform also moves away from the term *inquiry* used in other documents (National Research Council, 1996, 2000) because of the many interpretations of this term. Through engagement in these practices integrated with specific content, students learn how science knowledge develops, and they develop understanding of the body of knowledge accepted by the community of scientists (i.e., the disciplinary core ideas and cross-cutting concepts) (NGSS Lead States, 2013; NRC, 2012). Thus, the goal for science education, including elementary science, is to facilitate the development of the ability to engage in active participation in the practices of the community of scientists.

By setting new goals for elementary science education, this vision also sets new goals for elementary science teaching. Although elementary students are capable of engaging in this work of integrating content and science practices in learning about natural phenomena, students require support and guidance to learn science in this way (Lehrer & Schauble, 2006; Metz, 1997; Songer & Gotwals, 2012). Supporting students to learn science practices integrated with science content is complex, and teachers take on a variety of roles that require a large repertoire of knowledge and teaching practices (Abell, 2007; Crawford, 2000; Lehrer & Schauble, 2010; McNeill, 2009; National Research Council, 2007) However, the complex teaching involved in supporting this type of learning does not often happen in U.S. classrooms, suggesting that teachers need to learn new abilities and knowledge to engage students in this work (Banilower et al., 2013; Forbes, Biggers, & Zangori, 2013).

Focusing on a Specific Practice: Constructing Evidence-Based Claims

To further illustrate how science involves participation in science practices and what elementary students' participation in practice might entail, I zoom in on a specific science practice: constructing evidence-based claims. In this section, I consider how scientists engage in this science practice and decompose my definition of this science practice in elementary classrooms.

How Scientists Engage in Constructing Evidence-Based Claims. The active participation in the practice of science (Lampert's fourth definition) involves the science practices (Lampert's second definition) of investigating natural phenomena, collecting and analyzing data, constructing explanations of the phenomena, and engaging in communication and argumentation about the findings in an iterative, interconnected process (Bell et al., 2012;

NRC, 2012; NGSS Lead States, 2013). Part of this work of investigating natural phenomena involves taking data collected through direct observation or the use of tools, and working through multiple representations that summarize the data to move toward identifying a claim that fits the evidence seen in the data (Latour, 1999; Mayr, 2004; Popper, 1972). This process of identifying claims involves starting with data collected from direct observation or models of the phenomenon of interest. Then, the scientist recursively distills and interprets the data using representations to analyze the data, making claims that summarize the expansive data collected. Because of the social nature of science, this process is done in conversation with others and drawing on the tools and knowledge of the community. For example, in investigating a forest, scientists may start with individual samples of the soil and plant-life from locations in the forest and work through multiple representations that first describe the individual samples and, then, identify patterns in the sample to arrive at claims about the data. Along the way, the scientists discuss their thinking with one another and draw on tools of the field (Latour, 1999). Thus, constructing evidence-based claims involves analyzing and interpreting the data in order to relate the data to the claim.

Constructing an evidence-based claim about a natural phenomenon also involves justifying one's claim in the complex interaction of theory, data, and evidence in science (Duschl & Osborne, 2002; Latour, 1999; Popper, 1972). As a scientist analyzes data and identifies a claim, the individual also needs to simultaneously consider and argue how the evidence sufficiently and appropriately fits the claim and belongs in the theories of the discipline (Hudson, 1986; T. S. Kuhn, 1996; Latour, 1999; Popper, 1972; Willson, 1987). This work involves considering why other refuting claims do not fit the data collected (Popper, 1972) and providing a logical argument for why this particular claim best fits the data (see Toulmin's (2007) discussion of logical arguments). For example, whereas a scientist considers the patterns found from analyzing soil samples and tries to identify claims, this scientist also deliberates on alternative claims about what may be occurring in the soil, weighs the sufficiency of the evidence for a particular claim, and consistently considers how this work fits in with the theories of the discipline and their own initial hypothesis (Latour, 1999). This construction of evidence-based claims enables the scientist to extend and refine the body of knowledge of the phenomenon in question.

Constructing Evidence-Based Claims in Elementary Science. The science practice of constructing evidence-based claims involves collecting, analyzing, and interpreting data to identify patterns and relationships central to answering the investigation question. The data can be analyzed through representations (e.g., tables or graph) or through mathematical and statistical computation (Lehrer & Schauble, 2004; Lunsford, Melear, Roth, Perkins, & Hickok, 2007; NGSS Lead States, 2013; NRC, 2007, 2012; Wu & Krajcik, 2006). Data analysis entails studying and determining the nature and relationship of the parts. Data interpretation requires explaining the meaning of this analysis (Rivet, 2014).

Although collecting data is an important component of science investigations, I focus on the sense-making involved when using collected data to construct an evidence-based claim and not the data collection itself. Thus, I draw on these goals for elementary students for analyzing and interpreting data from NGSS: (a) "use observations (firsthand or from media) to describe patterns and/or relationships in the natural and designed world(s) in order to answer scientific questions and solve problems," (b) "represent data in tables and/or various graphical displays … to reveal patterns that indicate relationships," (c) "analyze and interpret data to make sense of phenomena, using logical reasoning, mathematics, and/or computation," and (d) "compare and contrast data collected by different groups in order to discuss similarities and differences in their findings" (NGSS Lead States, 2013, Appendix F, p. 9). To answer an investigation question, a scientist might "look for patterns, significant features, relationships, trends, and anomalies" in their data (Rivet, 2014, p. 38, cf. Latour, 1999, Poppler, 1978). In elementary classrooms, students might do similar work in the service of moving from data collection to construction of evidence-based claims, such as noting patterns and relationships (e.g., the patterns between weather and changing seasons, the interactions of living things in an ecosystem); comparing groups (e.g., comparing plants and animals; noting different characteristics of phases of matter), and comparing predicted results to actual results (Rivet, 2014; NGSS Lead States, 2014). These different possibilities for analysis and interpretation of the data are included in my conception of analyzing data to construct evidence-based claims.

In addition to analyzing data to reveal patterns and relationships, constructing evidence-based claims is also connected to explanation of scientific phenomena. Science education has used three types of explanation: explication (e.g., providing definition for terminology, describing the procedure or strategies for problem solving), causation (e.g., giving the simple cause-effect for an event), and justification (e.g., argument construction using claim and reasoning) (Braaten & Windschitl, 2011), yet the NGSS emphasizes explaining causes of a phenomenon using "a claim that relates how a variable or variables relate to another variable or a set of variables" (NGSS Lead States, 2013, Appendix F, p. 11). This practice of explanation involves describing the "how" and "why" of a phenomenon to allow the construction of knowledge (Berland & McNeill, 2012; Braaten & Windschitl, 2011; Osborne & Patterson, 2011). For example, a high school student may explain how and why a phenomenon occurs (e.g., the implosion of a tank due to a change in pressure) with a full causal story relying on powerful science ideas (e.g., kinetic molecular theory) (Braaten & Windschitl, 2011). In an elementary school setting, NGSS has identified goals such as the following: (a) "construct an explanation of observed relationships (e.g., the distribution of plants in the back yard)," (b) "use evidence (e.g., measurements, observations, patterns) to construct or support an explanation or design a solution to a problem," and (c) "identify the evidence that supports particular points in an explanation" (NGSS Lead States, 2013, Appendix F, p. 11). Each of these three goals is incorporated into my conceptualization of constructing evidence-based claims in elementary classrooms.

In addition to explanation, constructing evidence-based claims requires justification of one's claims, an aspect of scientific argumentation. NGSS underscores that argumentation involves "the process for reaching agreements about explanations" (NGSS Lead States, 2013, Appendix F, p. 13). This work involves understanding why one claim is stronger than other claims, as well as persuading others of one's claim (Berland & McNeill, 2012; NRC, 2012; Osborne & Patterson, 2011; Reiser, Berland, & Kenyon, 2012). For example, students might be involved in a consensus discussion of deciding which claim is appropriate for the data provided and of persuading others of one's view (Reiser et al., 2012). In describing the work involved in scientific argument, the science education field has drawn on multiple perspectives (Berland & McNeill, 2012; Bricker & Bell, 2008; Osborne & Patterson, 2011). Many have drawn on Toulmin's (2007) framework for thinking about argumentation (e.g., Bell, 2000; Berland & McNeill, 2010; Erduran, Simon, & Osborne, 2004), but others have pushed for considering other frameworks of argumentation from areas such as the learning sciences and science studies (Bricker & Bell, 2008). In this dissertation, I consider these goals for argumentation for elementary students, as highlighted in the NGSS: (a) "compare and refine arguments based on an evaluation of the evidence presented," (b) "identify arguments that are supported by evidence," (c) "distinguish between explanations that accounts for all gathered evidence and those that do not," (d) "analyze why some evidence is relevant to a scientific question and some is not," (e) "construct and/or support an argument with evidence, data, and/or a model," and (f) "use data to evaluate claims about cause and effect" (NGSS Lead States, 2013, Appendix F, p. 13).

The science practices, including analyzing data, constructing explanations, and scientific argumentation, co-occur as scientists work to make sense of data and construct meaning in an iterative process (Bell et al., 2012; Berland & McNeill, 2012; NRC, 2007, 2012; Reiser et al., 2012). For example, Reiser and colleagues (2012) describe how the two practices of constructing explanations and argumentation depend on each other and state, "For students to practice explanation construction, they must engage in argumentation" (p. 1). Likewise, the practice of analyzing data facilitates the ability to identify the claims to construct explanations and engage in argumentation. Thus, in elementary classrooms, mirroring the practice of science, constructing explanations, analyzing data, and argumentation overlap in constructing evidence-based claims where claims are identified from analysis of the data to make sense of a phenomenon and justification is used to support the claim made (Berland & McNeill, 2012; Osborne & Patterson, 2011; Zembal-Saul, McNeill, & Hershberger, 2013). Thus, this study considers this process as one science practice with individual components.

A Definition of Constructing Evidence-Based Claims in Elementary Science. Figure 2-1 shows my theoretical understanding of the components of constructing evidence-based claims in an elementary setting. The science practice of constructing evidence-based claims is split into two subpractices: analyzing the data to reveal patterns and relationships and making a claim justified by evidence and reasoning. To analyze the data to reveal patterns and relationships, a learner needs to (a) organize the data to reveal patterns and relationships, (b) interpret the organized data to identify the patterns and relationships, and (c) share and justify one's thinking about the patterns and relationships. Then, to make a claim justified by evidence and reasoning, the same learner would (d) identify appropriate and accurate claims based on the patterns in the data, (e) coordinate evidence to back up the claim, (f) link evidence to the claim with reasoning or scientific principles, and (g) communicate a constructed evidence-based claim about the natural phenomenon in a logical structure. All of this work is integrated with the specific science content (i.e., the disciplinary core idea and/or crosscutting concept) that is the focus of the evidence-based claim. The lines in the model describe the connections that exist between these decomposed pieces of making evidence-based claims. Interpreting data and analyzing the data facilitates the identification of a claim. Considering the justification of one's thinking about a claim enables the identification of the appropriate reasoning and evidence. Bringing together the claim, evidence, and reasoning allows students to communicate a constructed evidence-based claim in a logical structure. The pieces identified are a combination of the practices of analyzing data (a, b, c), constructing explanations (c, d, e, f, and g), and argumentation (d, e, f, and g) as described by the NGSS.

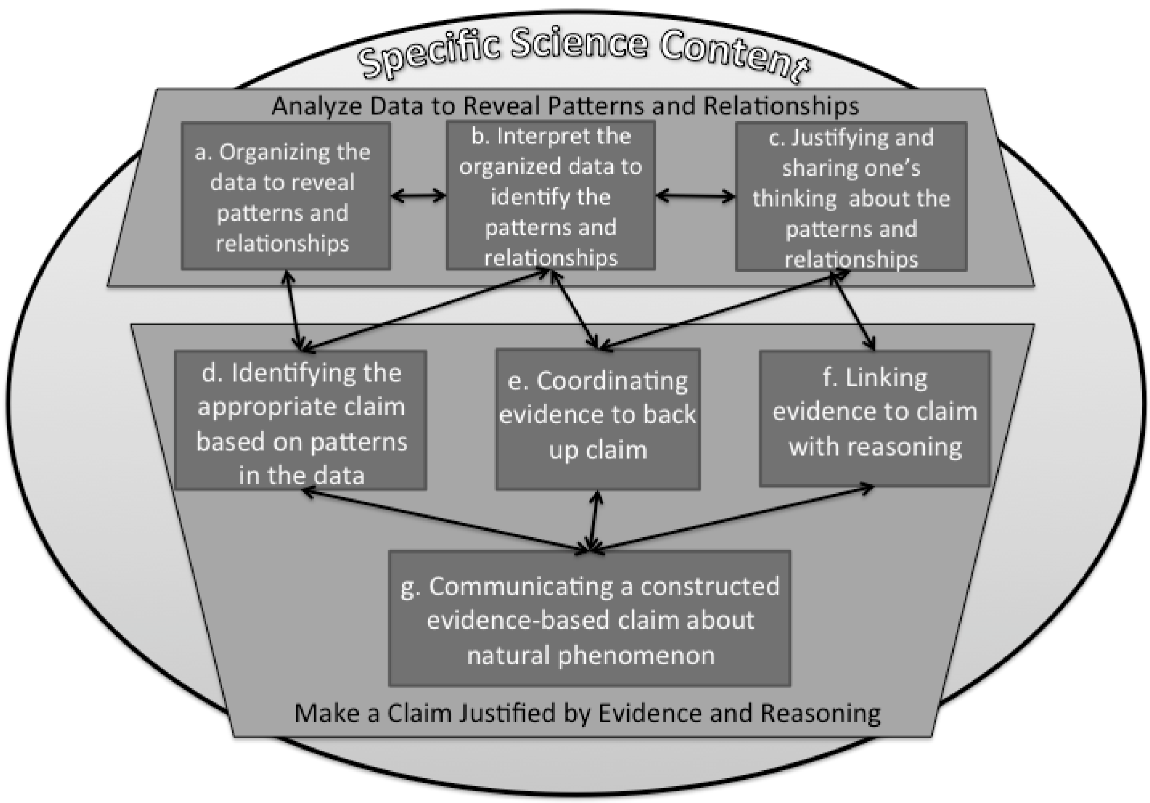


Figure 2-1: Theoretical Framework of the Science Practice of Constructing Evidence-Based Claims

Learning the components of constructing evidence-based claims in elementary classrooms seems to occur by adding complexity over time (Berland & McNeill, 2010; Zembal-Saul et al., 2013). For example, a learner may first learn to align evidence with claims and then move to provide evidence and reasoning to justify their claims (Berland & McNeill, 2010). Supporting the progressive movement toward more complex work in constructing evidence-based claims helps students to develop their understandings and practices over time (Berland & McNeill, 2010; NRC, 2012). Given the progression that students take in learning the practices of science, using reasoning in evidence-based claims may not be expected in lower elementary grades, yet these students are capable of naming reasoning in particular cases as described in the next section (Berland & McNeill, 2010; NRC, 2012; Metz, 2000; NGSS Lead States, 2013; Zembal-Saul et al., 2013).

Supporting Elementary Students' Engagement in Constructing Evidence-Based Claims. Despite the common assumption that elementary children cannot engage in constructing evidence-based claims (NRC, 2012), several studies have shown that elementary students can engage in the work of constructing evidence-based claims, yet they do need support to do this work (e.g., Herrenkohl, Palincsar, DeWater, & Kawasaki, 1999; McNeill, 2011; Metz, 2000; Songer & Gotwals, 2012). Likewise, students can draw on their nascent abilities to do this work, including everyday engagement in observing natural phenomena and persuading others (Bricker & Bell, 2008; Eberbach & Crowley, 2009). Thus, a goal of supporting student learning to engage in evidence-based claims is appropriate for elementary science.

Despite their ability to do this work, students often struggle with the complexity of constructing evidence-based claims about natural phenomena. Learners may not have access to the theoretical and epistemological knowledge to construct evidence-based claims. Students struggle to coordinate evidence with claims in scientific explanations and argumentation (e.g., Keys, 1999; D. Kuhn, 1989; Sandoval & Millwood, 2005). In addition, including the reasoning that connects claim to the evidence or connects thinking to theoretical understandings of a specific discipline is also challenging. Even after learning about the importance of reasoning or providing backing for one's thinking, some students continue to struggle to include it in their written science explanations of phenomena (Bell, 2000; Beyer & Davis, 2006; McNeill, 2009; Sandoval & Millwood, 2005). Likewise, students struggle with making and understanding representations that would support their ability to analyze data to reveal patterns and relationships (Garcia-Mila & Andersen, 2007; Keys, 1999; Lehrer & Schauble, 2004; Lunsford et al., 2007; P. Shah, Mayer, & Hegarty, 1999). Thus, learners face many challenges in constructing evidence-based claims, pointing to the need to support students in this work.

Supporting Students to Construct Evidence-Based Claims. Many types of supports have been used to support students in engaging science practices including constructing evidence-based claims. Variations in teachers' support for explanations show differences in students' ability to do this work (Erduran et al., 2004; Lizotte, McNeill, & Krajcik, 2004; McNeill, 2009; McNeill & Krajcik, 2009). This suggests that the type of support matters in the opportunities created for student learning.

To support students in science practices, teachers can provide opportunities for the students to engage in a practice with increasing levels of complexity and authenticity over time (Berland & McNeill, 2010; Lehrer & Schauble, 2010). Tools such as sentence stems, charts, and physical resources facilitate student work and interaction with one another around the practices (Bell, 2000; Zembal-Saul et al., 2013). Students also need support to understand how, when, and why to use particular practices (NGSS Lead States, 2013). Learners require guidance to understand how the practice connects to the disciplinary ideas being learned (NGSS Lead States, 2013; NRC, 2012).

Drawing on my theoretical framework for the science practice of constructing evidence-based claims in elementary classrooms, I decompose the teaching practice of supporting students to construct evidence-based claims of natural phenomena into two subpractices, supporting students to analyze the data to reveal patterns and relationships and supporting students to make claims justified by evidence and reasoning (See Figure 2-2). I break down these subpractices into smaller components. The subpractice of supporting students to analyze the data to reveal patterns and relationships includes supporting students to analyze the data and supporting students to share their thinking about the pattern. The subpractice of supporting students to make a claim justified by evidence and reasoning can be decomposed into supporting students to use a logical structure to justify their claims and supporting students to make a claim. In a manner similar to the way Ball and colleagues (2009) describe components of the practice of leading a classroom discussion, I theorize these subpractices and their components as decomposed pieces of the practice of supporting students to construct evidence-based claims.

These subpractices for the teaching practice align with the components of the science practice as seen in Figure 2-2. The subpractices of the teaching practice of supporting students to construct evidence-based claims are indicated by dark gray hexagons, and their components are the light gray rounded rectangles. The elements of the science practice of constructing evidence-based claims are indicated by the gray rectangles. This teaching practice requires coordination with one's science knowledge for teaching, signified by the large gray box in Figure 2-2. In the following sections, I consider ways in which teachers can support students in the science practice of constructing evidence-based claims with increasing complexity, facilitating knowledge of how and why to engage in this science practice, and providing tools for engagement for each of the subpractices.

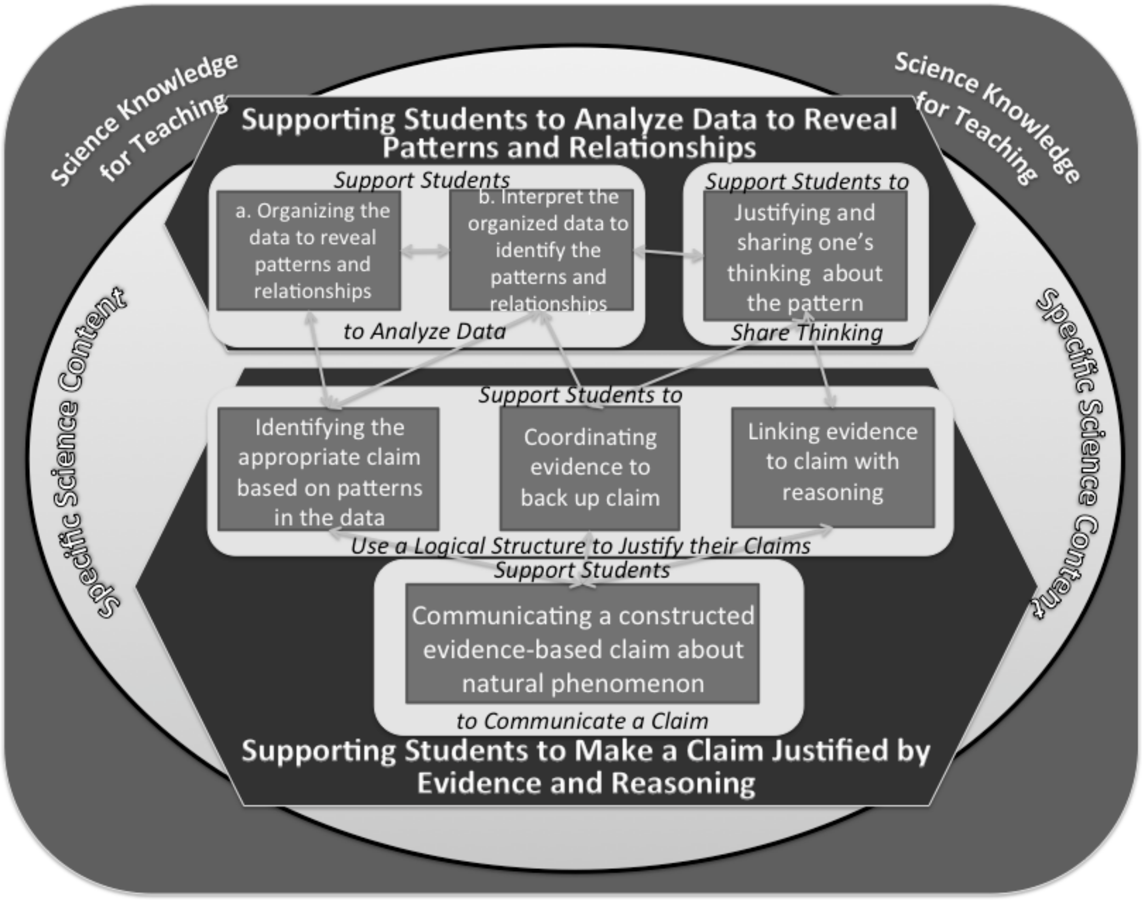


Figure 2-2: The Teaching Practice of Supporting Students to Construct Evidence-Based Claims.

Supporting Students to Analyze the Data to Reveal Patterns and Relationships. The first teaching subpractice is supporting students to analyze the data to reveal patterns and relationships, which includes the components of supporting students to analyze the data and to share their thinking. Supporting students to analyze the data is linked to the science subpractices of organizing data to reveal patterns and relationships and interpreting the organized data to identify the patterns and relationships. These science subpractices are indicated by the light gray rectangles in Figure 2-1 and Figure 2-2. To support students in these components, a teacher can facilitate the selection of appropriate representations that organize data to answer the investigation question (McDiarmid, Ball, & Anderson, 1989; P. Shah et al., 1999; Wu & Krajcik, 2006). Other teaching moves include explicitly discussing features in a representation, linking the investigation to the data, and highlighting inconsistencies in the data (Herrenkohl et al., 1999; D. Kuhn, 1989; Lunsford et al., 2007; McDiarmid et al., 1989; McNeill & Krajcik, 2009; White & Frederiksen, 2000; Wu & Krajcik, 2006; Zembal-Saul et al., 2013). Tools such as graphs and charts can facilitate this work for learners in the same way they do for scientists (cf. Latour, 1999; Lunsford et al., 2007; P. Shah et al., 1999). Discussions of why and how analyzing the data leads to evidence-based claims and providing a clear rationale for using a representation may facilitate learners' development of knowledge for this science practice (Herrenkohl et al., 1999; cf. Latour, 1999; Lunsford et al., 2007; Wu & Krajcik, 2006).

A second component of the subpractice of supporting students to analyze the data to reveal patterns and relationships is supporting students to share their thinking, which facilitates students' ability to justify and share their thinking about the pattern. This is another science subpractice (c) in a light gray rectangle in Figure 2-1. This teaching subpractice may involve teaching moves such as probing student thinking to facilitate students to make their thinking about patterns visible, or having student consider alternative ideas about the patterns (Reiser et al., 2012; Zembal-Saul, 2009; Zembal-Saul et al., 2013). To engage students in the process of justification, teachers may provide tools like verbal prompts such as, "Why do you think that?" or even facilitate students to use these prompts with one another (Herrenkohl et al., 1999; Zembal-Saul et al., 2013). Several studies point to the small-group and whole-class opportunities to discuss ideas and consider one another's claims as key steps in students' development of evidence-based claims (Berland & Reiser, 2009; Erduran et al., 2004; Herrenkohl & Cornelius, 2013; McNeill, 2009). These discussions facilitate sense-making about the natural phenomenon as students try out their thinking and build on one another's thinking (Berland & Reiser, 2009; Herrenkohl et al., 1999).

Supporting Students to Make a Claim Justified by Evidence and Reasoning. The second teaching subpractice is supporting students to make a claim justified by evidence and reasoning. As seen in Figure 2-2, this subpractice involves two components supporting students to: (a) use a logical structure to justify their claims and (b) communicate a claim. The first component facilitates elementary students in identifying the claim, evidence, and reasoning—three science subpractices indicated by the light gray rectangles in Figure 2-1 and Figure 2-2. One tool to support this work is an application of Toulmin's (2007) framework for argumentation. The application of this framework involves students using a claim-evidence-reasoning framework such as, "I think ___ (claim). I think this because I have seen or done____ (evidence). I know this because ___ (reasoning)" (McNeill, Lizotte, Krajcik, & Marx, 2006; Zembal-Saul et al., 2013). Students' use of written or verbal scaffolding around this framework has been shown to be productive in helping learners develop evidence-based claims (Bell, 2000; McNeill, 2009; McNeill et al., 2006; Sandoval & Millwood, 2005; Songer & Gotwals, 2012).

Other teaching moves that can provide students with the support to understand a logical structure for evidence-based claims have been identified and include (1) modeling how to make an evidence-based claim, (2) discussing a framework for evidence-based claims, (3) connecting to everyday use of arguments, and (4) using appropriate and accurate scientific language (Avraamidou & Zembal-Saul, 2010; Beyer & Davis, 2008; Lizotte et al., 2004; McNeill, 2009, 2011; Reiser et al., 2012; Zembal-Saul et al., 2013). Providing a rationale for having a claim, evidence, and reasoning can support students' knowledge development of why to engage in the science practices and improve students' engagement in the science practice (Lizotte et al., 2004; McNeill & Krajcik, 2009; Zembal-Saul et al., 2013). McNeill and Krajcik (2009) describe how students of teachers who did not provide a rationale for the components of evidence-based claims did not perform as well as students who were provided a rationale. In addition, Herrenkohl and Cornelius (2012) describe a set of supports teachers and researchers drew on to develop elementary students' ability to justify their claims as part of the epistemic work involved in learning about natural phenomena. The authors describe how the supports and teaching moves included discussing how claims need evidence, asking students to consider alternative claims, and considering what evidence is used in making the claim (Herrenkohl & Cornelius, 2013).

The second component of the subpractice of supporting students to make a claim justified by evidence and reasoning is supporting students to communicate an evidence-based claim. To support this communication, a teacher may provide opportunities for students to share claims with the class and to receive feedback for their claims (Erduran et al., 2004; McNeill, 2009). This fourth component aligns with the science subpractice of communicating an evidence-based claim about natural phenomena as represented in Figure 2-1 and Figure 2-2. Support for this communication may involve facilitation of writing and speaking one's claim. This also allows for multiple claims to be considered and built on in constructing understanding of the phenomenon (Berland & McNeill, 2010; McNeill et al., 2006; Songer & Gotwals, 2012; Zembal-Saul et al., 2013). Tools such as shared representations of thinking, prompts or graphic organizers for writing, and scaffolded questions have been used to support students' engagement in communicating their claims (Herrenkohl & Cornelius, 2013; Songer & Gotwals, 2012). For example, supporting students to take on questioning roles focused on linking theory and evidence seemed to facilitate complex discussions of how to develop science theory (Herrenkohl et al., 1999).

Another strategy for supporting the communication of claims is providing feedback. Students can receive feedback from the teacher or classmates on how they are able to support and defend their claims (Herrenkohl & Cornelius, 2013; Herrenkohl, Tasker, & White, 2011). Using rubrics can facilitate making these expectations of evidence-based claims clear and allow for directed feedback (Bismack, Arias, Davis, & Palincsar, 2015; Zembal-Saul et al., 2013). This feedback promotes continued improvement in their development of the practice and in their thinking about the practice (Black & Wiliam, 1998; Herrenkohl et al., 1999; White & Frederiksen, 2000).

Supporting Students to Do the Intellectual Work. Underlying each teaching subpractice of supporting students to construct evidence-based claims is the assumption that students will do the intellectual work involved in analyzing the data and justifying their claims with evidence and reasoning. Research suggests that teachers often do not give students the opportunities to be cognitively engaged in sense-making (Pasley, Weiss, Shimkus, & Smith, 2004; Stein, Grover, & Henningsen, 1996). Without these opportunities, students have less opportunity to develop their own understanding of the science practices and content involved in the lessons (Blumenfeld, Kemplar, & Krajcik, 2006; National Research Council, 2007; Stein et al., 1996).

In the case of supporting students to construct evidence-based claims, several examples exist of teachers providing support in ways that decrease the students' involvement in the intellectual work. These examples include naming justification for students rather than pressing students to justify their responses with reasoning and evidence, lowering expectations by minimizing the scientific ideas involved, and not allowing students to communicate and consider one another's ideas (Beyer & Davis, 2008; Forbes et al., 2013; McNeill, 2009). A teacher might give students the answer to the investigation question or problem, removing the motivation and thinking required to engage in the investigation, analyze the data, and construct an evidence-based claim (Forbes et al., 2013; National Research Council, 2000, 2007). Similarly, Blumenfeld and Meece (1988) describe how not expecting students to assume an active role in the learning, asking few or no students to justify their thinking, and asking questions that focus on memorization can lower cognitive engagement in science classrooms. However, the evidence suggests that when students are supported to do the work of constructing evidence-based claims themselves, they are capable of this work and develop more connected understandings of science practice and content (Berland & Reiser, 2009; Herrenkohl et al., 1999; McNeill, 2009; Songer & Gotwals, 2012). Thus, this teaching practice requires giving students the opportunity to engage in the intellectual work of the science practice integrated with science content.

Summary

In conclusion, science involves active participation in science practices to extend, add to, and refine the body of knowledge regarding natural phenomena. Science education sets a goal for students to engage in these science practices integrated with science content. In one science practice, constructing evidence-based claims, scientists make sense of data to identify and justify their claims. Science education reform has identified engaging in this practice as a goal for elementary students. Elementary students can construct evidence-based claims, yet this science practice poses challenges for learners. Thus, elementary students need support. A set of teaching moves for the teaching practice of engaging students in this work have been identified, but using these moves in classrooms is challenging, complex work that does not often happen in U.S. classrooms. This suggests that teachers need support to learn how to facilitate student engagement in the science practice of constructing evidence-based claims.

Learning to Teach Elementary Science

Because of the complexity of supporting students to engage in science practices integrated with science content as described in the previous section, this section considers the challenges involved in learning to teach elementary science in this way. Then, I focus on how these teachers learn to support elementary students in constructing evidence-based claims to underscore the challenges and potential in this work.

The Challenge and Complexity of Learning to Teach Science

Teaching itself is complex work. Teachers coordinate interactions with content, students, and contexts as well as between students and content and across time and environments (Ball &

Forzani, 2009; Cohen et al., 2010; Grossman, Hammerness, & McDonald, 2009; Hawkins, 1974; Lampert, 2001). The complexity of teaching makes learning to teach complex and challenging. Many have highlighted the challenges that beginning teachers face in general (Ball & Forzani, 2009; Dewey, 1965; Feiman-Nemser & Buchmann, 1985; Grossman, Hammerness, et al., 2009) and in specific subject areas (Davis, Petish, & Smithey, 2006; Grossman & Thompson, 2008; McDiarmid et al., 1989). Elementary teachers face additional complexity in teaching as they are expected to be experts in each subject area (Appleton, 2007).

Given the complexity and challenge of learning to teach, Feiman-Nemser (2001) suggested a continuum of learning to teach starting with entering a teacher education program, continuing through induction, and extending into the years of teaching in classrooms. Learning to teach occurs over time through work in classrooms, professional development, and interacting with the teaching community (e.g., Arzi & White, 2008; Grossman et al., 2001; Lampert, 2001; Wilson & Berne, 1999). However, this study will focus on the first phase in the continuum of learning to teach: the work done as a preservice teacher.

Learning to Teach Elementary Science

Helping students learn science as science practices integrated with science content creates complexity and challenge in learning to teach elementary science. Learning science in this manner is different from how elementary teachers were taught (Lortie, 1975), making it difficult to envision how to teach science aligned with the new standards. Beginning science teachers face other challenges, including understanding the content and disciplines of science (e.g., the disciplinary core ideas, crosscutting concepts, and practices of science), understanding learners (e.g., that students may have alternative ideas about a concept), understanding instruction (e.g., productive strategies for supporting student learning), understanding learning environments (e.g., how to use curriculum materials), and understanding professionalism (e.g., appropriate ways to interact with parents and colleagues) (Davis, et al., 2006). Likewise, science in elementary classrooms is not often emphasized during teacher education programs or seen as a priority in elementary learning, which creates additional challenges to learning (Banilower et al., 2013; Bianchini & Brenner, 2010; Marx & Harris, 2006).

These challenges create difficulties for prospective science teachers' ability to design and enact productive learning opportunities for students in science. For example, beginning teachers who do not know aspects of disciplinary core ideas may struggle to make productive decisions about which representations of the content to provide (Davis & Petish, 2005; McDiarmid et al., 1989). Likewise, a struggle to understand how learning occurs may result in an inability to notice and respond to the needs of one's students (Anderson, Smith, & Peasley, 2000; Davis, 2006). These challenges in beginning teaching highlight the importance of considering how to support this learning.

Despite the challenges, these beginning elementary teachers have potential for learning to teach reform-oriented science. For example, beginning teachers may have sophisticated ideas about science instruction yet struggle to use these ideas in their practice (Davis et al., 2006). With support, preservice teachers can develop practices that support student learning of science (Bryan & Abell, 1999; Davis & Smithey, 2009; Forbes & Davis, 2010b; Nelson, 2011; Zembal-Saul, 2009; Zembal-Saul, Blumenfeld, & Krajcik, 2000). For example, preservice teachers can adapt science lessons to be more reform-aligned (Forbes & Davis, 2010b; Zembal-Saul et al., 2000). These and other examples suggest that preservice teachers can learn to support student learning of science if they themselves are given support.

Research has documented teachers' successful ability to implement reform-oriented science during their first years of teaching in elementary classrooms; however, variation in the beginning teachers' ability to implement reform-oriented science also exist (Avraamidou & Zembal-Saul, 2005, 2010; Bianchini & Brenner, 2010; Forbes & Davis, 2010a; McGinnis, Parker, & Graeber, 2004). This variation appears to be connected to many factors, including the individual's beliefs, knowledge, and orientations; mentors' knowledge and beliefs; the context of the school; and supports during induction (Bianchini & Brenner, 2010; Forbes & Davis, 2010a;

Luft et al., 2011a; Roehrig & Luft, 2006). The beginning teachers' prior experiences and learning in teacher education programs also seem to influence their practice. For example, Avraamidou and Zembal-Saul (2010) describe how learning opportunities focused on evidence and explanation during university courses may have influenced a teacher's ability to use appropriate science language in her classroom teaching. These studies on beginning teachers' success point to the need for meaningful learning opportunities during their preparation.

Research into science preservice education suggests several possible avenues for providing meaningful learning opportunities (Davis & Smithey, 2009; Schwarz, 2009; Zembal-Saul, 2009). For example, emphasizing scientific argumentation, curriculum materials, and student thinking facilitated the development of a range of useful supports and learning opportunities for preservice teachers (Davis & Smithey, 2009; Zembal-Saul, 2009). Examples of supports are well-designed curriculum materials and the development of criteria for analyzing curriculum materials (Beyer, 2009; Beyer & Davis, 2009b; Forbes & Davis, 2010b). Video records of teaching and reflection on their teaching practice also appear to create productive space for developing practices and knowledge for teaching elementary science (Davis, 2006; Zembal-Saul, 2009).

In summary, learning to teach elementary science is challenging given the ambitious goals set for elementary science learning, the limitations that elementary teachers may have in terms of science practices and knowledge, and the expansive knowledge and abilities expected of elementary teachers. Despite these challenges, evidence exists that prospective teachers can develop practices and knowledge for teaching during teacher education programs and use these practices and knowledge during their first years of teaching. The next section considers these challenges in the specifics of learning to teach elementary students to construct evidence-based claims

Learning to Support Students in Constructing Evidence-Based Claims

Teachers show areas of strength and of struggle in learning to support students in constructing evidence-based claims (e.g., Avraamidou & Zembal-Saul, 2010; Beyer & Davis, 2008; Erduran et al., 2004; McNeill, 2009; Thompson et al., 2013). For example, case studies describe the large range of teachers' proficiency and trajectories for learning to support this science practice (Erduran et al., 2004; McNeill, 2009; Thompson et al., 2013). Moreover, beginning teachers show a range of success when engaging in this science practice themselves (Haefner & Zembal-Saul, 2004; Land & Zembal-Saul, 2003; Lunsford et al., 2007; Zembal-Saul, Munford, Crawford, Friedrichsen, & Land, 2002). For example, some prospective teachers linked claims with evidence and engaged in discussion that led to deeper understanding of how evidence supports claims (Land & Zembal-Saul, 2003; Zembal-Saul et al., 2002). Having more prior knowledge seemed to enable these teachers to link claims with evidence and theoretical understandings of content (Land & Zembal-Saul, 2003). Other prospective teachers struggled with aspects of this science practice, including recognizing relationships between data and claims, not providing justification, and not including multiple pieces of evidence (Haefner & Zembal-Saul, 2004; Park Rogers, 2009; Zembal-Saul et al., 2002).

Beginning elementary teachers are capable of supporting elementary students to construct evidence-based claims (Avraamidou & Zembal-Saul, 2010; Beyer & Davis, 2008; Zangori & Forbes, 2013), yet they face challenges. For example, a set of four preservice teachers had the knowledge for teaching students to construct evidence-based claims, including giving a clear purpose for the practice, yet most of these teachers struggled in using this knowledge in practice (Zangori & Forbes, 2013). Other challenges include emphasizing claims, but not evidence, when supporting students to construct evidence-based claims (Beyer & Davis, 2008) and conflating interpretation of evidence with constructing explanations (Zangori & Forbes, 2013). Beginning elementary teachers, like most teachers, often struggle to provide opportunities for students to engage in this work (Banilower et al., 2013; Pasley et al., 2004; Zangori & Forbes, 2013).

Fortunately, in view of the challenges of learning to support students to engage in constructing evidence-based claims, several types of tools and supports are available to facilitate this work (e.g., Braaten & Windschitl, 2011; Davis et al., 2012; Windschitl, Thompson, & Braaten, 2011; Zembal-Saul, 2009). Educative supports for teachers provided in curriculum materials explain how and why teachers might engage students in this work (Davis et al., 2012; McNeill, 2009). Discourse tools can provide beginning teachers support in how to do this work in the classroom (Braaten & Windschitl, 2011; Thompson et al., 2013; Windschitl et al., 2011). Windschitl and colleagues (2011) describe the beginning teachers' inclusion of argumentation and science explanation in their instruction with the support of discourse tools and their university courses. University courses, including methods courses and science content courses, sometimes provide opportunities for teachers to construct evidence-based claims and to do this work with students (Avraamidou & Zembal-Saul, 2005; Haefner & Zembal-Saul, 2004; A. M. Shah, 2011; Zembal-Saul, 2009). For example, focusing on the role of evidence in science in conjunction with these practices seems to facilitate preservice teachers' learning to teach ambitious science in methods classes (Zembal-Saul, 2009). Likewise, prospective teachers moved toward emphasizing the role of evidence in science after having the opportunity to engage in the practice of explanation and argumentation themselves (Haefner & Zembal-Saul, 2004). Although some supports to facilitate teacher learning of how to engage students in making evidence-based claims have been described through a practice-based approach, little research exists describing how these supports facilitate changes in preservice teachers' practice over time, particularly in an elementary setting.

Summary

In summary, learning to teach elementary science as science practice integrated with science content is challenging, complex work, but, with well-structured support, beginning teachers can learn how to do it. In particular, beginning teachers may not have the knowledge or ability to support elementary students to construct evidence-based claims, yet beginning teachers can learn to enact the teaching practice of engaging students in constructing evidence-based claims. Supports such as discourse tools and engaging in the science practices can support interns in learning to support elementary students to construct evidence-based claims. However, little is known about how elementary teachers learn to support elementary students in constructing evidence-based claims.

A Practice-Based Approach to Learning to Teach

A practice-based approach to teacher education has been proposed to support beginning teacher learning. This section outlines what is meant by a practice-based approach, as well as its potential for supporting elementary science teacher learning.

A Focus on High-Leverage Practices

A call has been made to focus teacher education on the practice of teaching or what teachers do in classrooms (Ball & Forzani, 2009; Grossman, Hammerness, et al., 2009). Although this focus on practice in teacher education is not new (Zeichner, 2012), teacher educators and researchers propose focusing on a collection of selected teaching practices (as in Lampert's (2010) second definition of practice) along with important subject matter knowledge to support beginning teacher learning (Ball et al., 2009; Davis & Boerst, 2014). In particular, Ball and Forzani (2009) call for outlining a set of high-leverage practices "that are essential for skillful beginning teachers to understand, take responsibility for, and be prepared to carry out in order to enact their core instructional responsibility" (p. 504). Ball and colleague's (2009) criteria for selecting a high-leverage practice for teaching elementary mathematics include considering the centrality, frequency, applicability, and effectiveness of the practice in mathematics teaching, as well as the possibility that a novice could be taught, could rehearse, and could increase in proficiency in the practice (Ball et al., 2009). Some examples of high-leverage practices include eliciting and interpreting student thinking and leading a class discussion (Ball et al., 2009; Boerst, Sleep, Ball, & Bass, 2011; Sleep & Boerst, 2012). Others have similar criteria for selecting high-leverage or core practices based on practical knowledge and empirical research, yet these lists often have different grain sizes for practices or are focused in particular content areas (Grossman, Hammerness, et al., 2009; Windschitl et al., 2011; Zeichner, 2012).

A Focus on Knowledge for Teaching

In addition to high-leverage teaching practices, a practice-based approach acknowledges the knowledge needed for teaching. This knowledge for teaching includes (1) pedagogical knowledge (e.g., classroom management, how learning occurs) (2) knowledge of context and students (e.g., issues of diversity, knowledge of individual students' lives), and (3) knowledge of the content (Abell, 2007; Shulman, 1986). Although developing a beginning understanding of pedagogical knowledge and knowledge of context and students is important in preservice teacher education (Feiman-Nemser, 2001; Zeichner, 2012), this dissertation focuses on knowledge of content for teaching, as this is more pertinent to the emphasis on teaching science in elementary classrooms.

Shulman (1986) discussed two types of content knowledge for teaching that others have elaborated on: subject matter content knowledge and pedagogical content knowledge. Likewise, other researchers elaborated on these two types of knowledge and made connections to specific disciplines. For example, science education research describes how science teachers need substantive knowledge about the body of knowledge of science and syntactic knowledge, an understanding of the scientific practices of a discipline and how they are used in a field to support students' learning of science (Abell, 2007; Magnusson, Krajcik, & Borko, 1999; Schwab, 1964). For example, if a teacher plans to support student learning to construct evidence-based claims about series and parallel circuits, she needs to know the body of knowledge about how electric circuits work (substantive knowledge) and the ways of constructing an argument in physical science (syntactic knowledge). A teacher also needs to be able to engage in the practice of constructing evidence-based claims herself. Thus, for every topic, teaching requires extensive subject-matter content knowledge.

In addition to subject-matter content knowledge, Shulman (1986) describes pedagogical content knowledge: "the particular form of content knowledge that embodies the aspects most germane to its teachability" (p. 9). Building on Shulman's (1986) work, Magnusson and colleagues (1999) and Abell (2007) outlined four areas of pedagogical content knowledge in science teaching: knowledge of science learners, instructional strategies, curriculum, and assessment. An example of each of these areas for constructing evidence-based claims about electric circuits includes knowledge of alternative ideas that students may have about electrical energy (knowledge of science learners), how to represent the flow of electrons in electric circuits that allow productive understandings (instructional strategies, science curriculum goals for electric circuits at the state-level curriculum), and methods of assessing students' evidence-based claims of electric circuits (assessment). As seen in this example of electric circuits, the pedagogical content knowledge involved in a specific science topic incorporates a large breadth and depth of ideas and concepts. Given this breadth and depth, teachers' pedagogical content knowledge varies (Abell, 2007; Schneider & Plasman, 2011; Van Driel, Jong, & Verloop, 2002). Teachers, particularly beginning teachers, may need support to learn the range of knowledge for teaching particular content and practices (Abell, 2007; Davis et al., 2006; Schneider & Plasman, 2011; Van Driel et al., 2002), which is part of continuing professional development (Feiman-Nemser, 2001, p. 1050; Schneider & Plasman, 2011). Thus, a goal for teacher education programs is to begin the process of learning the knowledge for teaching.

The Connection between Teaching Practices and Knowledge for Teaching

The knowledge that teachers have intertwines with the practices that teachers enact; teachers use their knowledge in action as they interact with students in a classroom (Hammerness et al., 2005; Lampert, 2010b; cf. Schön, 1983). For example, a teacher might engage in the practice of supporting students to construct an evidence-based claim during an investigation of chemical change. This practice involves using at least the following: (a) knowledge of how to construct an evidence-based claim from the data, (b) syntactic subject matter knowledge of how to analyze data to reveal patterns and relationships, (c) substantive subject matter knowledge of chemical changes, (d) pedagogical knowledge of making knowledge explicit to learner, (e) pedagogical content knowledge of instructional strategies involved in constructing explanations, (f) pedagogical content knowledge of students as science learners to know how students might struggle, and (g) pedagogical content knowledge of instructional aims to understand the importance of learning about chemical change and analyzing data. Additional forms of knowledge and abilities that enable the teacher to plan for and enact these practices are needed, but this limited list highlights the many intersections of knowledge and ability required for enacting the high-leverage practices that facilitate student learning. To enact the teaching practice, teachers draw on this science knowledge for teaching. Interacting with students in the class and reflecting on their practice, the teachers build and develop their science knowledge for teaching.

Pedagogies of Teaching Practice

In addition to focusing on the knowledge and practices that prospective teachers need to learn, a practice-based approach suggests a set of pedagogies to use in teacher education. As Dewey (1965) pointed out, recognizing the complexity underpinning a practice requires more than watching and doing without understanding. Grossman and colleagues (2009) offer a framework for teaching practice that provides a method for noticing and learning the complexity of practice. This framework identified three pedagogies common across the programs: representations, decompositions, and approximations of practice.

Representations include the variety of ways in which practice can be illustrated from direct observations of teachers teaching to lesson plans. The representations have the possibility of varying significantly in terms of comprehensiveness and authenticity; examples of representation can range from an entire year's set of videos of classes, student work, and teacher lessons (Lampert, 2001) to one short written case. Agreeing with Little's (2003) thoughts on representations of teaching practice, Grossman and colleagues (2009) suggest that "the nature of these representations has consequences for what novices are able to see and learn about practice" (p. 2065). For example, a skilled teacher educator may highlight her thinking throughout a read-aloud presentation with the class of prospective teachers, providing space for novices to think about and question aspects of her practice. However, this kind of representation does not allow the prospective teacher to see how a third-grade student might react to this read-aloud. On the other hand, watching a teacher interact with third-grade students without attention drawn to particular aspects of the complexity may not enable the novice to see the work involved in supporting student learning (Dewey, 1965; Feiman-Nemser & Buchmann, 1985). Thus, careful, deliberate selection of representations that allow particular aspects of the practice to be made visible to novices seems necessary in leveraging this pedagogy for teaching practice (Grossman, Compton, et al., 2009).

Next, Grossman, Compton, and colleagues (2009) describe the pedagogy of practice of decomposition, "breaking down complex practice into its constituent parts for the purposes of teaching and learning" (p. 2069). Given the struggle of novices to notice complexity in the work of a practice (Dewey, 1965; Feiman-Nemser & Buchmann, 1985), the decomposition of practice provides novices with the pieces of practice to look for and ways to interpret what they see. This decomposition allows the novice to become more incorporated into the discourses and ways of thinking of a community of practice (Grossman, Compton, et al., 2009).

Approximations of practice require novices to enact an aspect of practice with more or less authenticity. These approximations of practice allow the novices to practice or rehearse (as in Lampert's (2010) third definition of practice) the facets of a profession. Grossman, Compton, and colleagues (2009) describe a continuum of authenticity in approximations ranging from less authentic, with fewer facets of the practice, to more authentic, with a complete, integrated enactment of practice. Less authentic approximations, such as analyzing written cases, provide for narrow participation in practice and greater opportunity for rehearsal. For example, novice teachers could have multiple opportunities to practice writing follow-up questions to a written case about student thinking. Removing authenticity and complexity focuses novices on challenging aspects of professional practice, thus facilitating learning (Boerst et al., 2011; Grossman, Compton, et al., 2009; Kazemi et al., 2009). As novices enact more authentic approximations, such as teaching a lesson with the support of a mentor teacher, novices are more fully integrated into the practice. The novice no longer has the opportunity to stop and start or reword a question, but this approximation does allow the novice to experience the greater complexity of the actual practice. Thus, having opportunities to experience approximations of practices along the continuum of less authentic to more authentic provides possibilities to focus on important facets of practice and to experience how these facets fit together (Grossman, Compton, et al., 2009).

Research on a Practice-Based Approach to Teacher Education

Research on teacher education courses and programs that draw on Grossman, Compton, and colleagues' (2009) framework highlight some of the challenges and possibilities of this approach to teacher education (Ball & Forzani, 2009; Ball et al., 2009; Davis & Boerst, 2014; Grossman, Hammerness, et al., 2009; Kazemi et al., 2009; Windschitl et al., 2011). One of the challenges of this approach is the careful work and knowledge required by the teacher educator to support beginning teachers' learning. Kazemi and colleagues (2009) list the responsibilities of a teacher educator in developing instructional activities and using these with beginning elementary teachers of mathematics, such as decomposing the instructional task, rehearsing the task themselves, providing representations of the task to the beginning teachers, supporting beginning teachers' rehearsal of the task, and creating opportunities for the beginning teachers to enact the task in an elementary classroom.

Another challenge of this work is changing the status quo of teacher education programs. This approach runs counter to many common customs in teacher education, including changing the typical pedagogy used in teacher education and the separation made between university courses and field work (Feiman-Nemser & Buchmann, 1985; Grossman, Compton, et al., 2009;

Grossman & McDonald, 2008; Lampert, 2010b). Many education programs typically use a "pedagogy of investigation" that facilitates describing the complexity in teaching through video cases and teacher inquiry, whereas a practice-based approach focuses on "pedagogy of enactment" by supporting teachers to engage in multiple iterations of a practice (Grossman & McDonald, 2008). This approach requires a more closely linked relationship between university courses and field work (Davis & Boerst, 2014; Grossman & McDonald, 2008; Kazemi, Franke, & Lampert, 2009). For example, Davis and Boerst (2014) summarize the relational-work and creativity required to embed courses in school settings to allow "support[ing] and maintain[ing] settings for practice-based, ethical, and content-rich learning opportunities" (p. 24). Continued work is needed to develop connections between fieldwork and university courses to allow the intertwining of knowledge and practices in teacher education.

Despite the challenges of this approach, practice-based teacher education shows great potential for supporting beginning teachers' learning. One area of potential is the development of discourse and tools for representing, decomposing, and approximating practice in teacher education. In 1975, Lortie discussed the lack of a common technical vocabulary and understanding for teaching, and currently, the field continues to identify the lack of common discourse to analyze and improve teaching as a major constraint to improving teaching (Ball & Forzani, 2009; Grossman & McDonald, 2008; Morris & Hiebert, 2009). Practice-based teacher education has provided an opportunity to develop tools and language for supporting the learning of teaching (Ball & Forzani, 2009; Ball et al., 2009; Grossman, Hammerness, et al., 2009; Kazemi et al., 2009; Lampert, 2012; Lampert & Graziani, 2009; Windschitl et al., 2011). For example, Ball and colleagues (2009) describe their work designing grading tools that clearly articulate the components of a practice. These grading tools create artifacts that allow knowledge to be distributed among the teacher educators (Ball et al., 2009).

This practice-based approach to teacher education shows potential in supporting the development of well-started beginners in education. For example, using a multi-case study following beginning teachers' movement through a graduate practice-based teacher education program and into their first year of teaching, Thompson, Windschitl, and Braaten (2013) describe beginning secondary teachers' trajectory toward more sophisticated science teaching. Moreover, this approach seemed to facilitate beginning science teachers' ability to support secondary science students in constructing evidence-based explanations of big ideas in science through the support of several tools (Braaten & Windschitl, 2011; Windschitl et al., 2011).

Teacher educators have also applied Grossman's framework of pedagogies to elementary science methods classes. Shah (2011) highlights the ways that an elementary science methods course provided learning opportunities for guiding science discussions involving a combination of decomposing, representing, and approximating practice. This use of practice-based learning opportunities seemed to have "surfaced both the rationale for doing something and how to do it in an integrated way across course activities" rather than "learning the reasons why a teacher would enact particular actions …. first, and then practicing how to actually enact those actions while teaching later" (Shah, 2011, p. 204). In a multi-case study of prospective teachers in an elementary science methods class, Nelson (2011) suggests that including approximations of practice in methods classes "may enable prospective elementary science teachers to develop science teaching skills, ideas, and confidence to even greater levels prior to beginning student teaching" (p. 282). The prospective teachers that she studied identified both areas of learning and potential limitations from the different types of approximations used in the course (Nelson, 2011). These studies suggest the potential of a practice-based approach to supporting prospective elementary science teachers, but additional research is needed to determine how this approach supports elementary science teacher learning.

Summary

A practice-based approach to teacher education has been suggested to support prospective teachers in learning the complex work of teaching. This approach focuses on supporting teachers to learn a set of high-leverage practices as well as knowledge for teaching.

To support teachers' learning of these practices and knowledge, the field has identified pedagogies of practice including representations, decompositions, and approximations of practice. Such a practice-based approach has shown potential for supporting the learning of elementary science teaching.

A Theoretical Framework for Learning to Teach Science

The previous sections of this chapter highlight how learning to teach elementary science as science practice integrated with science content is complex and the potential of a practice-based approach for supporting this work. In this section, I offer my view of how learning the practice of teaching (Lampert's (2010) fourth definition) occurs.

Situated Cognition and Sociocultural Theories on Learning a Practice

Learning is situated in a particular physical and social context (J. S. Brown, Collins, & Duguid, 1989; Greeno, Collins, & Resnick, 1996; Putnam & Borko, 2000). Because the physical space and social situation where one learns a concept are deeply tied to the learning itself, the tasks for learning should be authentic (J. S. Brown et al., 1989). Thus, in learning to teach, the learning should be placed in the context of schools and classrooms of students (Ball & Cohen, 1999; Fishman & Davis, 2006; Lampert, 2010b; Putnam & Borko, 2000). For example, in-service teachers might analyze student work from their classrooms, focusing on understanding student thinking in the context of their teaching (Ball & Cohen, 1999). Likewise, prospective teachers might debrief their thinking about student understanding with a classroom teacher after a conversation with an individual student (Putnam & Borko, 2000). These tasks have the authenticity of being the work that teachers actually do in an authentic context, providing the possibility of developing the ability to do these tasks with more complexity in the future in similar contexts (J. S. Brown et al., 1989).

Learning is social; it involves becoming further initiated into the activities of a community of practice, a group of people who practice or do the same activity and self-identify as a group. Learning occurs through opportunities to participate legitimately and peripherally in the activities of the community of practice. Moving toward the participatory ability to interact in this group, a person develops the ability to enter into the discourse with others, to share in and add to the knowledge of the community, and to perform the practices shared by the community (Lave & Wenger, 1991). For example, a prospective teacher may begin by watching a classroom and then slowly begin to facilitate individual students' learning by helping with class assignments. The prospective teacher may continue to take on more of the responsibility of classroom teaching over time as she begins to do tasks such as co-planning how to teach a specific topic, discussing knowledge of students' learning with other teachers, and teaching sections of classes. In this manner, this former outsider to the community moves toward becoming part of the community. This learning or movement toward becoming a member of a community of practice requires interactions with others that enable the individual to have access to the knowledge and practices of the community (Lave, 1996; Vygotsky, 1978).

Others can facilitate this learning, the movement toward legitimate participation, by making resources and opportunities available for the learner (Lave, 1996). In particular, a knowledgeable other (e.g., a teacher) can aid this movement by creating opportunities and support for a learner to more fully participate in the tasks of the community (Vygotsky, 1978). Vygotsky (1978) describes the zone of proximal development as the region between what a person can do on his own and what he can do with the help of a knowledgeable other. The supports and resources provided by another person facilitates learning (Vygotsky, 1978). For example, a teacher educator may structure an activity where a novice teacher has the opportunity to work with a few children on a particular mathematics problem. The teacher educator might support this novice by working together to develop the lesson, enabling the novice to do more of the work of the practice of teaching with the help of the knowledgeable other than the novice could do on her own. Over time, the novice will be able to plan and facilitate a discussion of a problem without the support of the teacher educator, and thereby move more toward legitimate participation in the practice of teaching. This support provided by the knowledgeable other requires careful planning and sequencing (J. S. Brown et al., 1989; Kazemi et al., 2009; Lave, 1996; Vygotsky, 1978).

Learning is distributed; groups of people share in the co-construction of knowledge using tools and signs. Working with others allows the sharing of knowledge across individuals and the ability to construct deeper meanings (Pea, 1993; Putnam & Borko, 2000). Each individual brings her knowledge and experience to work of the group. Over time, individuals are able to serve as knowledgeable others for one another in order to develop deeper understanding of the practice as a whole (Vygotsky, 1978). For example, as the teacher educator facilitates a novice in helping a student with a mathematics problem, the teacher educator may learn more about how to teach mathematics problems through the questions and ideas of the novice. Likewise, two teachers discussing how to interpret student thinking from student work may create a deeper understanding about how to support learning for both teachers. Thus, the distribution of work is across the members of a community of practice (Putnam & Borko, 2000). Both the newer "peripheral" members and the well-established members enable a deeper construction of knowledge of the practice of teaching as a whole (Lave, 1996; Lave & Wenger, 1991; Putnam & Borko, 2000).

Learning is also distributed across tools and signs that enable the performance of tasks beyond the capacity of the individual (Pea, 1993; Vygotsky, 1978). Language and signs allow the communication across individuals in the community of practice (Vygotsky, 1978). Thus, as one becomes a more integrated member, one learns to participate in the discourse of the community of practice and to share the work of the practice (Lave & Wenger, 1991; Putnam & Borko, 2000). For example, as a novice teacher begins to participate in conversation about students' thinking in a classroom, this teacher learns the discourses particular to the practice of teaching and is able to take on some of the responsibility of supporting the students' thinking.

Tools and signs also enable the performance of tasks beyond the capacity of the individual or group. Inscriptional systems such as scientific notations or written language allow the ability to transform meanings and carry understandings (Pea, 1993; Vygotsky, 1978). Tools such as curriculum materials or computers facilitate learning by taking on aspects of the work (Pea, 1993). For example, as beginning teachers interact with existing curriculum materials to learn to plan a lesson, the sum of the understandings of the community of teaching exists in the representations and words in the written document (Hiebert & Morris, 2012b). The curriculum materials share in the work of developing the lesson, as the teachers make decisions about how to enact a lesson on the basis of suggestions from the curriculum materials (M. W. Brown, 2009; Remillard, 2005). In this manner, the learning becomes distributed across the teachers, signs, and tools to facilitate integration into the practice of teaching.

In light of this distributed nature, Lampert (2012) highlights the concept of a "'generative dance'" (Cook & Brown, 1999) between the organizational knowledge of practice distributed in tools and the people in the community of practice who use this knowledge. Individuals in a community of practice draw on the knowledge distributed in the community and add to this knowledge as they face problems of practice (Cochran-Smith & Lytle, 1999; Hammerness et al., 2005; Lampert, 2012). For example, when faced with a novel student answer to a math problem, a teacher relies on her own practices of teaching and the teachers' manual to help her proceed in the conversations. Later, she may discuss this novel answer with others as a problem of practice to make decisions about how to proceed in her classroom. In this case, the teacher both (1) relies on the knowledge and practice of the community distributed in the teachers' manual and others and (2) adds to the understandings of the practice through her thinking about the novel answer with others. The teachers (individuals in the community) become generators of the knowledge and practices of the community of practice (Cochran-Smith & Lytle, 1999; Lampert, 2012). Thus, being a member of community of practice (and learning to be a member) involves co-constructing knowledge through making sense of and enacting the practices of the community.

A Theoretical Framework for Learning to Teach as Practice

Figure 2-3 shows my theoretical framework for learning to teach as practice. This figure shows how learning the practice of teaching is the process of moving from being an outsider of a community of practice to becoming part of the community of practice. During this process, an individual co-constructs meaning with others to make sense of and to act as part of the community practice. The process of learning is distributed across people and tools, situated in a particular context, and social. This process of learning is facilitated by a knowledgeable other, in this case a teacher educator. In a practice-based approach to supporting this process of learning, the teacher educator uses a set of pedagogies including decomposition, representation, and approximations of practice. These pedagogies support learning of a set of high-leverage practices for teaching (e.g., the practice of supporting elementary students to construct evidence-based claims) and knowledge of teaching.

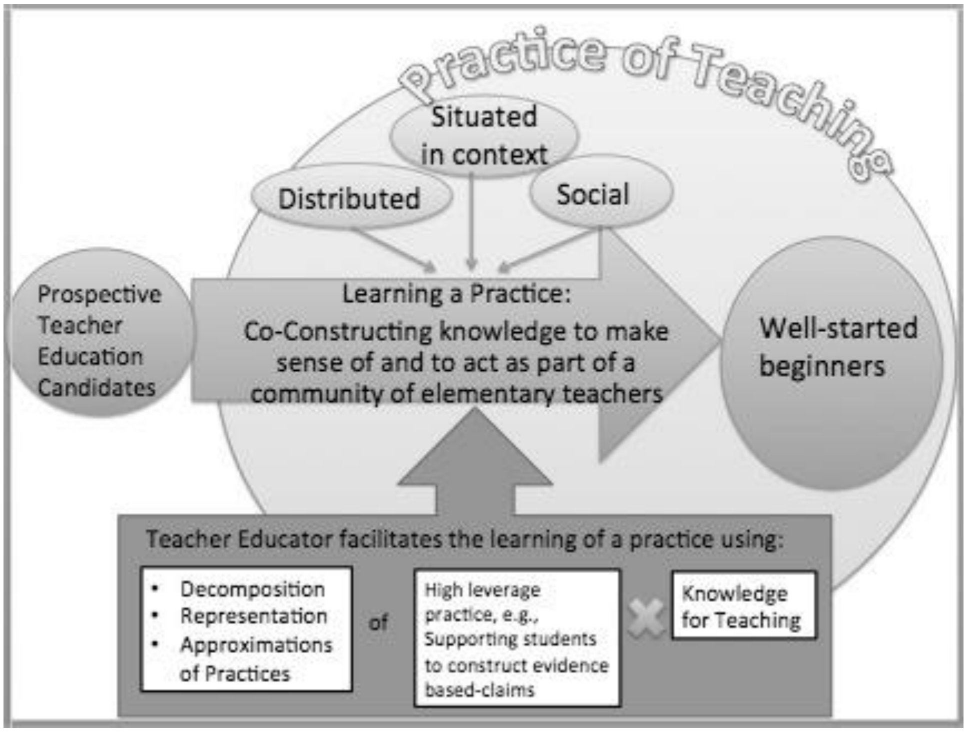


Figure 2-3: Theoretical Framework for Learning to Teach

Conclusion

This chapter outlined the empirical and theoretical literature about supporting elementary students in science practices integrated with science content, as well as the particular teaching practice of supporting students to construct evidence-based claims of natural phenomena. I also outlined my view of the components of this teaching practice by drawing on the research base. Next, this chapter described the practice-based approach to teacher education and the potential it shows for facilitating beginning teacher learning. Finally, I presented my theoretical framework for the study, which draws on a sociocultural, situated perspective of learning. The next chapter describes how I draw on my theoretical framework as well as the research base in developing the study design, the collection of data, and analysis of the study.

CHAPTER 3

METHODS

This longitudinal qualitative case study considers the change in teaching practice and knowledge for *supporting students in constructing evidence-based claims* for one cohort of 54 preservice elementary teachers (called interns) during their four semesters in a two-year practice-based teacher education program. From the cohort, I purposefully selected five interns to serve as focal interns. The descriptions of the experiences of these five focal interns serve as sub-cases embedded in the larger case study of the entire cohort of 54 interns. To develop these descriptions, I collected and analyzed a variety of records of practice, assignments, and surveys from two courses and programmatic assessments. The records of practice include lesson plans and videos of enactments of lessons or parts of lessons. The lesson plans and video-records of enactments allowed the analysis and description of the interns' practices for engaging students in constructing evidence-based claims. I collected written reflections on lessons, class assignments, and surveys about science practices and teaching practice to characterize the interns' knowledge for engaging students in constructing evidence-based claims. Interviews with the focal interns helped triangulate the descriptions from other data sources and describe the interns' thinking about their learning of this practice.

These data sources enabled me to describe the teaching practice and knowledge for supporting students to construct evidence-based claims that the interns use at particular points in the program. Looking across these descriptions facilitates characterization of changes over time in terms of practice and knowledge in this cohort. I looked for the variation and trends in learning to support students to construct evidence-based claims. As a reminder, I ask: With regard to supporting elementary students to construct evidence-based claims about natural phenomena, how do the interns' practice and corresponding knowledge change over time in a practice-based teacher education program? And How do interns describe how and why their knowledge and practice changed over time? This chapter describes the study design, including the role of the researcher, instructional context, participants, data sources, and analyses for the research questions.

Role of the Researcher

I have been involved in this two-year undergraduate teacher education program for several years. I first apprenticed in the Science Methods Course in the fall of 2010. Through observations of interns in the methods course and in the field, I first became interested in preservice teachers' ability to engage students in science practices. Since this time, I have been involved in planning, observing, and giving feedback to preservice teachers for this course. In the fall of 2012, I had an opportunity to serve as the instructor for the course, where I noticed variation in interns' practice for supporting students to engage in evidence-based claims. Assessing and providing feedback on the interns' practice also highlighted the variation in their knowledge and teaching moves for supporting students in science practices.

In the fall of 2011, I also became involved in the Children as Sensemakers I Course that occurs during the first month of the program. My involvement in this class as an observer and grader also allowed me to notice the variety of interns' moves and knowledge for supporting students to share their thinking about natural phenomenon. Having the opportunity to work with classes across multiple time points in the program made me wonder about how interns might learn to do the work of supporting students in science practices. I also became interested in how classes and experiences throughout the program help the interns develop their knowledge for teaching and teaching practice.

During this dissertation study, I served as the instructor for one of the two sections of the Science Methods Course, a grader for the Children as Sensemakers I class, and as the primary researcher for this study. Assuming these roles required that I define each ahead of time (Luft, Bragg, & Peters, 1999). As an instructor of the Science Methods Course, I planned for class sessions with other instructors, facilitated learning to support students to engage in constructing evidence-based claims, and provided feedback on written work (including the assignments included in data collection). As a grader for the Children as Sensemakers I class, I observed class sessions and provided feedback on the interns' class assignments. As a researcher, I invited interns to participate in my work through a brief discussion that described the research and the possibilities for involvement at the beginning of the year. I obtained consent from interns to be involved in the study and informed interns that their involvement would not be related to the grades for the course. Although my role as course instructor or grader may have limited the interns' trust and openness during interviews, my data suggest that I can believe what the interns said. For example, several of the interns commented that they did not read the assignments for the class, even though this was a requirement of the course.

Because the collection of data involved assignments and work that occurred regularly in the Science Methods Course, I foregrounded my role as instructor during the course in order to make the best decisions for the interns' learning in the courses. I focused on my role of instructor and grader while the Science Methods Course and Children as Sensemakers I Course were in session and waited until the course and grading were complete before beginning analysis of the data. This enabled me to support interns in their work without feeling that my role as researcher would compromise my ability to act as their teacher educator.

In terms of the interviews with the subset of focal interns, I conducted the first interview before the course began or within the first week of the course. In obtaining consent, I described how the interviews provided the interns with an opportunity to reflect on their science teaching and provided feedback for improving learning for future interns. These rationales for participating enabled the interns to see the interviews as tasks in our relationship as instructor and students rather than inconsistent with the course goals of supporting their learning to become an elementary teacher. I also reminded interns that the interviews were not associated with their grade for the course. During the rest of the course, I had another researcher conduct the interviews with those interns in my class to avoid conflicts of interest and to enable the interns to speak more frankly about their struggles and successes in the class. I conducted the interview with those interns in the other section of the course, which I did not teach. I assumed the role of interviewer and researcher once the courses and grading were completed.

Study Setting and Participants

This study's context is a two-year practice-based teacher education program, and its participants include interns in one cohort. This section describes the program, the focus courses of the study, and the participants. Then, I outline some of the features of the courses and the program that focused on facilitating intern learning of how to support elementary students to construct evidence-based claims. In this section, I also describe some of the opportunities to learn provided to interns during the Teacher Education Program, including in the Children as Sensemakers I Course, Science Methods Course, and other coursework and clinical work in the program. I draw on Grossman, Compton, and colleagues' (2009) framework for teaching practice in this description, giving examples of representations, decompositions, and approximations of practice to support learning in the program.

The Teacher Education Program

This research study focused on a cohort of interns in an undergraduate teacher education program at a large Midwestern university in the United States. The program consisted of four semesters of professional study, and students typically enter the program in their junior year. The program was accredited by the Teacher Education Accreditation Council (TEAC), which certifies that the program adheres to TEAC's quality principles.

Three pillars undergirded the focus of the program: teaching practice, preparing "subject-matter serious" teachers, and recognizing and acting on professional obligations. These pillars served as design principles for the program and continued to focus the aims and goals of the program (Davis & Boerst, 2014). The program has outlined a set of high-leverage practices that are used throughout the courses in the program (see Appendix A). These high-leverage practices are not content specific but rather are focused across the courses and in various subject matters throughout the program to support the learning of these practices in subject-matter serious ways. The program also outlined a set of ethical obligations that are infused in the teaching of the courses.

The program had a series of courses that focus on content-specific teaching, learning about the social and political contexts of teaching, and developing an understanding of how people learn. There were also three semesters of clinical practicum, where interns worked six to nine hours per week in elementary classrooms learning to plan, enact, and assess elementary lessons using high-leverage practices with the guidance of field instructors and mentor teachers. Interns spent their last semester in the program in student teaching, where they were in classrooms full time while receiving guidance from a mentor and field instructor. The interns were expected to act as lead teacher for two to three weeks during student teaching, where they took on the responsibility of planning, enacting, and assessing instruction. The program also required interns to take a series of courses in particular subjects (e.g., a physics course for educators). In this program, consistent with state policies, interns had major academic subject area. A major required interns to take additional courses in this subject area.

This program also designed a series of program-level assessments that allowed formative feedback to be provided to interns and provided information for instructors to use in the courses and re-design of the program. These assessments focused on gauging an intern's subject-matter knowledge, ability to enact high-leverage practices, and application of ethical obligations. For example, interns took a subject-matter knowledge assessment of their science knowledge for teaching in the content of ecosystems during the winter of their first year. Another assessment involved interviewing a standardized student about his thinking of a mathematical concept to evaluate the interns' ability in the practice of eliciting and interpreting student thinking. These assessments occurred over the course of the program and were sometimes used as pre- and post-tests to look for changes in knowledge and practice over time (Boerst, 2013).

Opportunities for Learning the Teaching Practice of Supporting Elementary Students to Construct Evidence-Based Claims. The learning opportunities for teaching elementary science provided in this program drew on the research base in selecting appropriate and productive strategies, as well as on design work from multiple iterations of the courses and the program (Beyer, 2009; Davis & Boerst, 2014; Davis & Smithey, 2009; Forbes & Davis, 2010b; Nelson, 2011). Opportunities to learn about and enact aspects of the teaching practice of supporting students to construct evidence-based claims existed throughout the program, including in courses and during their field experiences.

Courses also focused on elements related to the teaching practice of supporting elementary students to construct evidence-based claims including planning for science lessons and providing explanations of content. The next sections describe contexts that could facilitate the interns' development in supporting children to construct evidence-based claims in science. Drawing on Grossman, Compton, and colleagues' framework (2009) described in Chapter 2, I outline the representations of this teaching practice (e.g., videos of teaching practice), decompositions that break down the practice into smaller pieces, and approximations of practice that allow the interns to enact the practice in different contexts and courses.

Learning Opportunities for Supporting Students to Construct Evidence-Based Claims in the Children as Sensemakers I Course. The Children as Sensemakers I Course met for three hours each week during the first month of the first year in the program. The course focused on learning to elicit, interpret, and develop students' thinking about natural phenomenon through course assignments and readings. The course aimed to highlight how elementary children make sense of the natural world through their everyday experiences. The interns engaged in two interviews with a lower-elementary student about their understanding of what causes day and night using multiple modalities (speaking, drawing, and modeling). The interns also enacted a read-aloud with the same students about what makes day and night and used a physical model to represent the phenomenon.

The course required reading articles that focus on how children learn or possible instructional techniques for working with student ideas. Instructional activities included watching video-records, engaging in modeling, rehearsals, and discussions that allow interns to co-construct understandings about student thinking and practice to elicit student thinking. Interns completed three assignments where they engaged in a discussion with a lower elementary student about what makes day and night and then reflected on this experience.

The Children as Sensemakers I Course offered multiple opportunities for interns to learn about the knowledge and practice of supporting students to construct evidence-based claims. Table 3-1 lists some of these opportunities that occurred during the course and when these opportunities occurred throughout the course. Representations of this teaching practice included modeling eliciting student thinking and justification, as well as video-records of students sharing their own thinking about a natural phenomenon. These representations highlighted some of the specific components of the teaching practice of eliciting students' claims about natural phenomena and knowledge needed to do this work. For example, a video-record of students explaining their thinking about how light works underscored how students' ideas about natural phenomena are persistent and reasonable. Some of these aspects of eliciting students' claims about natural phenomena were decomposed during the discussion about the representations of practice and reading about student thinking. The instructional tasks and reading asked interns to focus on specific aspects of the practice—for example, the kind of questions asked to learners. The approximations of practice, including the rehearsals, interviews, and read-aloud, with an individual student enabled interns to engage in some aspects of supporting students to construct evidence-based claims with a high amount of support. The rehearsal, interviews, and read-aloud had protocols with specific questions for interns to engage in teaching moves, such as supporting students to justify their thinking or probing for evidence or reasoning in students' claims about the natural phenomenon (see Appendix B for an example part of the protocol). Through the representations, decompositions, and approximations of practice, this course provided the opportunity to learn about students' ideas and the foundational elements of supporting students' construction of evidence-based claims.

Table 3-1: List of Activities and Assignments That Focus on Supporting Elementary Students to Construct Evidence-Based Claims in the Children as Sensemakers I Course

Week	Activity or Assignment
1	Video of students sharing their thinking of the natural phenomenon of light
1	Modeling of read-aloud, including eliciting student thinking
1,4	Writing claims for the question, "What makes day and night?"
1,2,3	Rehearsal of eliciting students' claims about the natural phenomenon
1,3	Interview to elicit students' claims about what makes day and night
1,2,3,4	Discussion of student claims and how to elicit student claims about what makes day and night
3	Read-aloud with students about what makes day and night
2,3,4	Reflection on students' thinking and teaching moves from interviews and read-alou

Components of Constructing Evidence-Based Claims Emphasized in the Children as Sensemakers I Course. The Children as Sensemakers I Course focused on three components of the teaching practice of constructing evidence-based claims: supporting students to (1) communicate claims, (2) draw on representations to make claims and analyze data to reveal patterns, and (3) share and justify their thinking. Table 3-2 lists the potential investigation questions, potential data analysis, and potential evidence-based claims for the course.

Table 3-2: Potential Investigation Questions, Potential Data Analysis, and Potential Evidence-Based Claims for the Children as Sensemakers I Course Assignments

Lesson	Children as Sensemaker I: What causes day and night?
Potential Investigation Question	What makes day and night?
Potential Data Analysis	Making sense of a clay model of Earth, with a flashlight as the sun, by noticing the pattern of where light falls on the Earth model as it spins Connecting the physical model to a representation of Earth spinning in the picture book
Potential Evidence-Based Claim	**Claim:** Earth spins on its axis. As it spins, half of Earth is in the sunlight and half of Earth is in Earth's shadow **Evidence:** When I spun the model Earth, the toothpick representing people moved in and out of the light from the flashlight. When the toothpick on one side of Earth is in the sun, the toothpick on the other side of Earth is in the shadow. **Reasoning:** Spinning around allows the people to move in and out of the light. Earth blocks the light from the sun during the nighttime.

In terms of supporting students to communicate claims, the protocols for the interviews required the interns to have students share their answer to the question, "Please tell me how you think we have day and night" [CaSM#1InterviewProtocol]. According to the protocol, the interns first worked to support students to state their answer verbally; second, the intern supported students to draw a representation of their thinking; and finally, the interns asked students to represent their thinking using a model (including clay and a flashlight). The class discussions included conversation about how and why to support students to communicate their claims in this way. The tool used to assess the interns' work and provide feedback included an expectation that the intern "asked a clear question to introduce that task that appeared to be understood by the child" [Interview2_FeedbackTool]. This expectation highlights the focus on supporting a student to communicate a claim about the natural phenomenon of day and night by asking clear questions.

The class assignments, class discussions, protocols, and feedback tools also had an emphasis on drawing representations to make claims and analyze data to reveal patterns. The read-aloud with a student included an emphasis on supporting a student to make sense of a representation in the text as well as in a model, to give an explanation of what causes day and night. For example, the protocol included supporting the students to use the model to show how the spinning of Earth can cause day and night. The protocol also highlighted some of the implicit features of the representation such as pointing out the perspective of the representation. Class discussions also highlighted some of the challenges of using and understanding representations to make claims such as how to match the model with the drawn representation in the book. The class discussion also pointed out the importance of allowing students the opportunity to make sense of the representations in order to develop claims and evidence in service of an explanation of what makes day and night. On their assignments, interns were required to reflect on their teaching moves that might have facilitated the students to make sense of the phenomenon. They received feedback on their ability to use these representations and discussed their experiences in class.

The course also had an emphasis on eliciting, probing, and interpreting student thinking, which can facilitate the interns to support students to share and justify their thinking about the patterns or claims. Example follow-up questions were included on the interview protocol, such as “How does this happen?” [CaSMInterviewProtocol]. The class discussed the importance of asking these follow-up questions to further understand what a child is thinking. The tools used for assessment and feedback included these two expectations:

(1) Asked follow-up questions that targeted the scientific phenomenon, including questions that that elicited the child’s understanding of what causes day and night

(2) Asked follow-up questions that were tied to what the child said or did [CaSMInterviewFeedbackTool]

These expectations would support students to share their thinking about the phenomenon in question.

Learning Opportunities for Supporting Students to Construct Evidence-Based Claims in the Science Methods Course. The Science Methods Course met for three hours a week for nine weeks during the second year of the teacher education program. The course goals for interns were (a) describing the vision of science learning outlined in the Next Generation Science Standard, (b) incorporating this vision into their developing science teaching practices (e.g., appraising and modifying science lesson plans and activities to address a specific learning goal; explaining core content and supporting students in constructing scientific explanations), (c) enacting instructional practices that make science accessible to all students, and (d) learning to prepare, teach, and reflect on elementary science lessons that incorporate investigations. The course used the EEE framework for elementary science teaching (Benedict-Chambers, 2014), which is designed to decompose pieces of elementary science lessons and provide a vision for how a teacher could support science learning. The EEE framework divides elementary science teaching with investigations into three elements: engage, experience, and explain with evidence (see Appendix C). During the Engage element, teachers facilitate the identification of an investigation question and support students to share their prior knowledge about the investigation question. In the Experience element, a teacher supports the collection of data from an investigation. The Explain with Evidence element involves supporting students to analyze the data to reveal patterns and relationships, construct evidence-based claims, and apply their knowledge to a new situation. The course was designed to consider closely each element of the framework, and assignments used the framework as a way of decomposing the larger practice of science teaching.

The course worked on the learning goals through a number of assignments, instructional activities, and readings (see Appendix D for Syllabus). Instructional activities for the course included engaging in portions of science lessons as students, analyzing videos of teachers' practice, analyzing student work, and discussing course readings and problems of practice. One major set of activities was called Peer Teaching (see Appendix E). During Peer Teaching, interns taught portions of science lessons to a small group of their colleagues who acted as elementary students. Each enactment was followed by a debriefing session with a teacher educator, the intern, and their "students." The Peer Teaching occurred three times, so interns had the opportunity to teach each element of the EEE framework. Interns co-planned for Peer Teaching during class the week before. These instructional activities were designed to provide representations of science teaching, to decompose elements of science teaching, and to approximate the practice (Grossman, Compton, et al., 2009)

Required assignments for the course included (a) a write-up of a conversation with their mentor teacher about teaching elementary science, (b) lesson plans and reflections for three Peer Teachings, (c) Experience-in-the-field, and (d) Reflective Teaching (see Appendix F for the assignment). Experience-in-the-field required interns to plan for, enact, and reflect on the experience portion of a science lesson with elementary students in their placements. For the Reflective Teaching assignment, interns planned for, enacted, and reflected on an entire lesson in their placement classrooms. The Peer Teaching, Experience-in-the-field, and Reflective Teaching asked that interns use existing curriculum materials that they would analyze and modify rather than creating their own lesson using a set of lesson-planning considerations (see Appendix G for the considerations). Thus, these assignments required interns to engage in planning for, enacting, and reflecting on science teaching throughout the course.

The Science Methods Course provided several learning opportunities for developing practice and knowledge for supporting students' construction of evidence-based claims. Table 3-3 provides a summary of the activities and assignments related to supporting students to construct evidence-based claims of natural phenomena. The course began with an overview of how evidence-based claims fit into science lessons and then focused on each element of the EEE framework (see Appendix C). The course ended with considering assessing student learning.

Table 3-3: Summary of Activities and Assignments in the Science Methods Course Related to Supporting Students to Construct Evidence-Based Claims (See Appendix C for EEE Framework)

Week	In-Class Activities and Assignments
1	• Modeling of a science lesson involving constructing evidence-based claims • Overview discussion of including evidence-based claims in science teaching • Homework: Readings on designing lessons to include evidence-based claims and on NGSS including the practices of science explanations and argumentation
2	• Discussion of Engage element of EEE framework • Co-planning of a Peer Teaching lesson to include evidence-based claims with focus on Engage element
3	• Peer-teaching of Engage element of Peer Teaching lesson • Homework: Readings on representing and analyzing data
4	• Reflection on Engage element of Peer Teaching lesson due • Discussion of Experience element of EEE framework • Co-planning of Experience element of Peer Teaching lesson focused on collecting data and possibly analyzing data
5	• Enacting of Experience element of Peer Teaching lesson • Homework: Readings on explanation and argumentation
6	• Reflection on Experience element of Peer Teaching due • Experience Element-in-the-field due • Discussion of Explain-with-evidence of EEE framework • Co-planning of Explain-with-evidence element of Peer Teaching lesson focused on analyzing data and constructing an evidence-based claim
7	• Enacting Explain-with-evidence element of Peer Teaching lesson focused on analyzing data and constructing an evidence-based claim • Homework: Readings on assessing evidence-based claims
8	• Discussion of assessing students' evidence-based claims • Analyzing sample student work of evidence-based claims
9	• Synthesis discussion of class • Incorporating literacy into science elementary lessons • Finding resources for teaching elementary science including secondary data sources

The Science Methods Course involved a variety of representations of practice to facilitate interns' learning of supporting students in constructing evidence-based claims. During the first class session, interns experienced an example of an elementary science lesson as students. During this experience, the instructor modeled how a teacher might support students to construct evidence-based claims. This modeling and the following discussion focused on including integrating science content with science practices, including constructing evidence-based claims that might occur in an elementary classroom. Throughout the course, interns viewed video-records of teachers engaging students in conducting investigations and constructing evidence-based claims. Use of the video-records was intended to show the teaching moves and language involved in this work. For example, interns were asked to pay attention to the questions that the teachers ask to elicit student justification of a claim. Many of the readings included vignettes of teachers' practice that described teachers' planning for, enactment of, and reflection on supporting student learning of science practices. These representations and others aimed to make visible particular aspects of the practice of supporting students in constructing evidence-based claims.

The Science Methods Course used a variety of instructional tasks to decompose the teaching practice of supporting students to construct evidence-based claims. The purpose of the EEE framework was to lay a foundation for this decomposition by outlining components of this work in elementary classrooms. The whole class also engaged in discussions that decomposed this work after experiencing different representations of the teaching practice. In these discussions, the instructor and interns identified and named specific teaching moves, representations, and language used in the representations of practice. For example, the class named specific questions used to elicit student justification such as, "How do you know?" Course readings also provided decompositions of this practice. In particular, *What's Your Evidence* (Zembal-Saul et al., 2013) named explicit discourse moves and planning steps for the practice of supporting students to construct evidence-based claims. The interns also decomposed their practice when reflecting on their enactments of science lessons. These decompositions were intended to facilitate interns' ability to interpret, enact, and analyze the teaching practice.

Several types of approximations of practice in the Science Methods Course allowed interns to enact aspects of the teaching practice of supporting elementary students to construct evidence-based claims. Co-planning with colleagues for the Peer Teaching and with their mentor teacher for the lessons in their classrooms required interns to draw on existing curriculum materials to decide on the evidence-based claims that students can construct and the teaching moves, representations, and language that could be used to support students in this work. Peer teaching allowed interns to enact the teaching moves involved in supporting student construction of evidence-based claims without the complexity of working with elementary students. The Reflective Teaching required interns to enact these teaching moves with more complexity but still with the support of their mentor teacher. The sequencing of the approximations of practice aimed to increase the complexity of the work over time.

Components of Supporting Students to Construct Evidence-Based Claims Emphasized in the Science Methods Course. The Science Method Course focused on these components of the teaching practice of supporting students to construct evidence-based claims: (a) supporting students to analyze data, (b) supporting students to communicate a claim, (c) supporting students to use a logical structure for evidence-based claims, and (d) science knowledge for teaching students to construct evidence-based claims. The course also touched on other aspects of the teaching practice, but these were the major areas of emphasis.

The decomposed teaching practices in the EEE framework give insight into how this teaching practice was discussed and practiced in the course. Figure 3-1 shows the decomposed subpractice of supporting students to analyze the data to reveal patterns and relationships from the EEE framework, and Figure 3-2 shows the decomposed subpractice of supporting students to justify their claims with evidence and reasoning. During the course, the class identified these decomposed elements in the representations of science teaching and discussed why these components are important. In these discussions, the instructors highlighted specific teaching moves such as using a sentence stem to support learning or connecting students' ideas to each other.

Identify patterns and trends in the data for answering the investigation question or problem (entails *analyzing and interpreting data, using mathematics thinking*)	Support students in making sense of the data so that they can generate claims with evidence. This includes ... • Compiling class data, and if relevant, organize or represent the data in meaningful ways (e.g., in tables or graphs). • Directing students to particular aspects of the data to help them identify and make meaning of patterns or trends in the data. • Helping students select appropriate and sufficient data to use as evidence to support claims.

Figure 3-1: The Decomposed Practice of Supporting Students to Analyze the Data from the EEE Framework.

Generate scientific claims with evidence and reasoning (entails *constructing explanations, engaging in argument from evidence)*	Facilitate a discussion that enables students to answer the investigation question by using the data to generate evidence-based claims. Provide students with scaffolds, such as "I think ____(*claim*) because I observed _____ (*evidence*)" or "What I know: ____ (*claim*). How I know it: _____ (*evidence*)." Provide opportunities for students to share their explanations with others, including peers, parents, etc. Help students... • Revisit their initial ideas about the investigation question, expanding upon or developing new evidence-based claims. • Compare their own explanations with explanations reflecting scientific understanding, via direct instruction, textbooks, models, etc. This includes introducing new terms to students, as appropriate. • Question one another about their explanations

Figure 3-2: The Decomposed Practice of Supporting Students to Make Claims Justified by Evidence and Reasoning from the EEE Framework.

The course instructors expected the interns to use these elements in their lesson plans and enactments for class assignments including Peer Teaching and Reflective Teaching. These assignments included a variety of content and types of data analysis. Table 3-4 shows the investigation question, potential data analysis, and potential evidence-based claims for the two focal lessons for the Peer Teaching Assignment (called "Stems Lessons" and "Energy Lesson"), and Appendix H lists this information for the focal interns' Reflective Teaching lessons. The feedback for Peer Teaching asked colleagues and the teacher educator to comment on how the interns enacted these decomposed elements with questions such as, "How did the teacher facilitate a discussion that enables students to use data as evidence to answer the original question or problem? Give specific examples." [PeerTeachingFocusQuestions]. The Reflective Teaching assignment required interns to identify locations in the video-records of their lesson where they enacted these decomposed elements of the teaching practice, and to reflect on how their enactments support student learning. The instructors commented on these reflections as well as on their enactment of the teaching practice.

Table 3-4: Potential Investigation Questions, Potential Data Analysis, and Potential Evidence-Based Claims for the Peer Teaching Lessons

Lesson	Peer Teaching Stem Lesson The purpose of a stem for K-3 grades	Peer Teaching Energy Lesson The transfer of heat energy for 4-6 grades
Potential Investigation Question	What is the purpose of a stem? By asking: What happens when a celery stem is placed in red water (and clear water)?	What happens when a bag of cold water is placed into a container of hot water?
Potential Data Analysis	Comparison of observations of the celery stem before and after it is placed in water Creation of a table to notice these comparisons	Creation of line graph of temperature of containers at 1-minute time points Comparison of two lines on the graphs
Potential Evidence-Based Claim	**Claim:** The purpose of a celery stem is to hold up the leaves and transport water. **Evidence:** Celery stem was flexible before it was placed in the water and became stiff afterward. The tubes inside the stem became red. **Reasoning:** The tubes inside of the stem transport the water. The length of the stem allows it to hold up the leaves.	**Claim:** The hot water decreases in temperature. The cold water increases in temperature until the two temperatures are the same. **Evidence:** The hot-water temperature changed from X degrees to Y degrees. The cold-water temperature changed from Z degrees to Y degrees. They both reached the same temperature of Y degrees at the end. **Reasoning:** Heat energy transferred from the hot water to the cold water, causing the changes in temperature.

In addition to the focus on these components of the teaching practice, the course also facilitated opportunities to develop science knowledge for teaching. Course instructors introduced the claim, evidence, and reasoning framework to interns through class discussion and readings. The interns wrote several evidence-based claims in the class, discussed these claims, and practiced assessing sample student work with evidenced-based claims. The course also included an emphasis on potential alternative ideas of elementary children, struggles elementary students might have in engaging constructing evidence-based claims, and how to develop a content storyline across science lessons.

Opportunities to Learn to Support Students to Construct Evidence-Based Claims in Placement Classrooms. The interns spent the entire second year in the same placement classrooms in nearby schools. In the first semester of the second year, interns spent one morning and one entire day in the classroom. During this time, they were given opportunities to work with individual students, teach portions of lessons for their assignments for their courses, and observe their mentor teachers' lessons. The interns might have had the opportunity to see science teaching and provide science-teaching support to small groups, but these opportunities were not consistent. The interns also taught two assignments for the Science Methods Course, Experience-in-the-Field and Reflective Teaching, in these classrooms.

In the second semester of the second year of the program, interns remained in these same classrooms for their student teaching. During this semester, the interns were expected to be in the classrooms full time each school day. The interns gradually took responsibility for subjects and were required to teach all subjects as full-time teachers for three weeks. During this time, interns may have had opportunities to teach science and support students to construct evidence-based claims. The interns' responsibilities included planning and enacting an entire unit. Some interns chose to design a science unit, giving these interns more opportunities to focus on the practice of supporting students to construct evidence-based claims.

Other Opportunities to Learn to Support Students to Construct Evidence-Based Claims during the Teacher Education Program. In addition to the specific courses described here, other courses throughout the program also connected to elements of supporting students to construct evidence-based claims, including planning for science lessons, providing explanations of content, and probing student thinking. For example, interns considered how to evaluate curriculum materials for teaching in the Teaching with Curriculum Materials Course. This class introduced the Lesson Planning Considerations. These Considerations were used throughout the program, including the Science Methods Course, to support the interns in adapting lessons plans for their classroom context (see Appendix G). The Children as Sensemakers II Course provided support for giving explanations of content that were accurate and appropriate. Although these learning experiences were less explicit in their connection to the teacher practice of supporting students to construct evidence-based claims of natural phenomena, they did lay foundational work for interns' abilities and knowledge for this practice.

Participants

The participants in this study included the interns in one cohort of an undergraduate elementary teacher education program who gave their consent for analyzing coursework for research purposes. There were 54 interns enrolled in this program, 53 women and one man. The interns had these teaching majors: 46% language arts, 18% mathematics, 7% social studies, 23% integrated science, and 7% fine arts. Of these interns, 15% had transferred from another institution before entering the teacher education program. The interns self-identified as white (86%), Hispanic (3.5%), black (3.5%), and two or more ethnicities/races (7%).

The participants were selected in part for their typicality (Stake, 2000). The majority of participants were white females who were traditional third- and fourth-year college students, which is typical of teachers in the U.S. population (National Center for Education Statistics, 2008). This cohort was also similar to other cohorts that have completed the same teacher education program. For example, the previous cohort had a similar proportion of men to women (2:50) and a similar proportion of interns who identified as white. However, as in every instance, these interns had distinctive experiences and backgrounds. These particulars enabled these cases to be telling of the possibilities that could occur in learning to teach elementary science (Stake, 2000).

A group of five interns from this cohort participated in a series of interviews and additional observations. Table 3-5 outlines the self-identified characteristics of these interns. The experiences of the five interns represent sub-cases in the larger case of the experiences of the entire cohort of interns. These sub-cases allowed a focus on the particular, and these participants are called focal interns throughout the dissertation. The five focal interns were purposively sampled on the basis of certain similar characteristics (Miles et al., 2014). Four of the five interns selected had a teaching major in science. Selecting interns with a teaching major in science points to interest in teaching science. This interest suggested that these interns may have had more potential to teach elementary science than their peers with other teaching majors. In addition, the interns with science majors had taken more university-level science content courses, suggesting they have substantive science content knowledge for teaching elementary students. The fifth focal intern showed an interest in teaching science during her student teaching, but she discussed her concern over her limited knowledge of science, making her an interesting comparison to the other cases. Using this sampling technique enabled me to consider the variation in learning the practice of supporting students' construction of evidence-based claims for interns with high interest in teaching science. Although the interns had certain similarities, they also brought their unique personal experiences, knowledge, and beliefs. For example, I selected interns with a range of experience at the university and in different placement contexts. This purposeful sampling should allow me to see what is possible for interns in the context of the teacher education program (Miles et al., 2014).

Table 3-5: Self-Identified Characteristics of the Focal Interns

Name	Mr. Cruise	Ms. Atkins	Ms. Kelly	Ms. Michaels	Ms. Schuster
Gender	Male	Female	Female	Female	Female
Race/Ethnicity	White	White	White	Asian-American	White
Major	Science	Science	ELA	Science	Science
Transfer Student	No	Yes	No	No	No
Grade of Student Teaching Placement	4	4	1	K	5

Study Methods

This longitudinal qualitative case study drew on multiple data sources (Merriam, 2009; Miles et al., 2014; Saldana, 2003; Stake, 2000). The collection of these data occurred over two academic school years, Year One (2012-2013) and Year Two (2013-2014). Table 3-6 provides an overview of the timeline for the data collection. The method of longitudinal qualitative case studies allowed for in-depth analysis of the changes in teaching practice and knowledge of interns over two years in the program. I used these methods to be able to describe the variation in the practice and knowledge of the interns at a specific time point and to consider how the practice and knowledge of individual interns changed over time.

Table 3-6: Timeline for Data Collection

Year	Time Point	Data Source
Year One	September	**Children as Sensemakers I Course** Week 1: Interview with a student Week 2: Read-aloud with a student Week 3-4: Interview with a student
	End of Winter Semester (April)	Survey
Year Two	September-October	Year Two Interview I
	October-December	**Science Methods Course** Week 1: Standardized Student Assessment Week 2: Lesson plan for Engage Element due Week 3: Peer teaching of Engage Element and reflection Week 4: Lesson Plan for experience element of Peer Teaching due Week 5: Peer teaching of Experience Element Week 6: Lesson plan for Explain with Evidence Peer Teaching due Turn in Experience-in-the-field Assignment Interview 2: Standardized Student Assessment Enactment Week 7: Peer teaching of Explain with Evidence Element and reflection Week 8: Turn in revised Peer Teaching lesson plan Week 9: Survey and Standardized Student Assessment Turn in Reflective Teaching Assignment Interview 3
	Winter Semester	Observations of Science Lessons with Focal Interns Interview 4
	End of Winter Semester (April)	Interview 5: Standardized Student Assessment Year Two Focus Group Interview 5

Data Collection and Sources

The data sources for this study included video-records of practice, lesson plans, interviews, surveys, and other class assignments. Most of the data for this study came from course assignments and assessments already used in the teacher education program, including surveys of teacher knowledge and views, video-records of enactments of class assignments, lesson plans for class assignments, and reflections and written work from class assignments. Interviews were conducted two to five times with the focal interns. I also observed the focal interns as they taught lessons during their student teaching semester, and I collected field notes and video-records of their practice. Table 3-7 provides an overview of these data sources.

Table 3-7: Overview of Data Sources for Study

Data Source	Time of Collection	Total Collected	Group for Analysis	Purpose of Data
Video-records of class assignments from Children as Sensemakers I	Fall 2012	10 video-records (2 per focal intern)	Focal interns	To describe interns' practice for supporting elementary students to construct evidence-based claims
Video-records of class assignments from Science Methods Course	Fall 2013	10 video-records (2 per focal intern)	Focal interns	To describe interns' practice for supporting elementary students to construct evidence-based claims
Survey of Beliefs, Knowledge of the Science Practice, and Science Knowledge for Teaching	Winter 2013, End of Science Methods in Fall 2013	~100 surveys (2 per intern)	All interns	To describe interns' change in knowledge of the science practice of constructing evidence-based claims; to describe interns' change in knowledge for supporting students to construct evidence-based claims
Lessons Plans from Peer Teaching and	Fall 2013	~300 lesson plans (4 per focal intern)	All interns	To describe interns' practice for planning for supporting students to construct evidence-based claims; to describe change in ability to construct evidence-based claims
Video-records and field notes from student teaching	Winter 2014	17 video-records of lessons	Focal interns	To describe interns' practice for supporting students to construct evidence-based claims
Standardized Student Assessment	September 2013, after Methods Course	8 interviews (1-2 per focal intern)	Focal interns	To describe interns' change in practice for supporting students to construct evidence-based claims; to describe change in ability to construct evidence-based claims
Interviews (4 main interviews)	Throughout 2013-2014	18 hours (2-5 interviews per focal intern)	Focal interns	To describe how interns' describe their learning of the teaching practice of supporting students to construct evidence-based claims over time; to describe interns' change in knowledge for the teaching practice of supporting student to construct evidence-based claims over time

Video-records of Enactments for Class Assignments. As part of class assignments for the Children as Sensemakers I and Science Methods Course, interns submitted videos of their enactment of approximations of practice involving supporting students to construct evidence-based claims for class assignments at their field placements. For approximations of practice in the Science Methods Course (e.g., Peer Teaching), I recorded the videos myself. Table 3-8 outlines the lesson assignments for which I collected video-records of enactments.

Table 3-8: Class Assignments Requiring Enactments of Practice and Reflections

Class Assignment	Frequency	Year and Course
Interview with a student	2	Year One, Children as Sensemakers
Interactive read-aloud	1	Year One, Children as Sensemakers
Peer Teaching	3	Year Two, Science Methods
Experience-in-the-field	1	Year Two, Science Methods
Reflective Teaching	1	Year Two, Science Methods

Year One. In Year One, the class assignments involving enactments of practice from the Children as Sensemakers I Course included "interviews with a student" and the "interactive read-aloud" assignments. The "interviews with a student" assignment involved eliciting student thinking about what makes day and night before and after an interactive read-aloud about the phenomenon. During the interview, an intern had a child describe his thinking aloud, write his thinking, and model his thinking. The "interactive read-aloud" assignment required interns to read a book about what makes day and night with the same children. During the read-aloud, interns modeled the phenomenon, enabling students to observe how sunlight might hit portions of Earth. Both the interviews and interactive read-aloud had protocols developed by the instructor to support the intern's moves.

Year Two. In Year Two, the interns engaged in three Peer Teaching enactments. These enactments were typically 15 to 30 minutes long. During the Peer Teachings, interns enacted portions of investigation-based science lesson with their peers and a teacher educator acting as elementary students. The student "role" required that colleagues act cognitively as if they were elementary students but not take on disruptive behaviors. Interns in the role of teacher were expected to use the teaching moves, representations, and language they would use with elementary students. Interns and teacher educators can pause the lesson to return to a particular spot or discuss a problem of practice. The intern and their colleagues acting as students discussed the enactment afterward with a teacher educator. Although I collected data for all three enactments of the Peer Teaching, I particularly focused on the "explain with evidence" Peer Teaching for analyzing what teaching moves, language, and representations interns use in supporting elementary students to construct evidence-based claims. (See Appendix E for a description of the assignment.)

In Year Two, interns also completed the Reflective Teaching assignment, which required interns to plan, teach, and reflect on an entire science lesson involving an investigation. Interns selected a lesson from already existing curriculum with their mentor teacher. Interns were required to video-record their lessons, which allowed me to consider their enactment of the practice of supporting elementary students to construct evidence-based claims. (See Appendix F for a description of the assignment.) Because the interns selected lessons based on the school curriculum and needs of the students in their placement classroom, these lessons covered a range of topics, data analysis, and evidence-based claims (see Appendix F for a summary of the Reflective Teaching Lesson of the Focal Interns).

Lesson Plans for Class Assignments in Year 2. In Year 2, during the Science Methods Course, interns turned in their lesson plans for class assignments. When creating lesson plans, interns analyzed lessons from existing materials using criteria from the teacher education program. Then, interns used a template from the teacher education program modified by the instructors for science lessons. This template is called the "Instructional Planning Template for science." This template includes a place for interns to write their investigation question and proposed evidence-based claim for the investigation. The template also provides specific space for interns to identify learning goals, possible alternative ideas, assessments, and the instructional sequence for each of the three elements from the EEE framework (see Appendix I). Interns completed this template while co-planning for their Peer Teaching, and they turned in a version of the plan before each Peer Teaching. The interns also turned in a revised Peer Teaching lesson plan after having completed all of the Peer Teachings. A version of the Instructional Planning Template was required for the Experience-in-the-field and Reflective Teaching assignments. Table 3-9 provides a complete list of the required lesson plans.

Table 3-9: Lesson Plans for Science Methods Course Assignments from Year 2, and Their Timing

Week Due	Lesson Plan
3	Initial Sketch of Peer Teaching Lesson and Engage Element
5	Experience Element of Peer Teaching Lesson
6	Experience-in-the-field Lesson
7	Entire Peer Teaching Lesson
8	Revised Peer Teaching Lesson with Assessment Plan
End of Semester	Reflective Teaching

Surveys. Interns completed a survey about their knowledge and views for teaching science at the end of the first year in the program and after the Science Methods Course. This survey was part of the assessments used by the teacher education program. The survey included a set of questions about interns' knowledge for teaching science (see Appendix J). This survey's questions required interns to describe science practices and how and why to support students in these practices. For example, an item following a scenario describing constructing evidence-based claims in an elementary classroom asks interns to "Name two challenges that upper elementary grade students may face in constructing an evidence-based claim about these data." A question also asked interns to make an evidence-based claim about a set of data and how they would represent these data. Another item focused on how interns would support students in the practice of constructing evidence-based claims in the context of elementary classrooms. Other items asked interns to construct an evidence-based claim about a set of data. I used this survey to learn more understanding about interns' knowledge for the teaching practice of supporting students to construct evidence-based claims.

Assessment. Interns engaged in an assessment of their ability to plan for and support elementary students in constructing evidence-based claims. This assessment was considered a "standardized student" assessment because interns engaged an adult acting as a student in constructing an evidence-based claim (Appendix K). This adult had a protocol of behaviors, responses, and lines of thought to use in interacting with the interns (Boerst, Ball, Shaughnessy, Sleep, & Lai, 2012; Sleep & Boerst, 2012). Interns were given a scenario about teaching students to construct evidence-based claims including the data collected and student work from an "investigation" in an elementary class. All 54 interns in the cohort planned how they would support students to make sense of the data in order to answer the investigation question posed. The entire cohort completed this portion of the assessment at the beginning and at the end of the Science Methods Course. This acted as pre-assessment and post-assessment for the course.

After completing the planning, the focal interns worked with the "standardized student" to construct an evidence-based claim. They could ask questions, write representations, and have the student write down their thoughts. After the interaction with the standardized student, interns answered questions about the teaching moves they made and their rationale for their choices. The focal interns interacted with a "standardized student" around this protocol at the beginning of the Science Methods Course and at the end of the year. These interactions with a "standardized student" occurred for the focal interns at the beginning of the Science Methods Course and at the end of the year. This data source allowed me to analyze interns' teaching practice in planning for and supporting students to construct evidence-based claims in a less complex, more standardized setting than an elementary classroom.

Observations during Student Teaching. I observed three to five enactments of science lessons involving investigations during the student teaching of four of the five focal interns. (The fifth intern, Ms. Schuster, did not teach science during student teaching). I video-recorded these lessons and took field notes describing the teaching moves of the intern and any discourse I could record from student responses. I collected any intern-created material from the science lessons. These observations enabled me to describe the interns' practice for supporting students to construct evidence-based claims without the support of the courses. The lessons during student teaching included a range of science content, data analysis, and evidence-based claims. See Appendix H for a summary of each of these lessons for the five focal interns.

Interviews. Researchers interviewed the focal interns five times during Year Two. The first interview occurred at the beginning of the school year before interns began the science course or within the first week of the course. The second interview occurred during the middle of fall semester. The third interview was conducted at the end of the Science Methods Course. The final interview was conducted at the end of the winter semester. The interviews lasted between 45 minutes and an hour. The interviews were transcribed before analysis.

These interviews had a semi-structured format with sample questions to be used to probe the interns' thinking. I asked additional questions for clarification or to follow up on an idea or line of thinking (Weiss, 1994). (See Appendix L for the interview guide.) I designed the interview questions to probe deeper into interns' knowledge for supporting students to construct evidence-based claims. For this purpose, a set of questions asked interns to describe practices that they would use in supporting students to do this work and why the intern would use these practices. To more closely understand interns' thinking, a set of interview questions were specific to particular time points when interns might engage in supporting the construction of evidence-based claims.

The interviews' purpose was to capture how interns describe their learning of supporting elementary students to construct evidence-based claims. All the interviews included a set of questions asking about the interns' learning over time in the teacher education programs. In addition, individual interviews were designed to ask about learning in the specific courses and experiences that are a focus of this study.

Other Course Materials. I collected other course materials from the Children as Sensemakers I Course and Science Methods Course relevant to the study, such as syllabi, in-class work, reflections on assignments, and representations of practice used in class. I used these materials to support the findings of other data collected.

Data Coding and Analysis

To answer research question 1, which focused on how the interns' knowledge and teaching practice for supporting elementary students to construct evidence-based claims change over time, I characterized the interns' lesson plans, video-records, and assignments to describe changes in their teaching practice and corresponding knowledge for supporting elementary students to construct evidence-based claims about natural phenomena. To answer research question 2, which focused on how the interns described the change in their knowledge and teaching practice for supporting elementary students to construct evidence-based claims, I characterized how the interns describe their learning of the knowledge and practice on the basis of emergent themes from their interviews. This section describes the coding schemes and analyses used to answer the research questions.

Question 1 Analysis. To answer research question 1 - "How did the interns' teaching practice and corresponding knowledge for supporting elementary students to construct evidence-based claims about natural phenomena change over time?" - I used two main coding schemes. The first coding scheme characterized the teaching moves used for supporting learning to construct evidence-based claims that interns included in their lesson plans and used in their interactions with students. The second coding scheme considered the quality of the lesson or interaction with students. I also characterized interns' science knowledge for teaching as represented in their surveys and assignments throughout the program.

Coding Scheme for Describing Teaching Moves. I developed a set of coding schemes for describing the teaching moves that interns used to support their students in constructing evidence-based claims in science (see Table 3-10, Table 3-11, and Table 3-12). These coding schemes were based on examples in the literature (e.g., Erduran et al., 2004; Lizotte et al., 2004; McNeill, 2009, 2011; Zembal-Saul et al., 2013). Teaching moves described in the literature that resulted in missed opportunities for supporting students in engaging in the practice (e.g., lowering the cognitive demand through closed-ended questions) were also included in this coding scheme (McNeill, 2009; Stein et al., 1996; Zangori & Forbes, 2013). I also added other emergent codes to the coding scheme on the basis of patterns seen in the lesson plans and enactments. For example, I added the code "Only considers portions of the data" because I saw several examples where interns did not support students to consider all of the data when making claims.

Table 3-10: Coding Scheme for Teaching Moves That Support Students in Learning to Analyze the Data to Reveal Patterns and Relationships

Codes	Definition	Examples
Analyze the data to reveal patterns and relationships	The intern supports students to identify patterns/relationships in the data	Asks students what patterns they see in the data; checks for students understanding; uses representations to show patterns in the data; underscores the patterns in a representation
Highlight implicit features of representations	The intern highlights the features of a representation that may not be explicit for students through asking questions of students or pointing them out as the learners work	Points out difficult aspects of a representation (e.g., axes, perspective); highlights differences among representations, (e.g., a physical model vs. a paper model); calls attention to the units in the representation; provides rationale for the representation
Make connections between representations and investigation	The intern makes connections between the investigation question, how the data were collected, the data collected, and the representation	Reminds students of investigation question; asks about how the data were collected; has students pull out their data; asks where pieces of the data are in their representation
Provide rationale for justifying one's claim with the evidence	The intern provides a rationale for justifying one's thinking, describing the need for accurate and sufficient evidence	Discusses the need for accurate and sufficient data to support claims; discusses the need to include all data collected in their claims
Require students to justify their thinking	The intern requires students to think about justifying their thinking	Discusses whether evidence collected is appropriate and sufficient; discusses the need to include all data collected in their claims
Probe student thinking	The intern asks the students to share more of their thinking	Asks students to share thinking about what happened after investigation is completed, asks why; asks what makes them think that

Table 3-11: Coding Scheme for Teaching Moves That Support Students to Make Claims Justified by Evidence and Reasoning

Code	Description	Examples
Considers alternative claims	The intern poses an alternative claim for the data or allows students to offer alternative claims.	Asks if other students disagree with a claim provided; suggests a possible alternative claim for the data; allows students to share other interpretations of the data
Provides structure with rationale	The intern describes the parts of an evidence-based claim and gives a rationale for including elements.	Describes what a claim is and provides rationale for claim; describes what evidence is and provides rationale for evidence
Uses supports for structure	The intern uses a set of supports for using the structure of evidence-based claims.	Provides sentences frames; provides verbal reminders; allows students to work in pairs/groups
Supports to make claims	The intern supports students to make and share evidence-based claims.	Students verbally share claims; students write claims; intern probes for evidence
Provides feedback for claims	The intern provides students with informal or formal feedback about their claims.	Praises claim in whole-class setting; comments on claim to individual; writes comments on claim
Connects to prior knowledge	The intern connects the construction of evidence-based claims to students' prior knowledge.	Discusses students' prior knowledge or experiences; reminds students of their experience in investigation/question; compares predictions to claim
Connects to reasoning/scientific principle	The intern connects the claim to reasoning or larger scientific principles.	Discusses connections to other principles from the class; describes what the larger principle is; connects larger principle to everyday phenomena
Supports students to connect ideas	The intern supports students to add to or build onto one another's ideas	Discusses claims as whole group; Asks students if they agree or want to add on
Extends to another situation	The intern has students answer another question connected to the claim.	Gives the students a different example to think about; Asks students to answer a written follow-up question

Table 3-12: Coding Scheme for Missed Opportunities for Supporting Students to Construct Evidence-Based Claims

Codes	Definition	Examples
Does not consider alternative claims	The intern does not attend to alternative offered by students	Tells a student their claim is not correct Gives space for only one claim to be shared
Ignores inconsistencies in the data	The intern ignores inconsistencies in the data	Gives student different data rather than discussing inconsistency Changes the data
Asks a closed-ended question that limits the reasoning and thinking required by the student	The intern uses only closed-ended questions that provide students with the thinking rather than requiring students to do this work	Uses closed-ended question that shuts down student thinking by giving away the reasoning Asks leading questions that seem to have only one answer
Does the intellectual work for justifying claims with evidence and reasoning.	The intern tells the student the evidence or reasoning rather than having the student do this work	The teacher states the claim rather than asking; teacher states evidence rather than asking
Does the intellectual work in analyzing the data	The intern reveals the pattern or gives the justification for a student's thinking when the student could do this work	Does the mathematical work of finding the pattern when the student could do this Makes connections rather than supporting students to do this work
Encourages confusing ideas	The intern encourages a confusing idea about the content or practice	Asks a closed-end, leading question that includes an alternative idea Tells students they are correct when they give an alternative idea

To apply these coding schemes to the lesson plans, I divided the instructional sequence of the lesson plans into steps, usually a new bullet in the lesson. For each step, I coded for the presence or absence of a teaching move or missed opportunity. For example, an intern's lesson plan might include a step where the teacher asks the other students in the class if they agree with what is said; this step is coded as "supports students to connect ideas." To apply these same coding schemes to the interns' enactments of lessons, I divided the videos into two-minute segments drawing on Borko and colleagues' (2008) discussion that this length of time enabled analysis of teaching practices. Using partial-interval time sampling, I coded each two-minute segment for the presence or absence of each teaching move or missed opportunity.

Coding Scheme for Quality of Support. In addition to describing the types of teaching moves the interns used, I also developed coding schemes for the quality of support provided to students in constructing evidence-based claims based on the literature and the expectations set forth in the program courses regarding this teaching practice. For example, the "meets expectations" codes for making claims justified by evidence and reasoning match the expectations outlined in the EEE framework, which were used to evaluate the interns' teaching during the course. These coding schemes considered three areas: science knowledge for teaching, support for analyzing data to reveal patterns and relationships, and support for making claims justified by evidence and reasoning (see Table 3-13, Table 3-14, Table 3-15). Each of the interns' lesson plans and enactments of lessons were coded with these schemes holistically. In this case, I considered both the strengths and challenges of each lesson in terms of supporting students to construct evidence-based claims.

Table 3-13: Coding Scheme for Considering the Quality of Science Knowledge for Teaching

Code	Possible Teaching Moves Interns Use
Exceeds expectations	• Discusses the "big idea" or mechanism thoroughly • Presents all content accurately • Clarifies confusing items of content • Connects content to everyday experiences
Meets expectations	• Presents all content accurately • Mentions "big idea" or mechanism • Does not use problematic terms
Partially meets expectations	• Does not mention big idea or mechanism • Uses problematic terms • Presents content fairly accurately
Does not meet expectations	• Uses inaccurate descriptions to explain scientific phenomenon

Table 3-14: Coding Scheme for Quality of Support for Analyzing the Data to Reveal Patterns and Relationships

Code	Possible moves of the intern
Exceeds expectations	• Engages students in the intellectual work • Engages students in the creation and use of a representation that supports students to analyze the data to reveal patterns and relationships that answer the investigation question • Draws on data that is representative of all the data • Uses a representation that is well labeled and easy to follow • Supports the students to see why and how the representation fits the data • Makes implicit parts of the representation explicit • Acknowledges and discusses anomalous data
Meets expectations	• Engages students in the intellectual work. • Engages the students in creating the representation (teacher can do the writing or students can do it on their own) • Uses a representation that supports students to identify a pattern/relationship or see something that is "invisible" about the phenomenon
Partially meets expectations	• Engages students somewhat in intellectual work • Selectively chooses data to fit the pattern they want to see • Discusses a clear pattern or relationship related to the goal of the lesson, but representation that would be useful is not provided • Provides a representation with patterns and does not make clear how representation was created, but uses representation to support student thinking
Does not meet expectations	• Does not engage students in the intellectual work • Tells students answers • Uses a representation that is confusing for the student (obvious from classroom interactions that the student cannot follow) • Uses a representation that neither supports the student to see patterns in the data nor supports the student to see something that is "invisible" about the phenomenon • Does not provide a representation or a discussion of patterns

Table 3-15: Coding Scheme for Considering the Quality of Support for Constructing an Evidence-Based Claim

Code	Possible Teaching Moves of the Intern
Exceeds expectations	• Supports the students to make an accurate claim that addresses the investigation question • Supports students to identify evidence/reasoning for claim based on all relevant data (e.g., a pattern is identified from the three groups) • Discusses with students the mechanism of the phenomenon (e.g., where the salt "goes") • Supports students to evaluate on the basis of the evidence and reasoning
Meets expectations	• Supports the students to make an accurate claim that addresses the investigation question • Supports students to connect evidence to the claim • Discusses one piece of evidence and one piece of reasoning or multiple pieces of evidence to support claim
Partially meets expectations	• Supports students to make an accurate claim (this claim may not address the investigation question directly or include all of the data) • Supports claim with one piece of data or one piece of reasoning • Does the intellectual work for the students by naming pieces of the evidence or reasoning • Asks closed-ended questions
Does not meet expectations	• Does the intellectual work for the student by telling the answer • Does not check for understanding • Identifies an inaccurate claim or does not connect claim to evidence

Coding for Science Knowledge for Teaching. In considering each intern's science knowledge for teaching, I looked at their science content knowledge and their pedagogical content knowledge. To describe the interns' science content knowledge, I focused on their ability to construct accurate evidence-based claims by coding the evidence-based claims they wrote on assignments and surveys using the coding scheme in Table 3-16. Based on McNeill and Krajcik (2012)'s coding scheme, each evidence-based claim was coded for the quality of the claim, evidence, and reasoning.

Table 3-16: Coding Scheme for Interns' Evidence-Based Claims from McNeill & Krajcik (2012)

	Claim	Evidence	Reasoning
1	Does not make claim, or makes inaccurate claim.	Does not provide evidence, or only provides inappropriate evidence (that does not support claim).	Does not provide reasoning, or only provides inappropriate reasoning.
2	Makes an accurate but incomplete claim.	Provides appropriate but insufficient evidence to support claim. May include some inappropriate evidence.	Provides reasoning that connects the evidence to the claim. May include some scientific principles or justification, but it is not sufficient.
3	Makes an accurate and complete claim.	Provides appropriate and sufficient evidence to support claim.	Provides reasoning that connects the evidence to the claim. Includes appropriate and sufficient scientific principles to explain why the evidence supports the claim.

Four questions from the end of year one survey were coded using an open coding scheme to characterize the interns' pedagogical content knowledge for teaching connected to the focus teaching practice. I developed the codes on the basis of categories from the research base (e.g., McNeill, 2009; Wu & Krajcik, 2006; Zembal-Saul et al., 2013) and added emergent codes from the answers on the survey. The coding unit was a response from an intern on the survey.

Inter-Rater Reliability. To ensure trustworthiness of the claims, a second researcher coded 10% of the data using the coding schemes. For the teaching moves scheme, the two coders reached an inter-rater reliability of greater than 90% agreement. For the quality coding schemes, the two coders reached a Cohen's Kappa of greater than .65 on all three schemes. This magnitude suggests substantial agreement. In each case of disagreement, the researchers discussed and came to agreement.

Analyses for Research Question 1. Drawing on the multiple analyses of the interns' lesson plans, enactments, surveys, and assignments, I considered change over time for the entire cohort during the program. For the entire cohort, I analyzed how each of the subpractices and science knowledge for teaching changed separately, and then I looked for similarities across these areas. At each stage of identifying patterns, I also considered disconfirming evidence that existed (Maxwell, 2005). Throughout the coding and analyses, I wrote analytical memos to help clarify and consolidate my thinking about the findings (Merriam, 2009).

To describe the change over time for the entire cohort in the subpractice of supporting students to analyze the data to reveal patterns and relationships, I aggregated the coding of teaching moves used in the focal interns' enactments and the entire cohorts' lesson plans connected to this subpractice for each time point (e.g., during Children as Sensemakers, for the Reflective Teaching assignment). I also aggregated the coding of quality for supporting students to analyze the data to reveal patterns and relationships for these same data sources for the same time points. Then, for each time point, I compared these aggregations to see if patterns arose in the strengths or weaknesses of the support that the interns provided or planned to provide students for analyzing data to reveal patterns and relationships. I also considered my written memos and any survey data or assessment data that existed at the particular time point.

I then entered this information into a matrix (Miles et al., 2014) to see if change occurred over time in the strengths and weaknesses of support provided by the interns. This matrix allowed me to see areas of growth and stagnation in the interns' practice over time. I used a similar strategy for the subpractice of supporting students to make a claim justified by evidence and reasoning and for the science knowledge for teaching of the entire cohort.

In considering the changes over time for the focal interns, I developed a set of matrices that were similar to ones created for the entire cohort to look for their strengths, struggles, and growth over time. For example, I aggregated teaching moves used and quality of their enactments at each of three time points: before the Science Methods Course, during the Science Methods Course, and during student teaching. I entered these aggregations into a matrix. Through this matrix and using my analytical memos, I developed representations of each intern's practice at particular time points in the program. Then, I placed these representations next to each other to see the changes over time of each intern as well as their areas of strength and struggle. In analyzing the trajectory of each focal intern, I also drew on the analyses of the interview data described in the subsequent section.

Coding and Analyses for Research Question 2. Research Question 2 focuses on the interns' understanding of their knowledge and practice, requiring the researcher to look at the data from the participant's perspective rather than from the outside. I coded the interviewees' own descriptions of changes in their knowledge and ability by taking on an emic perspective. Therefore, rather than having a set of planned codes (with the possibility of adding emergent codes) as planned for the other research question, I looked for patterns in the interns' responses, allowing the identification of emergent codes. To do this, I first identified chunks of the interviews in which interns described the change in their practice or knowledge for supporting students to construct evidence-based claims. I broke these chunks into meaning units, usually a question and response. Then I jotted down initial thoughts to summarize what the interns might be suggesting in each meaning unit. Then I looked for patterns in these initial jottings to identify emergent codes (Weiss, 1994).

From the open coding, I identified four sets of themes around the research question, "How do interns describe how and why their teaching practice and corresponding knowledge for supporting students to construct evidence-based claims changed over time?" These four themes included (a) change in knowledge, (b) change in teaching practice, (c) why the change occurred, and (d) to what the intern attributes the change. “Change in knowledge” refers to the interns describing how their knowledge has change since they started the program. “Change in teaching practice” marks how the interns describe how their practice (what they do in a classroom) has changed. “Why the change occurred” included to what the interns attributed the change in their learning. “Where the intern attributes the change” represents the location to which the intern attributes their learning. Table 3-17, Table 3-18, Table 3-19, and Table 3-20 describe the coding scheme related to these themes. I applied these codes to the transcripts to reveal patterns in individual’s description of their change in knowledge and ability (Weiss, 1994).

Table 3-17: Interview Coding Scheme for Theme of Change in Knowledge

Codes	Code Description	Example
Knowledge of students' thinking	Intern describes how they now have new knowledge about how children think or learn	I think I learned that [children] have so many different misconceptions, just based off what they see or what they think they see.
Knowledge of students' capabilities	Interns describe how they now have new knowledge about what children are able to do	Some of the videos we watched were actually from a first-grade class, and they were able to do it, so I was, "Okay. If they can do it, my kids can do it."
Knowledge of pedagogy (general education)	Intern describes how they now have new knowledge of how to support learning, such as in managing a class or lesson planning	I guess to be a lot more aware of… to knowing the type of direction that needs to be given to children, and how much
Knowledge of realities of classroom	Intern describes how they now have new knowledge of what occurs in elementary classrooms	Being in the program has exposed me to some of the realities that are in the classroom, just through being in the field. There are some aspects that I'm challenged by.
Knowledge of science	Intern describes how they now have new knowledge of the science content or practices	The first thing I learned is that [science is] actually really hard to understand. That concept is difficult.
Knowledge of teaching science	Intern describes how they now have new knowledge of how to teach science	Just knowing and understanding what good science teaching and practice looks like encourages me to [want to] do that in my own classroom.

Table 3-18: Interview Coding Scheme for Theme of Change in Practice

Codes	Code Description	Example
Probing student thinking	Intern describes that she would now ask additional questions about student thinking	That class really taught me how to probe children's thinking … like, "What made you think that?"
Managing a class	Intern describes that she would be better able to organize the materials and interactions in the classroom	I would not have had the management skills that I do now.
Supporting students to do the intellectual work	Intern describes how she would now push students to do the intellectual work rather than doing the work for the students	If you're engaging other things, have that discovery be an answer, as opposed to just telling you what's going on.
Using explicit language	Intern describes how she would use more explicit language in teaching students (e.g., using scientific terminology accurately)	There really are many terms that are used in everyday language that don't have the same meaning as what they do in science
Being more confident, comfortable, or flexible	Intern describes how she feels more confident, comfortable, or flexible when working with elementary children	I feel more confident and I feel like I can actually teach.
Planning	Intern describes how her ability to plan for supporting students in constructing evidence-based claims has improved	You have to make sure you're all planned out in your lesson. You're presenting in a way that the student can fully understand.
Scaffolding students	Intern describes how she has learned to scaffold learning for students.	With kids, there has to be a lot of scaffolding
Incorporating Claim-Evidence-Reasoning	Intern describes how she would incorporate the claim, evidence, and reasoning framework into teaching	To teach how to do claims with evidence in a low-pressure situation, which was then helpful
Making connections	Intern describes how she makes connections across concepts or lessons	Constantly be drawing connections, like what concept are we talking about?

Table 3-19: Interview Coding Scheme for Theme of Why the Change Occurred

Codes	Code Description	Example
Discussion in class	The intern attributes her learning to the discussions that occurred in class.	Before I took this science course, I didn't really even know what claims with evidence was 'cause I don't remember doing that in school at all. We extensively talked about it in the class.
Approximations of practice	The intern attributes her learning to the work he did for approximations of practice.	[Peer Teaching] was helpful because it happened in an environment where it was totally fine. Then I was, "Okay. I planned for this one, but it wasn't enough."
Decomposition of practice	The intern attributes her learning to decomposing the elements of the practice.	Really picking that thinking apart, and [the] thinking [that] happens in planning lesson plans
Representation of practice	The intern attributes her learning to the representations of practice, such as videos or lesson plans.	Just some of the videos, seeing how the teachers analyze the data, I thought it was helpful.
Reflections on teaching	The intern attributes her learning to how she reflected on her own teaching.	We got to analyze what we were doing and in the beginning it was almost like miserable watching yourself. It's like, "Oh my gosh, what am I doing? This is terrible." Then that started making us think about what we were doing in the field, and just learning from those experiences that when we did change, we got better results.
Interactions with students	The intern attributes her learning to the interactions she had with elementary children	I just got to talk to kids and listen to what they had to say.

Table 3-20: Interview Coding Scheme for Theme of Where the Intern Attributes the Change

Codes	Code Description	Examples
Course in the program	Interns attribute their learning to courses in the program	Science methods, math methods, Children as Sensemakers
Other experiences as a student	Interns attribute their learning to other experiences as a student	University science course, high school science course
Experiences in the field	Interns attribute their learning to experiences in the field	Field placement, watching the mentor teacher teach
Other experiences with elementary children	Interns attribute their learning to other experiences with elementary children	Baby-sitting, substitute teaching, camp counselor

After applying the coding schemes to the identified meaning units from the interns' interviews, I compiled the coding for each intern into a single matrix. I looked for similarities and differences in the coding for each intern to see common patterns as well as possible areas of new growth over the program. This allowed me to name themes that emerged for each intern in how they described the change in their knowledge and practice over time (Merriam, 2009; Weiss, 1994). Then I considered how these themes match or did not match what I found in the coding of the lesson plans and enactments of lesson in order to develop a more complete picture of each intern's trajectory.

Conclusion

This chapter described the research context, participants, and methodological approach used in this study. This study used a longitudinal qualitative case-study design to investigate the change in the interns' practice and corresponding knowledge for supporting elementary students to construct evidence-based claims of natural phenomena over the course of a two-year practice-based teacher education program. To code the data, I developed coding schemes for lesson plans and enactments of lessons in elementary classrooms, as well as other course assignments and surveys based on the literature and on emergent codes. I also drew on the interviews with five focal interns to answer the research questions and triangulate the findings.

The next four chapters present the results of my analyses. Chapters 4, 5, and 6 consider the change over time for the entire cohort as seen in the lesson plans, assessments, surveys, and video-records of practice. In Chapter 4, I focus on the subpractice of supporting students to analyze the data to reveal patterns and relationships. That chapter looks at the strengths and struggles of the interns for this subpractice at particular time points, and then it considers how these strengths and struggles change over the two years in the program. Mirroring Chapter 4 in structure, Chapter 5 focuses on the change in subpractice of supporting students to make claims justified by evidence and reasoning for the entire cohort. Similarly, Chapter 6 considers the change in the entire cohort's science knowledge for teaching associated with constructing evidence-based claims of natural phenomena. Chapter 7 describes the trajectory of each focal intern in the teaching practice of supporting students to construct evidence-based claims by considering the analyses of the two subpractices and science knowledge for teaching along with the themes that emerged from the interviews. Chapter 7 ends by considering the similarities and differences among the trajectories of the focal interns.

CHAPTER 4

SUPPORTING ELEMENTARY CHILDREN TO ANALYZE THE DATA TO REVEAL PATTERNS AND RELATIONSHIPS

In this chapter, I discuss the interns' support for elementary children to analyze the data to reveal patterns and relationships and justify and share their thinking about these patterns across the program. This subpractice entails supporting students to organize the data that they collected and to interpret the organized data to identify patterns and relationships. It also includes facilitating students to share their ideas about the patterns and justify why they think they see these patterns in the data.

The analyses of the lesson plans, assignments, assessments, surveys, and enactments of lessons suggested that, over the two years in the program, the interns showed growth in their ability to support students to analyze the data to reveal patterns and relationships. However, the interns varied in their planning for and enactment of this practice. In the first month of the program, during the Children as Sensemakers I Course, the focal interns were able to support student in analyzing a representation to make sense of a natural phenomenon, yet some interns struggled in probing students' thinking. During the Science Methods Course in the fall of the second year, the interns typically planned for and enacted high-quality support for students to analyze data and share their thinking, especially on the Peer Teaching Assignment. During student teaching, consistencies arose in each focal intern's support for analyzing data to reveal patterns and relationships across the lessons they taught. In this section, I describe the interns' support for this subpractice during year one of the program, during the Science Methods Course, and during student teaching. The chapter ends with a discussion of the changes seen across these time points.

Before Science Methods: Beginning to Support Students to Analyze the Data and Share Thinking

During the first year in the program, the interns typically showed potential in their ability to use representations to facilitate student thinking. Some of the interns seemed to develop their practice in probing student thinking and requiring children to do the intellectual work, yet the interns varied in developing representations that would support student understanding of how to analyze data to reveal patterns and relationships.

Children as Sensemakers I Enactment: Supporting Students with Representations

During their read-aloud with a lower-elementary child in their Children as Sensemakers I Course, all five of the focal interns worked to make explicit implicit elements of the representations in the book and to make connections across representations. For this assignment, the interns used a protocol that called for helping students to understand the representations (see Chapter 2 for a more complete description). The interns showed fluency in incorporating these teaching moves into their interactions with the children. In addition, the interns tended to probe students' thinking. However, they struggled in other ways. For example, some of the interns tended to do aspects of the intellectual work for the students. Nonetheless, four of the five interns also supported the children to do the intellectual work of naming the pattern revealed through the representations and received a score of "meets expectations" in the quality of support for analyzing the data to reveal patterns and relationships.

The interns made explicit the implicit elements of the representations during their read-aloud of the book *What makes day and night* in multiple ways. When looking at a representation, Ms. Atkin asked the child she worked with, “Can you tell me where you think the sun would be?” The child pointed out the appropriate location of the sun [A_CaSM_Reading]. Ms. Kelly asked the child she worked with a similar question: “Where is the sun coming from?” [K_CaSM_Reading]. This work facilitated the child’s understanding of this representation through identifying an implicit feature of the representation, given that the sun is not represented in the picture. In this same representation, Mr. Cruise made it clear they were looking at the representation from the angle of the North Pole, asking, “Where would the North Pole be?” [C_CaSM_Reading].

In addition to working with representations in the book, the interns used a physical model to support student understanding: a Play-Doh ball (representing Earth) placed on a pencil, and a flashlight (representing the sun). The interns also made implicit features of this model more explicit. For example, Ms. Michaels pointed out that “the pencil just enables us to spin our model.” Ms. Schuster consistently made it clear that the toothpicks inserted into Earth represented people [S_CaSM_Reading]. All of the focal interns worked to name what the Play-Doh and flashlight represented when discussing the model with their students.

The interns also supported students to make connections across the representations (e.g., the diagram representations in the book and the model) in order to make sense of the patterns described in the text. Interns oriented their students to see how the model and the diagram in the text were related. After reading that the reader was looking at the picture in the book from high above the North Pole, Ms. Schuster asked, “Where would we be if we were high above the North Pole [in the model]?” The child responded by pointing above the “North Pole” of the model [S_CaSM_Reading]. The interns also had the students use their model to make it look like the diagram in the text. Ms. Kelly held the model in a particular way and asked, "Which picture do you think this one is?" The student was able to identify the appropriate diagram in the book [K_CaSM_Reading].

Most of the interns used the representations in the book and the model to support students to notice the pattern that as Earth turns, day and night occur. Ms. Kelly, Mr. Cruise, Ms. Schuster, and Ms. Atkin facilitated their students to describe that as Earth spun, the people in the representations moved in and out of the sunlight, going from day to night and back again. For example, Ms. Atkin's student held the pencil and spun the Play-Doh ball, showing how the people went "from day to night and then … day again" [A_CaSM_Reading]. However, unlike the four other interns, Ms. Michaels described and showed the pattern to the student she worked with without engaging the student in the intellectual work. Ms. Michaels turned the model for the student she worked with and said, "Sunrise, and then we're at day, and then, [night]" [M_CaSM_Reading]. In this interaction, Ms. Michaels seemed to allow the student she worked with to sit patiently while she described what was going on and used the materials. Like Ms. Michaels, Ms. Atkin also did aspects of the intellectual work for her student by describing how Earth spun to cause day and night, without allowing the student to share her thinking about the phenomenon afterward.

Four of the five focal interns also asked follow-up questions that allowed them to probe their students' thinking about the patterns they discussed. Mr. Cruise followed up with the question, "Where do you think we live?" when the child commented that he did not think we lived on the "dirt" or "brown stuff" in the picture of Earth [C_CaSM_Reading]. Ms. Atkin asked, "Why did you pick that one?" when the child pointed out which picture represented daytime [A_CaSM_Reading]. When the child said, “It’s nighttime,” Ms. Schuster probed with a question, “Why?” [S_CaSM_Reading]. Ms. Michaels asked, “Where [is the sun]?” when the child said that she could see the sun in the picture [M_CaSM_Reading]. However, sometimes the questions that the interns asked were closed-ended questions that may not require the children to share more of their thinking. Examples of these questions included, “Which picture represents daytime?” [S_CaSM_Reading] and “Is it nighttime, now?” [M_CaSM_Reading], but the interns did not ask the students to give reasoning for why the picture represented daytime or nighttime. These questions do not require students to share their reasoning or to do the intellectual work involved in considering the pattern involved in the phenomenon.

In conclusion, the focal interns showed several strengths in their ability to support students with representations to consider the patterns involved in the phenomenon of what makes day and night. As shown in Table 4-1, all of the focal interns made implicit features of the representations they used more explicit for their students and connected the different representations they used to each other. The interns also tended to probe their students’ thinking by asking follow-up questions, yet the questions they asked often did not elicit the entirety of the children’s reasoning. Moreover, one intern (Ms. Michaels) did most of the work of explaining what was going on in the representations, preventing the student from having the opportunity for sense making; she received a score of "partially meets expectations" for the quality of support for analyzing the data to reveal patterns and relationships.

Table 4-1: Teaching Moves Used and Quality for Supporting Students to Analyze the Data to Reveal Patterns and Relationships during Children as Sensemakers Read-Aloud

	Ms. Kelly	Ms. Atkin	Mr. Cruise	Ms. Michaels	Ms. Schuster
Makes implicit features of the representation clear	X	X	X	X	X
Connects representations to each other	X	X	X	X	X
Supports the child to analyze and interpret the data	X	X	X		X
Probes student thinking		X	X	X	X
Does not do the intellectual work involved in analyzing and interpreting the data	X		X		X
Does not ask leading question that provides the reasoning				X	X
Quality in terms of the expectation	Meets	Meets	Meets	Partial	Meets

End of Year One Survey: Emerging Knowledge for Supporting Students to Analyze the Data to Reveal Patterns and Relationships

After the Children as Sensemakers I class, interns experienced the rest of the first year of the program, including two literacy methods courses, a Social Students Methods Course, and a second Children as Sensemakers Course situated in mathematics, as well as other coursework and fieldwork. At the end of that year, they took a survey that explored their science knowledge for teaching, including a question about challenges that elementary students might have in analyzing data. This end of year one survey suggested that, typically, the cohort of interns had knowledge about supporting students in making and using representations to analyze data. As seen in Table 4-2, most interns were able to name challenges that elementary students may face in constructing a graph and analyzing data when shown data collected by a class. More than 95% of the challenges named focused on the complexity of selecting a representation, constructing the representation, using multiple data sources, and reading or interpreting the representation. The interns named ways to help students with these challenges, including teaching moves such as modeling how to interpret a graph or providing supports to scaffold students in the work.

Table 4-2: Common Types of Responses to the Question: "Name Two Challenges That Upper Elementary Students May Face in Constructing a Graph and Analyzing the Data."

Type	Percent of responses	Examples
Constructing the graph (including labeling the axes; an appropriate scale)	58%	• Upper elementary students may face the challenge of drawing the scale on the graphs incorrectly, which would lead them to incorrectly analyze the data. [Response 27]
Using multiple sets of data on the same representation	15%	• They may not know that when using bar graphs, they should put the two things they are comparing (larva and pupa) together for the same category (average depth). [Response 74]
Deciding on a representation	9%	• Students might struggle trying to decide which type of graph to use. They might not know that the different types of graphs serve different purposes. [Response 96]
Reading/interpreting the representation	13%	• Reading the graph correctly to analyze the data. [Response 93]
Other	5%	• Fine motor skills may skew or distort the data. [Response 37] • Understanding measurements; the use of standard versus metric. [Response 6]

Table 4-3 lists the common types of teaching moves that interns listed to help students with the challenges. As seen in the table, modeling how and providing an explanation were the most common moves that interns named. Interns named between 1 and 3 moves, with an average of 1.5 moves (standard deviation = 0.6) named per response. This end of year one survey suggests that interns were aware of challenges that students might have in analyzing data, and that they could describe moves to support students in this work. However, most interns named teaching moves focused on teacher explanation or modeling for students; these moves might cause an intern to do the intellectual work for students rather than allowing students to do the work themselves. This seems to be related to the challenges that interns had during the Children as Sensemakers Course, where interns did aspects of the intellectual work.

Table 4-3: Common Type of Responses to the Question: "How would you help students with the two challenges in constructing a graph and analyzing data that you named?"

Category	Percent of responses	Example
Model how for the students	52%	For constructing a graph, I might model how to do this first and then send students to work individually on their own graphs. [Response 40]
Explain how	40%	Discuss what the independent variable and dependent variable mean. [Response 30]
Add an additional mini-lesson	10%	We would have a mini lesson about how to create graphs. I would explain the important steps (such as choosing a graph type, determining which data to put on each axis, labeling) and show an example. [Response 31]
Scaffolding experiences	10%	Providing a range of experiences in creating graphs would be helpful, with scaffolding and a guided release of responsibility. [Response 2]

Pre-assessment Planning and Standardized Student Enactment: A Range in Supporting Students to Analyze the Data

After the first year of the program, interns returned in the fall for their second year and took their Science Methods Course. They completed a pre-assessment for this course in the first month of the second year in the program. On this assessment, the cohort's plans for and enactments of supporting a student to analyze the data to reveal patterns and relationships showed a range of teaching practice and knowledge. In both the plans and enactments, interns' work ranged from "does not meet expectations" to "exceeds expectations," suggesting the variation and the potential that interns had for this work.

Pre-assessment lesson plans. The pre-assessment plans of the entire cohort showed a range of quality for supporting students to analyze the data to reveal a pattern or relationship. All 54 interns completed this pre-assessment focused on the concept of conservation of mass, where a student is investigating that the mass of the solution is equal to the mass of the parts of the solution. The original plan did not include a representation that would facilitate finding the pattern in the data (e.g., a chart that shows the mass of the parts is equal to the mass of the solution). Thus, interns would need to plan for an additional representation to support students to see this pattern. On the pre-assessment, 43% of the interns' lesson plans "met or exceeded expectations" for supporting students in analyzing the data, 39% "partially met expectations," and 14% of the plans "did not meet expectations." Pre-assessments that "did not meet expectations" tended to propose telling students the pattern, or they did not plan for analyzing the data to reveal a pattern or relationship at all. Common struggles that led to "partially meeting expectations" included not planning for students to use a representation when one would be needed or using a confusing representation. For example, Intern 19 planned to have the student list the weight of only the solution but not the materials that made up the solution; this would not help the student see the pattern that the mass of the solution was equal to the mass of the materials. Another confusing representation included negative numbers, which could be difficult for an upper-elementary student to comprehend. Forty-three percent of interns did plan for supporting students to analyze the data to reveal a pattern or relationship through a clear representation such as a new chart, graph, or diagram. A few pre-assessments (18%) planned for students to identify patterns by using all of the data collected. These findings suggest that most interns were able to plan for students to analyze the data to reveal a pattern using a representation, yet the majority of the interns did not have a clear, complete plan for doing this work.

Despite their struggles in planning for finding the pattern, 94% of the pre-assessment plans included having students discuss the data from the investigation, suggesting that interns recognized the importance of supporting students to do the intellectual work involved in an investigation. In addition, just over half (53%) of the interns planned for helping students identify where the salt goes in the investigation, an implicit aspect of this phenomenon that is key to understanding the big idea of conservation of mass in the lesson. For example, Intern 10's work included the question to the student, "Where does the salt go?" as well as plans for the answer "dissolves/mixes, but adds weight" [PreA_10b]. This question explicitly addresses the common misconception that the salt disappears. Addressing this misconception would facilitate a student to identify the pattern that the weight of the materials equals the weight of the solution. Seventy percent of the interns also planned to ask follow-up questions to students to clarify or explicate their thinking, such as, "How much more?" [PreA_20b], "Which ones?" [PreA_43b], or "Why do you think so?" [PreA_46b]. These follow-up questions would enable a teacher to find out more about how the students were thinking about analyzing the data.

Pre-assessment enactments. As seen with the plans for the pre-assessment, which were characterized across all 54 interns, the five focal interns showed a range of enactments of these plans with a standardized student (i.e., an adult acting as a student). As seen in Table 4-4, the quality of supporting students to analyze the data to reveal patterns and relationships in the enactments ranged from "does not meet expectations" to "exceeds expectations." This variation was seen in the representations used, in how the interns supported students to do the intellectual work of discussing the data from the investigation, and in how the interns made explicit implicit features of the representation.

Table 4-4: Teaching Moves Used and Quality for Supporting Students to Analyze the Data to Reveal Patterns and Relationships during the Pre-assessment Standardized Student Enactment

	Ms. Kelly	Ms. Atkin	Mr. Cruise	Ms. Michaels	Ms. Schuster
Creates an additional representation to show the pattern	X	X	X	X	X
Amount of data considered	Portion	Portion	All	Portion	Portion
Makes explicit implicit features of the representation	More than one	Only one	More than one	More than one	More than one
Discusses the data in the investigation and connection to representations	By teacher	By student	By student	By teacher	By student
Supports the child(ren) to analyze and interpret the data		X	X	X	X
Probes student thinking	X	X	X	X	X
Does not do the intellectual work involved in analyzing and interpreting the data		X	X		X
Does not ask leading question that provides the reasoning	X		X	X	X
Quality in terms of the expectation	Does not meet	Partial	Exceeds	Meets	Meets

Each of the five focal interns created an additional representation in their interaction with the standardized student to reveal a pattern, yet the representations used during the enactment ranged in quality. For example, Ms. Schuster created a representation on an additional sheet to show that the amount of salt remained the same in the water and in the cup (see Figure 4-1). Ms. Kelly used a representation to show that the mass of materials before and after the investigation was the same by adding additional information on the data sheets. The representations used by Ms. Michaels and Mr. Cruise were similar to those used by Ms. Kelly and Ms. Schuster. Unlike the other focal interns, Ms. Atkin used negative numbers to reveal this pattern, using a representation that might be confusing for an elementary student [A_PreAssess]. Although all of the interns created these additional representations, often the representations represented only a portion of the data collected in the investigation. Ms. Atkin's, Ms. Schuster's, Ms. Kelly's, and Ms. Michaels' representations considered only one group's data. However, Mr. Cruise used a representation that considered all of the data from all of the groups. Using all of the data might provide the opportunity for the student to see that the pattern of conservation of mass is consistent throughout the investigation and better illustrates how scientists use multiple trials in experiments.

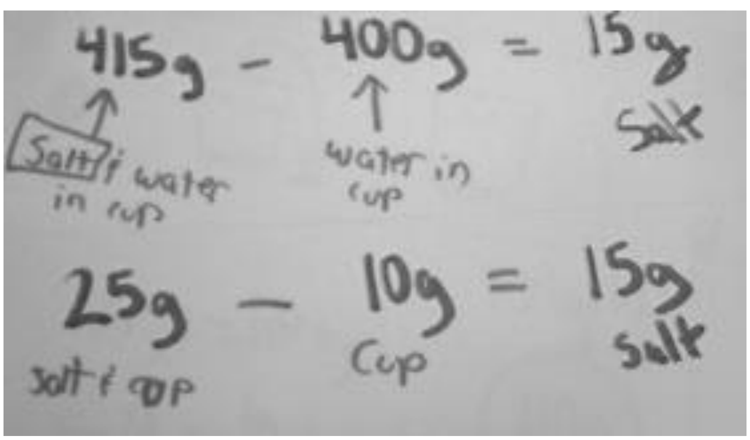


Figure 4-1: Ms. Schuster's Representation for Revealing a Pattern in the Data

All of the focal interns worked to make implicit aspects of the representations or investigation more explicit, as seen in Table 4-4. For example, Ms. Atkin used the data to make it clear that the weight of the salt moved from one cup to another. She asked, "Seeing that this [before mixing mass] decreased by fifteen [grams] and this [after mixing mass] increased by fifteen [grams], what do you think happened?" [A_PreAssess]. This question highlighted how the mass of the salt remained the same in the investigation. Mr. Cruise, Ms. Schuster, and Ms. Michaels also made this implicit part of the investigation clear, yet Ms. Kelly did not. Mr. Cruise, Ms. Schuster, Ms. Michaels, and Ms. Kelly went on to explicitly mention other implicit aspects, but Ms. Atkin did not. For example, Ms. Michaels reminded the students that "the weight includes the cup," an implicit part of the data collected for the investigation [M_PreAssess]. Four of the five interns (Ms. Schuster, Ms. Michaels, Ms. Kelly, and Mr. Cruise) made multiple implicit aspects of the investigation more explicit, whereas Ms. Atkin did this work for only one aspect.

Four of the five interns tended to support students to do the intellectual work of analyzing the data, whereas Ms. Kelly did this work for the student. Ms. Atkin and Ms. Schuster had the student calculate the differences between the masses collected in the investigation. Likewise, after modeling how to complete a chart, Mr. Cruise had the students complete the data table for the final two groups, saying, "Let's do that addition" [C_PreAssess] However, Ms. Kelly did the addition and subtraction work for the student in her enactment, and Ms. Michaels had the student do the math but wrote and drew the representation for the student she worked with. Ms. Atkin, Ms. Schuster, Mr. Cruise, and Ms. Michaels supported the students to name the pattern for themselves. For example, Mr. Cruise asked, "Do you see any similarity between [the numbers]?" and pushed the student to identify the pattern that the numbers are the same, marking conservation in the mass [C_PreAssess]. However, Ms. Kelly did this work for the student, saying, "We still counted the same amount of materials as before, but we just mixed them together" [K_PreAssess].

Ms. Michaels did some aspects of the intellectual work for the student by interpreting the students' calculation of the weights of the solution and the materials that made up the solution. Ms. Atkin also asked a leading question that included the interpretation of the pattern when the students finished the calculation, asking, "Does the weight of the salt stay with the water?" [A_PreAssess]. Ms. Atkin did not give the student an opportunity to make sense of this interpretation after asking the leading question. Mr. Cruise, however, continued to push the student to do this type of work throughout the interaction, resulting in a student's stating, "It looks like some of the salt was added" to describe the conservation of mass in the investigation [C_PreAssess].

All five focal interns used questions to follow up on what the student said about the patterns they saw in the data. Ms. Kelly asked about the student's prediction with "Tell me a little bit about how you thought it would be 100g" [K_PreAssess]. Ms. Michaels followed up on a student statement that the weight was less by asking, "Why do you think it was less?" [M_PreAssess]. These probes would allow the teacher to find out more about what the students are thinking about the data and the patterns they saw, as well as to push the students to think more deeply about the phenomenon.

In sum, the interns showed a range of quality in their practice for supporting students to analyze the data to reveal patterns and relationships in the pre-assessment at the start of their second year in the program. This range was seen in the lesson plans of all 54 interns from the cohort, as well as in the enactments of the five focal interns. Variation existed in the type of representations used, in making explicit implicit elements of the investigation and representations, and in the opportunity to do the intellectual work. The interns showed strength in their planning for follow-up questions and probing students' thinking about the patterns during their enactments.

Summary of Supporting Students to Analyze the Data to Reveal Patterns and Relationships before Science Methods

During the first year in their program, the cohort of interns showed an ability to support and probe student thinking about the patterns observed about a phenomenon by using representations. In their first month, the focal interns did this work through their Children as Sensemakers I Course. In their interactions with elementary students in this course, the interns supported the child to make connections between representations, and to use these representations to make sense of the phenomenon of what causes day and night. In the end of the year one survey, the interns were also able to describe students' strengths and challenges in using representations in analyzing data to reveal patterns and relationships and making sense of a phenomenon. However, variation existed in interns' planning for elementary students to analyze the data to reveal patterns and relationships in their pre-assessment for the Science Methods Course. This variation also arose in the five focal interns' enactments of these plans with a standardized student.

Science Methods Course: Strengths in Supporting Students to Analyze the Data to Reveal Patterns and Relationships

During the science methods class, the interns' practice and knowledge for supporting elementary students seemed to build on their early strengths. In the assignments for the Science Methods Course, the interns' practice showed several areas of strength such as developing useful representations of the data with students, probing student thinking about the patterns, and supporting students to do the intellectual work involved in analyzing and interpreting the data.

However, variation still existed among the interns in the quality of their knowledge and practice during the methods course.

Peer Teaching: Improving in Their Practice and Knowledge for Supporting Students to Analyze the Data

In their lesson plans for and enactment of their Peer Teaching lessons, the interns showed several areas of strength in supporting students to analyze the data to reveal patterns and relationships[1]. These strengths included co-constructing representations to show patterns in the data, working to make explicit implicit parts of multiple representations, and supporting students to do the intellectual work. In addition, the interns typically used all of the data collected to find the pattern, and they probed student thinking. These strengths are not unexpected given the amount of support that the interns were given. For example, in planning their lesson, the interns co-planned with at least two other interns in the class. Moreover, in their enactments, the interns could stop the lesson themselves (because they were teaching colleagues acting as "children" rather than children) to adjust a teaching move. In addition, a teacher educator might provide support to an intern who was struggling during their enactment. Despite this support, variation still existed among the interns' work, including in the representations they used and the degree to which they did aspects of the intellectual work for the students.

Peer Teaching Lesson Plans. In their lesson plans, more than 75% of the cohort "met or exceeded expectations" in terms of their quality of support for students to analyze the data to reveal patterns and relationships. A few plans (8%) "did not meet expectations"; these plans did

---

[1] The Stems Peer Teaching lesson focused on structure-function relationships in biology (explored using celery stems) and the Energy Peer Teaching lesson focused on energy transfer and thermodynamics (explored using containers of hot and cold water) (see Table 3-4 for more information).

not require the students to do the intellectual work or did not plan to analyze the data to reveal patterns and relationships. Other plans (17%) “partially met expectations.” These plans often did not include using a representation to support the students in analyzing the data; instead, the teacher and students would only discuss the patterns verbally. For example, to analyze the data to answer the question, “How does water travel from the roots to the leaves in celery?” Intern 35 planned only these four questions: “What happened to your group’s celery? Did that happen to everyone’s celery? Are we noticing a trend in our experiment? What is it?” [PT_35]. Without additional support or a representation, Intern 35’s questions may not provide all students with the opportunity to see the patterns in the observations that students made of their celery before and after placing them in the red water. In contrast, the interns who “met or exceeded expectations” planned representations that would facilitate students to see these differences. For example, Intern 33 planned to create two T-charts to show these differences:

> Teacher will:
> - Make two t-charts on a large piece of poster paper. (One t-chart for the clear water experiment and one t-chart for the dyed water experiment)
> - Ask students to share their observations of the celery before the experiment using the clear water.
> - Ask students to share their observations of the celery after the experiment using the clear water.
>
> Students will:
> - Point out patterns in the observations between the two experiments [PT_33].

These T-charts would make the patterns in the students’ observations more easily recognized than could be done by simply discussing the patterns aloud.

Although some interns struggled to “meet expectations,” 42% of the interns’ plans “exceeded expectations” in terms of quality of supporting students to analyze the data. These interns tended to plan for supporting students to notice implicit features of the representations, for highlighting patterns in the data, and for discussing anomalous data. Fifty-seven percent of the interns planned to highlight implicit features of the representations they used. For example, interns planned to highlight the labels of axes on the graph with questions such as, "What should the y-axis of our line graph be? The x-axis?" [PT_8]. Other interns planned to discuss explicitly how a representation showed particular trends. For example,

> What do you notice about the lines on my graph? (*The lines leveled off or got close to leveling off.*) What does this mean? (*It means that the containers of water reached the same temperature*.)" [PT_29].

Interns also planned to make more explicit the patterns in the data. Intern 33 planned to "circle the notable changes to the celery that occurred due to the experiment (use multiple colors)" to underscore the patterns seen on the T-charts described above [PT_33].

Several interns also "exceeded expectations" by planning to discuss the possible anomalous data that might arise in the investigation and how these data are common in investigations. Intern 41's plan to discuss the anomalous data that arose is an example of this:

> Sometimes scientists make mistakes when they are conducting experiments. This means it is really important to conduct the experiment more than once. That is why I had several groups conduct this experiment, so that we can have multiple sets of data to look at. This also means that scientists need to be aware of possible errors that they made during their experiment that could have skewed their data. [PT_41]

Other interns also planned to discuss anomalous data, possible sources of error, and the importance of replicating an investigation in science.

In addition to their strengths in terms of using representations to analyze the data, the interns planned to support students to do the intellectual work involved in analyzing and interpreting the data and to ask open-ended questions. One intern planned to do the intellectual work for the students, whereas the other 47 interns' lesson plans[2] included questions that would support students to name the patterns themselves. Similarly, 96% of the interns planned to ask

[2] Only 48 of interns' peer teaching lesson plans were complete and turned in for this assignment.

open-ended questions. Examples of open-ended questions that would support students to name the patterns included, “What patterns do you notice in the data on the board? What is the same in all of them?” (E_PT_Explain) and “What does this mean?” [PT_3]. Despite the plans to ask open-ended questions, most interns did not plan follow-up questions that elicited more student thinking. Only 21% of the lesson plans included questions that probed student thinking, such as “Do you agree/disagree with student X? Why? What other thoughts do you have?” [PT_6]. It is possible that interns may already know how to use follow-up questions in the moment and therefore did not include them in their plans.

Peer Teaching Enactment. As seen in the Peer Teaching lesson plans from the entire cohort of 54 interns, the focal interns also showed strengths in supporting students to analyze the data to reveal patterns and relationships during their enactment of the Peer Teaching lesson plans (see Table 4-5). All five of the focal interns’ enactments were determined to “meet or exceed expectations” in terms of the quality of their support for analyzing the data. Two interns, Ms. Atkin and Mr. Cruise, “exceeded expectations.”

Table 4-5: Teaching Moves Used and Quality for Supporting Students to Analyze the Data to Reveal Patterns and Relationships during Peer Teaching Enactments

	Ms. Kelly	Ms. Atkin	Mr. Cruise	Ms. Michaels	Ms. Schuster
Creates an additional representation to show the pattern	X	X	X	X	X
Amount of data considered	All	All	All	All	All
Makes explicit implicit features of the representation	More than one	More than one	More than one	More than one	More than one
Discusses the data in the investigation and connection to representation	By student	By student	By student	By student	By student
Supports the child(ren) to analyze and interpret the data	X	X	X	X	X
Probes student thinking	X	X	X	X	X
Does not do the intellectual work involved in analyzing and interpreting the data	X	X	X		X
Does not ask leading question that provides the reasoning	X	X	X	X	X
Quality in terms of the expectation	Meets	Exceeds	Exceeds	Meets	Meets

In their enactment, each of the five focal interns created an additional representation that would support students to analyze the data to reveal a pattern. Ms. Kelly, Ms. Atkin, and Ms. Michaels taught a lesson on stems where they created a chart to summarize the patterns in student thinking. For example, for her stems lesson, Ms. Kelly used a chart such as the one in Figure 4-2 and worked with the "students" (colleagues in the class) to add information from their observations. Mr. Cruise and Ms. Schuster, teaching the energy lesson, supported their students to create line graphs from their data tables and used the line graphs to discuss trends in the data such as in Figure 4-3. Each of these representations included all of the relevant data collected in the investigation.

	Red Water	Clear Water
Before		
After		

Figure 4-2: Table That Ms. Kelly Created with Students to Analyze the Data during Peer Teaching

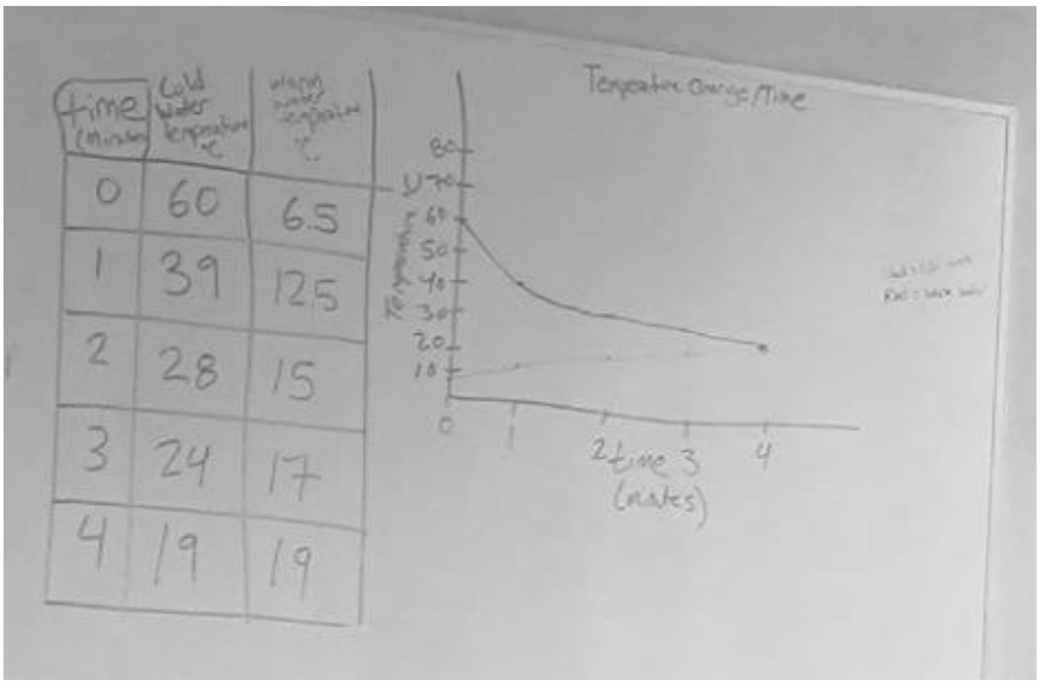


Figure 4-3: Representations That Mr. Cruise Used to Support Students to Analyze the Data to Reveal Patterns and Relationships

When using representations, all five focal interns made implicit aspects of the representation more explicit in order to support students to see the patterns. For example, Ms. Schuster called attention to the title and axes of the graph and underscored the “two different colored lines” that represented the two different containers in the investigation [S_PeerTeach]. Mr. Cruise’s work to support students to understand the features of the graph was similar. Ms.

Kelly, Ms. Michaels, and Ms. Atkin made connections to the students' observations to analyze the data to reveal patterns. In addition, Ms. Kelly and Ms. Atkin also circled trends that occurred on the charts that they created.

All five of the focal interns also supported students to do the intellectual work of analyzing and interpreting the data. For example, in an investigation of the purpose of a stem in transporting water, Ms. Atkin pointed out some of the changes that occurred when the stems were placed in the water. Then she asked the students, "Is there another … difference that you can see?" [A_PeerTeach]. This question facilitated the students to discuss changes that occurred in order to answer the investigation question. Likewise, after listing some of the students' observations in a chart on the board during a similar investigation, Ms. Michaels asked, "What are you noticing?" [M_PeerTeach]. The students then discussed changes they saw after the celery was placed in the water. However, Ms. Michaels did some of the intellectual work for the students by summarizing the reasoning for why the class's predictions were accurate, rather than giving students the opportunity to do this work. At other times, Ms. Michaels supported the students to share the reasoning.

The interns also probed student thinking, usually using open-ended questions. For example, when a student described that the scale seemed different on two graphs, Mr. Cruise asked, "What do you mean by your scale? Can you help us review that?" [C_PeerTeach]. Another example is Ms. Atkin's question, "What do you mean by that?" [A_PeerTeach].

Peer Teaching Summary. In summary, the interns' Peer Teaching lesson plans and enactments of the plans showed several strengths for supporting students to analyze the data to reveal patterns and relationships. Interns typically created an additional representation to facilitate finding the pattern and to support students in seeing implicit features of the representation or phenomenon. The interns also asked open-ended questions that would facilitate students to share thinking about the pattern or investigation.

Reflective Teaching: The Challenge of Interacting with a Classroom of Students

In their Reflective Teaching assignments, interns had moderate success in supporting elementary students in their placement classrooms to analyze the data to reveal patterns and relationships. Both the lesson plans of the entire cohort and enactments of the five focal interns had a greater range of quality. Despite early success in creating representations to reveal patterns in the data during the Peer Teaching assignment, only some interns did this work on their Reflective Teaching assignment. However, interns more regularly supported students to do the intellectual work in the lesson. The struggles seen in the Reflective Teaching assignment are not surprising given that interns now faced the challenges of teaching an entire lesson to a whole class of elementary children. In addition, interns were required to select and adapt a lesson plan on their own rather than being provided a lesson plan that would facilitate investigation-based science.

Reflective Teaching Lesson Plans. On their Reflective Teaching Lesson Plans, the entire cohort of interns showed a greater range of quality for supporting students to analyze the data to reveal patterns and relationships than they did in their Peer Teaching Plans. Moreover, fewer interns “met expectations” than they did in the Peer Teaching assignment.

Fifteen percent of interns’ Reflective Teaching plans did “not meet expectations” for supporting students to analyze the data to reveal patterns and relationships. Interns who did not meet expectations either planned to tell students the pattern or did not plan to analyze the data to reveal a pattern. For example, Intern 50 planned to tell students the basic survival needs of living things rather than using the investigation designed to support students to name these ideas. More than a third (38%) of interns' plans received a "partially meets expectations" for their Reflective Teaching plans. The most common reason for receiving a "partially meets expectations" was not planning for creating a representation to facilitate revealing a pattern. For example, Intern 47 asked the investigation question, "How do different cross sections [of a tree] differ from one tree to another?" and planned to "ask questions to compare the growth pattern of trees." However, this intern did not plan to use a chart to keep track of the observations [RT_47].

In contrast, 46% of interns' plans either "met" or "exceeded expectations" in terms of quality of support for analyzing the data. These plans used representations that would support students to analyze the data to reveal patterns and relationships or understand implicit aspects of the phenomenon. Intern 24 planned to "make [a] chart on the board with one column labeled fossils and the other present day objects" to support students to see patterns to answer the investigation question, "How do fossil[s] compare to present day objects" [RT_24]. Intern 24's chart would give students opportunities to see and keep track of the patterns in the data. Six percent of the interns "exceeded expectations" for the quality of supporting students in analyzing the data. These interns planned to use representations to help students see patterns and had several questions that would support students to think about the patterns and discuss their ideas with one another.

The interns' lesson plans for Reflective Teaching tended to show strengths and challenges similar to those in their Peer Teaching plans. Forty-one percent of the interns planned to make implicit features of the representations more explicit; this is compared with 57% of the Peer Teaching plans. For example, Intern 27 highlighted the implicit information regarding measurement to her students who were considering a table in their investigation of nutrition in cereals:

> Take a look at the serving size row of the table. What does that mean? Especially that number of servings row, what is that? (Describe how one serving size is the same for all of them, but that is the number of ¾ cups in the whole box.) [RT_27].

This discussion might support students to understand how to interpret the table they had created to analyze the data.

The interns also showed strengths in preparing students to do the intellectual work of discussing the pattern. Only one intern (2% of the group) planned to give students the answer rather than supporting students to analyze and interpret the data themselves. The interns also tended to plan open-ended questions that would support student thinking; 95% of the plans included open-ended questions such as “How were these models similar or different to the models we made in class?” [RT_11] and “What are some of [the] similarities you saw between the mushrooms?” [RT_51]. Thirty-six percent of the interns planned to ask probing questions to follow up on student thinking with questions such as “Why or why not?” [RT_52] or “How do you know?” [RT_34]. These types of questions were similar to those used in Peer Teaching, yet more interns planned to probe thinking in their Reflective Teaching plans than their Peer Teaching plans.

Reflective Teaching Enactment. As in the lesson plans for the entire cohort, the five focal interns also showed moderate success in supporting students to analyze the data to reveal patterns and relationships during their Reflective Teaching enactments. Ms. Atkin, Mr. Cruise, and Ms. Schuster “met expectations” in the quality of support, and Ms. Kelly and Ms. Atkin “partially met expectations” in the quality of support for analyzing the data (see Table 4-6). Each of the interns supported students to analyze and interpret the data, yet the explicitness of this work and clarity of the representations varied between interns.

Table 4-6: Teaching Moves Used and Quality for Supporting Students to Analyze the Data to Reveal Patterns and Relationships during Reflective Teaching Enactments

	Ms. Kelly	Ms. Atkin	Mr. Cruise	Ms. Michaels	Ms. Schuster
Creates an additional representation to show the pattern		X	X	X	X
Amount of data considered	All	All	All	Some	All
Makes explicit implicit features of the representation	None	More than one	More than one	One	One
Discusses the data in the investigation and connection to representation	By student	By student	By student	By student	By student
Supports the child(ren) to analyze and interpret the data	X	X	X	X	X
Probes student thinking		X	X	X	
Does not do the intellectual work involved in analyzing and interpreting the data		X	X	X	X
Does not ask leading question that provides the reasoning	X	X	X	X	X
Quality in terms of the expectation	Partial	Meets	Meets	Partial	Meets

During their Reflective Teaching lessons, four of the five focal interns used a representation of patterns in the data to support the construction of evidence-based claims; however, variation existed in the creation and completeness of the representations. Two of the interns (Mr. Cruise and Ms. Michaels) used teacher-created representations, whereas two other interns (Ms. Atkin and Ms. Schuster) used representations created by the students. Although Ms. Kelly did not make a representation to support students to see a pattern, the class did discuss all of the data collected during the investigation. For example, Mr. Cruise drew a food web in the front of the class with input from students[C_RT], whereas in Ms. Atkin's class, groups of students created graphs of their individual data from the investigation [A_RT]. Although most of the interns' representations included all of the data from the class's investigation, Ms. Michaels' representation missed portions of the data, resulting in a confusing representation. The class was investigating "What happens to a leaf in water when you put pennies on top?" During the wrap-up discussion, Ms. Michaels created a tally of the number of pennies used to sink the students' leaves, but her table did not have information on the weight and volume of the leaves despite students' having collected these data [M_RT_image1]. This missing information may have contributed to the class's struggle to identify a scientifically accurate, evidence-based claim.

The interns who created representations also highlighted implicit features of the representations that they used. Ms. Michaels pointed out the range of numbers in the data table the class had created and facilitated students to consider what this means, asking, "Why are there so many different numbers?" [M_RT]. Ms. Schuster reminded students of the importance of using the same units throughout their data table. Ms. Atkin and Mr. Cruise highlighted multiple implicit features of their representations. For example, Ms. Atkin highlighted the axes of the bar graph and how each of the "initial" bars on their graph would be 20 because "we all started with 20 beads" [A_RT].

All of the five focal interns supported the students to do the intellectual work involved in identifying patterns. Ms. Schuster supported students to make comparisons from their data table, asking, "Looking at our table, which cereal gives us the most calories?" [S_RT]. This enabled students to describe the cereal that had the most calories, an important pattern in allowing the students to answer the investigation question, "What cereal is the healthiest?"

Similarly, Ms. Kelly asked students to summarize what occurred in their investigation of evaporating water. Mr. Cruise asked, “Looking at this figure [of the interaction web the class had created], what is the pattern that you notice?” This question supported a student to describe that “it goes over and over again,” noticing the cycling of nutrients in an ecosystem [C_RT]. Ms. Atkin and Ms. Michaels made similar moves that pushed students to think about their investigation and the data they collected, and to notice patterns. Ms. Atkin, Ms. Michaels, and Mr. Cruise also followed up on student thinking with additional probing questions such as “What else?” [C_RT] and “What happened with yours?” [M_RT].

Although all of the focal interns supported students to do the intellectual work, Ms. Kelly did aspects of the intellectual work in analyzing and interpreting the data. For example, Ms. Kelly asked, “Where is the steam now?” when students were investigating evaporation, yet she answered this question herself, saying, “It became water vapor” [K_RT]. Throughout discussion, Ms. Kelly did the work of interpreting the data from the students’ observations of water evaporating from paper and from a boiling kettle. The other interns did not do the intellectual work for the students. None of the interns asked leading questions that provided the reasoning.

Reflective Teaching Summary. In summary, on their Reflective Teaching assignments, most interns had moderate success in supporting students to analyze the data. Most interns received a score of “partially meets expectations” or “meets expectations” on their written plans, and the five focal interns all received these scores on their enactments. Most interns supported students to analyze the data to reveal patterns and relationships in their lesson, and the most common struggle was planning a clear, accurate representation to support students in analyzing data to reveal patterns and relationships.

Post-assessment at the End of Science Methods: Showing Growth in Planning to Support Students to Analyze the Data to Reveal Patterns and Relationships

Since the post-assessment included the same requirements as the pre-assessment, direct comparison between the two time points seems reasonable. As seen in Figure 4-4, a greater proportion of interns' plans "met" or "exceeded expectations" on the post-assessment. Compared with the 42% of interns who "met" or "exceeded expectation" on the pre-assessment, 67% of the interns' plans had this quality on the post-assessment. As in the pre-assessment, approximately a third of the plans "partially met" expectations; these tended to plan to discuss the pattern or relationship without the support of a representation, or to use a confusing representation. Only one intern's plan (2%) "did not meet expectations" on the post-assessment compared with 14% on the pre-assessment. This plan included telling students the pattern in the data rather than supporting students to do the work of analyzing the data to reveal a pattern or relationship.

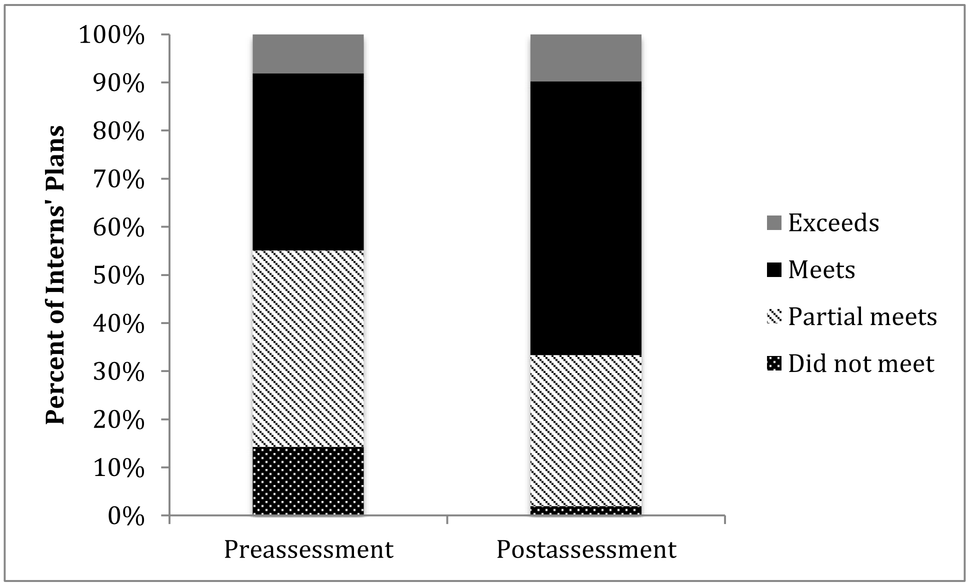


Figure 4-4: Graph of Quality of Supporting Students to Analyze the Data on the Pre-assessment and Post-assessment

Like the pre-assessment, the post-assessments also showed other areas of strength for supporting students to analyze the data to reveal patterns and relationships. On the post-assessment, 96% of the interns planned to have students discuss the data, a percentage similar to the 94% of the interns who planned to do so on the pre-assessment. Almost all of the interns (96%) also planned to ask follow-up questions on the post-assessment; however, less than half (44%) planned to help students identify where the salt goes, an implicit aspect of the investigation. In summary, the interns' plans showed growth in the quality of their support for analyzing the data to reveal patterns and relationships from the pre-assessment to the post-assessment. The interns also showed similar strengths and challenges in planning for analyzing the data across both assessments.

Summary of Supporting Students to Analyze the Data to Reveal Patterns and Relationships during Science Methods

During the Science Methods Course, most interns showed growth in supporting students to analyze the data to reveal patterns and relationships after their investigations. For example, across the assignments, the interns typically planned for students to name a pattern in the data and to share their thinking. In addition, the interns' plans for supporting students to analyze the data to reveal patterns and relationships increased in quality from the pre-assessment to the post-assessment. The lesson plans and enactments for Peer Teaching were particularly strong in using representations to make sense of the data. However, on the Reflective Teaching Assignment, the interns less frequently planned to use representations to support students' sense-making.

After Science Methods: Challenges in Supporting a Classroom of Learners

After the Science Methods Course, the focal interns continued to show moderate strength in their support for analyzing data to reveal patterns and relationships, yet variation still existed, especially during student teaching. In the end of the year standardized-student enactment, the interns showed great strength in their ability to support students to analyze and interpret the data; this was similar to the strengths shown during Peer Teaching.

Student Teaching: Typically Facilitating Students to Analyze the Data to Reveal Patterns and Relationships

During student teaching, only four of the five focal interns, Ms. Atkin, Mr. Cruise, Ms. Kelly, and Ms. Michaels, had an opportunity to teach science; Ms. Schuster taught other subjects during her student teaching. The four focal interns who taught science typically "met" or "exceeded expectations" for quality of support for analyzing the data to reveal patterns and relationship (see Table 4-7). Eight of the 11 investigations taught by the focal interns reached this standard. Moreover, each of the four focal interns enacted at least one investigation that "met expectations." This suggests that each intern showed variation for supporting students to analyze the data to reveal patterns and relationships among their lessons during student teaching. This variation is also seen in the many strengths of the interns' support during student teaching and the struggles they faced.

Table 4-7: Teaching Moves Used and Quality for Supporting Students to Analyze the Data to Reveal Patterns and Relationships during Student Teaching

Intern	Ms. Kelly			Ms. Atkin		Mr. Cruise				Ms. Michaels	
Investigation	1	2	3	1	2	1	2	3	4	1	2
Creates an additional representation to show the pattern		X		X	X	X	X	X		X	
All data considered		X	X	X	X	X	X	X	X	X	X
Makes explicit implicit features of the representation or phenomenon	X			X	X		X				
Student discusses the data in the investigation and connection to representation		X	X	X	X	X	X	X	X	X	X
Supports the child(ren) to analyze and interpret the data		X		X	X	X	X	X		X	X
Probes student thinking	X				X		X	X	X	X	X
Does not do the intellectual work involved in analyzing and interpreting the data		X						X			X
Does not ask leading questions that provides the reasoning	X	X	X	X	X	X	X	X	X	X	X
Meets or exceeds expectations		X		X	X	X	X	X		X	

During their student teaching, the interns typically used an additional representation to support students to reveal a pattern in the data. This occurred in 7 of the 11 lessons. For example, Ms. Kelly used a chart to record student findings about forces, and Ms. Atkins had students generate their own diagrams of complete circuits [K_Field2; A_Field2]. However, sometimes the interns did not create a representation when one would be needed. For example, Mr. Cruise had student groups share their findings about how their water filter was able to filter out particular pollutants (e.g., soap, toothpaste), yet he did not record these findings [C_Field4].

A public chart of these findings would have supported students to make claims about the quality of the filter, since each group had a different material and did not know other students' results.

Although the interns sometimes created representations to support students to find the patterns, they infrequently (only in 4 of the 11 investigations) made implicit features of these representations or the phenomena explicit. Ms. Kelly and Ms. Atkin both did so, Ms. Kelly through helping students label their diagrams and Ms. Atkin through explicating the category labels on a chart [K_Field1; A_Field1].

Interns typically supported students to do the work of discussing all of the data in connection to the representation. All investigations involved considering all of the data collected in the discussion, and only Ms. Kelly's first investigation did not have students discuss the data from the investigation. In this investigation, students collected data about seeds, but the class did not discuss the data collected at the end of the investigation [K_Field1]. Ms. Michaels' first investigation is an example of a lesson where students discussed all of the data collected in the investigation. During this investigation of the five senses, the kindergarten students shared their observations of the popcorn, making comments such as "it tastes like nothing" and "I heard popping and a big noise" [M_Field1]. Ms. Michaels wrote these comments on a chart as she asked students where their comments belonged. This chart and discussion supported students to see the commonalities and differences between the senses – a pattern in the investigation. Other interns did similar work to support students to discuss the data collected in the investigation and to connect it to the representation created as a class to analyze the data to reveal patterns and relationships.

In addition to supporting students to discuss the data from the investigation, the interns typically supported students to do the intellectual work of finding the patterns in the data. Eight out of the 11 investigations involved students doing this work. For example, in his third lesson, Mr. Cruise discussed with his students the common pollutants that they found around the school, using a chart to keep track of the patterns. Mr. Cruise often pushed his students to decide which categories certain pollutants belonged in, or whether certain items were pollution; the following interaction is an example of the latter:

> Teacher: Another example [of a pollutant]?
> Student 1: Birdseed
> Teacher: We found something that might fall in the other category…. might birdseed be considered pollution?
> Student 2: It could be either. You don't really have to put it outside…
> Teacher: Can you add on…
> Student 3: We found an apple core is like birdseed.
> Teacher: … Both of them decompose. I don't know if I would consider them pollutants.
> Student 4: … Would it be pollution if someone dumped a whole lot of birdseed in the river? [C_Field4p3].

In this interaction, multiple students and the intern weigh in about the birdseed as an example of a pollutant and how to make sense of the data that the students collected in their investigations. Other interns also supported their students to organize the data or identify the pattern they saw in the data. In contrast, in three of the investigations, students did not do the intellectual work. For example, in Mr. Cruise's Investigation 4, he does the work of analyzing and interpreting the data to identify the pattern for the students. During this lesson, he made the connections across the students' data about whether the filter worked, saying, "This kind of filter might not work so well" [C_Field4]. In doing this work, Mr. Cruise did not give students the opportunity to compare the data collected across the different pollutants to reveal patterns. Ms. Kelly did similar work for her students in two of the lessons.

Although the interns usually supported their students to do the intellectual work, in 8 of the 11 investigations, the interns did aspects of the intellectual work for the students during the lesson. Doing the intellectual work typically occurred for a short period of time, and then, the students would be allowed to do the rest of the intellectual work of analyzing the data to reveal patterns and relationships. For example, rather than asking students if they thought their predictions were correct on the basis of their observations, Ms. Atkin told the students, “You were right,” and she discussed the reasons based on what the students saw [A_Field2]. She did not allow the students to do the comparison work themselves or think about the comparisons that she made. Other interns did similar amounts of the intellectual work, yet sometimes they analyzed the data for the students, thinking as Mr. Cruise did in Investigation 4.

The interns often asked follow-up questions during the lessons. In 7 of the 11 investigations, the interns followed up with probing questions, such as, “Why do you think it was about the same?” [A_Field4] or “what did it sound like?” [M_Field2]. In 6 of the 11 investigations, the interns asked open-ended questions similar to the ones listed, to follow up on student thinking

In summary, the interns’ support for analyzing the data during student teaching showed several areas of strength. They typically used a representation to support students to analyze and interpret the data and facilitated students to discuss the data and do the intellectual work of analyzing and interpreting the data. The interns often asked follow-up questions during the lessons. However, interns sometimes did the intellectual work for the students. Moreover, the quality of the support varied across lessons for the same intern.

End of Year Two: Standardized Student Interactions Show Areas of Growth

Because of scheduling constraints, only three of the five focal interns enacted an end of the year standardized student enactment using the same protocol as the pre-assessment. These enactments suggested that these three interns had grown over the course of the second year in terms of supporting students to analyze the data to reveal a pattern or relationship. Comparing the enactments of facilitating a standardized student to reach the same learning goal with the same data at the beginning of Year Two during the pre-assessment enactments, Ms. Kelly and Ms. Atkin improved on their quality from "does not meet" and "partially met" expectations to "exceeded expectations" and "met expectations," respectively. Ms. Schuster's quality of support remained at "met expectations" for both the pre-assessment enactment and end of the year enactment. This suggests that all three interns showed several strengths in the subpractice of supporting students to analyze the data to reveal patterns and relationships during this interaction.

All three interns created an additional representation to show a pattern (see Table 4-8). They created similar charts to help the students notice a trend in the data (i.e., that the weight of the materials used to make the solution is equal to the weight of the solution). To highlight the pattern, these charts clearly listed the weight of the materials used to make up the solution and the weight of the solution. Ms. Kelly's chart included all three groups' data [K_SSEndofYear], whereas Ms. Schuster and Ms. Atkin used charts that included a portion of the data [S_SSEndofYear; A_SSEndofYear].

Table 4-8: Teaching Moves Used and Quality for Supporting Students to Analyze the Data to Reveal Patterns and Relationships during the End of the Year Standardized Student Enactment

	Ms. Kelly	Ms. Atkin	Ms. Schuster
Creates an additional representation to show the pattern	X	X	X
Amount of data considered	All	Some	Some
Makes explicit implicit features of the representation or phenomenon	X	X	X
Discusses the data in the investigation and connection to representation	X	X	X
Supports the child(ren) to analyze and interpret the data	X	X	X
Probes student thinking	X	X	X
Does not do the intellectual work involved in analyzing and interpreting the data	X		X
Does not ask leading question that provides the reasoning	X		X
Quality of support	Exceeds	Meets	Meets

The interns also worked to make explicit implicit features of the representations or phenomenon. For example, Ms. Schuster asked, "Why do you think they included the cup [in the weight]?" and supported the standardized student to think about why the student might need to consider the weight of the cup in the final measurements. She also showed these differences on the representation [S_SSEndofYear]. Ms. Kelly and Ms. Atkin did similar work to make this implicit aspect of the investigation and representation of the investigation more explicit. Similarly, Ms. Schuster pushed the standardized student to notice the implicit aspect of the phenomenon that is made more explicit using the representation as she asked, "Just because we can't see [the salt], does it mean that it is not there?" [S_SSEndofYear]. Ms. Kelly also supported the standardized student to understand this implicit aspect of the phenomenon.

All three of the interns supported the standardized student to discuss the data in the investigation, and to do the intellectual work of finding and naming the pattern. For example, Ms. Atkin asked the student to “walk me through the investigation,” facilitating the student to talk through aspects of the data that was collected. Later in the lesson, Ms. Atkin asked the student to calculate the changes in the weight of materials before and after the investigation. Ms. Atkin then supported the student to name the pattern in the data: “Do you see a similarity in the data?” After the student responded that the numbers are the same, she asked, “What changed?” [A_SSEndofYear]. This pushed the student to name that the salt moved from one cup to another, but the weight of the salt and the other materials stayed the same. Ms. Kelly and Ms. Schuster also supported the standardized student to describe the data collected and name the pattern in the data.

Although the interns supported the standardized student to do most of the intellectual work involved in analyzing data to reveal patterns and relationships, Ms. Atkin, at times, did the intellectual work for the student. Before the student had discussed the pattern that the weight of the salt was added to the weight of the water, Ms. Atkin did the interpretation of the data for the student with a leading question: “Did you notice that the weight of the salt was added to the weight of the water?” [A_SSEndofYear]. The way this question was framed required a particular “yes” response whether or not the student was able to see this pattern in her data. Ms. Atkin did not require the student to explain further how this interpretation of the data can be seen through analyzing the representation, limiting the intellectual work that the student was able to do. In contrast, Ms. Schuster and Ms. Kelly did not do the intellectual work for their students.

All three interns also followed up on student thinking during their interaction by asking probing questions. An example of this is Ms. Schuster's question, "How do you think a solution and a mixture is different?" after the student defined the two terms on the basis of prior knowledge [S_SSEndofYear]. The interns asked other, similar probing questions that would make the student's thinking visible during the interaction.

In summary, these three interns showed several strengths during the end of the year standardized student enactments. They used representations to support students to analyze the data to reveal patterns and relationships. Although Ms. Atkin did aspects of the intellectual work for the student, the interns usually supported the students to analyze and interpret the data and share their thinking. These interactions showed growth compared with similar interactions during the pre-assessment before the Science Methods Course.

I turn next to a depiction of how the interns' performances changed over time.

Change over Time in Supporting Students to Analyze the Data to Reveal Patterns and Relationships

The interns grew in their ability to support students to analyze the data to reveal patterns and relationships over their two years in the program. They built from a strong foundation from the Children as Sensemakers 1 course. However, they varied in their planning for and enactment of this practice. In addition, interns seemed to provide or plan for stronger support for students during the Science Methods Course. In this section, I summarize changes that occurred in the lesson plans and enactments in terms of supporting children to analyze the data to reveal patterns and relationships over the two years.

Change over Time in Lesson Plans

I had access to four sets of lesson plans from the entire cohort from the second year of the program: the pre-assessment from the beginning of the semester, Peer Teaching from the Science Methods Course, Reflective Teaching from the Science Methods Course, and the post-assessment at the middle of the second year. Figure 4-5 suggests that interns had the greatest success during their Peer Teaching, whereas they struggled more with writing their lesson plans for the Reflective Teaching Assignment. However, they were able to show growth on the post-assessment plans. From the pre-assessment to Peer Teaching, the lesson plans seemed to show growth in quality, with a more than 30% increase in the percentage of interns' plans that "met" or "exceeded expectations" (see Figure 4-5). However, this proportion decreased in the Reflective Teaching assignment (45%), but it increased again in the post-assessment (67%). The proportions of interns who did "not meet expectations" decreased overall.

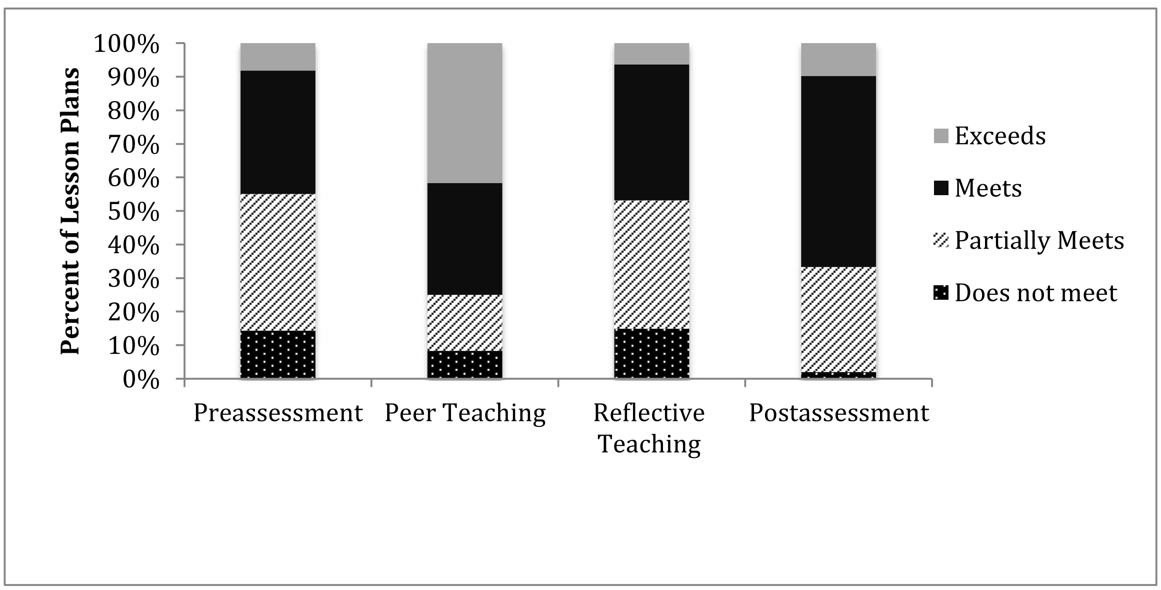


Figure 4-5: Graph of the Percentage of Quality of Lesson Plans for Supporting Students to Analyze the Data to Reveal Patterns and Relationships

Common strengths and variations existed across the plans (see Table 4-9). For example, in all four sets of lesson plans, more than 90% of interns planned to support students to analyze and interpret the data. Approximately half the interns planned to make particular implicit features of the representation or phenomena more explicit for each assignment. There was a decrease in the proportion of interns who planned probing questions for the Peer Teaching and Reflective Teaching assignments; this may result from the nature of the assignments themselves rather than being a signal that interns would not do this work when teaching students.

Table 4-9: Percentage of Interns Who Planned for Particular Moves for Supporting Students to Analyze the Data

Lesson Plan Assignment	Pre-assessment	Peer Teaching	Reflective Teaching	Post-assessment
Students discuss the data	94%	98%	98%	96%
Make implicit features explicit	53%	57%	41%	44%
Probing questions	70%	21%	36%	96%

In summary, the interns showed potential for supporting students to analyze the data to reveal patterns and relationships in their pre-assessment Lesson Plans. They showed the greatest strength in this subpractice in the Peer Teaching assignment, where they had high levels of support, including co-writing the plan with colleagues and facilitation from instructors of the course. Interns showed the greatest struggle in their Reflective Teaching assignment, where they faced the challenges of planning an entire lesson for a classroom of elementary students. On the post-assessment at the middle of the second year, interns showed growth from the pre-assessment, suggesting potential for being able to plan to support students to analyze the data on their own.

Change over Time in Enactments

The focal interns' enactments also showed strengths and struggles throughout the two years of the program. The interns tended to "meet" or "exceed expectations" in terms of quality of their support (see Table 4-10). The interns showed strength in this subpractice during their first month in the program, with most of the interns meeting expectations. At this point in the program, the interns were given a protocol that would facilitate their ability to do this work. The focal interns showed the most variation during the pre-assessment enactment and their student teaching lessons, with quality ranging from "does not meet" to "exceeds expectations." The variation in the pre-assessment is similar to the variation seen in the lesson plans of the entire group. Also, as seen with the lesson plans of the entire group, the focal interns showed the greatest strength during the Peer Teaching enactments. During these enactments, all of the focal interns exceeded or met expectations in terms of quality of support for analyzing data to reveal patterns and relationships. A similar success was seen for the three focal interns who enacted the end of the year standardized student enactment, with all three meeting or exceeding expectations.

Table 4-10: Quality of Support for Analyzing Data to Reveal Patterns and Relationships Seen in Enactments over Time

	Children as Sensemakers	Pre-assessment	Peer Teaching	Reflective Teaching	Student Teaching	End of Year
Ms. Kelly	3	1	4	2	2	4
Ms. Atkin	3	2	4	3	3.5	3
Mr. Cruise	3	4	4	3	3	n/a
Ms. Michaels	2	3	3	2	2.5	n/a
Ms. Schuster	3	3	3	3	n/a	3

Does not meet = 1; partial = 2; meets = 3; exceeds = 4

The interns tended to create new representations to support students to analyze the data to reveal patterns and relationships and make implicit features of the representations more explicit throughout the program. The interns also showed the greatest success during the Peer

Teaching enactments, and the greatest variation during the pre-assessment enactments (see Table 4-10). The focal interns also typically considered all of the data involved in the investigation, with the exception of the pre- and post-assessments involving the Standardized Student Enactments. This difference may be because of the type of data involved in the investigation and the standardized student enactment's focus on one student rather than on the whole class. The interns also tended to support students to discuss the data and to do the intellectual work of analyzing and interpreting the data.

The interns showed more variation in asking follow-up questions and in consistently asking open-ended questions. For example, all of the focal interns asked follow-up questions during the Peer Teaching, pre-assessment, and end of the year standardized student enactments, but only some interns asked follow-up questions during the Children as Sensemakers I interactions and Reflective Teaching assignment. The interns also tended to do aspects of the intellectual work of naming the reasoning for interpreting the data for the students. This remained a struggle of the focal interns throughout their enactments.

Table 4-11: Use of Teaching Moves to Support Students to Analyze the Data to Reveal Patterns and Relationships

	Children as Sensemakers	Pre-assessment	Peer Teaching	Reflective Teaching	Student Teaching	End of the Year Standardized Student
Creates an additional representation to show the pattern	n/a	XXXXX	XXXXX	XXXX _	XXXXXXX _ _ _ _	XXX
All data considered	n/a	X _ _ _ _	XXXXX	XXXX _	XXXXXXXXXX _	X _ _
Makes explicit implicit features of the representation	XXXXX	XXXXX	XXXXX	XXXX _	XXXX _ _ _ _ _ _ _	XXX
Supports students to discuss the data in the investigation and connection to represent	n/a	XXX _ _	XXXXX	XXXXX	XXXXXXXXXX _	XXX
Supports the child(ren) to analyze and interpret the data	XXXX _	XXXX _	XXXXX	XXXXX	XXXXXXXX_ _ _	XXX
Probes student thinking	XXXX _	XXXXX	XXXXX	XXX _ _	XXXXXXX_ _ _ _	XXX
Does not do the intellectual work involved in analyzing and interpreting the data	XX _ _ _	X _ _ _ _	XX _ _ _	XX _ _ _	XXX_ _ _ _ _ _ _	XX_
Does not ask leading question that provides the reasoning	_ _ _ _ _	X _ _ _ _	XX _ _ _	XX _ _ _	XXXXXXXXXXX	XX _

X= intern used this move; _= intern did not use this move.

Conclusion

This chapter described the quality and teaching moves used by the interns for the subpractice of supporting students to analyze the data to reveal patterns and relationships. The chapter discussed the strengths and struggles that the interns had in supporting students to analyze the data and share their thinking at several time points in the program. In addition to several common strengths and struggles, variation seemed to exist across interns in the cohort at the time points. The chapter ends by looking at the change in the interns' practice over time. The interns showed variability but seemed to show the greatest quality of support during their Peer Teaching. Chapter 5 focuses on the second subpractice, supporting students to make a claim justified by evidence and reasoning, and it includes a similar discussion of the interns' strengths, struggles, and growth over time.

CHAPTER 5

SUPPORTING ELEMENTARY CHILDREN TO MAKE CLAIMS JUSTIFIED BY EVIDENCE AND REASONING

This chapter considers how the interns' ability in the subpractice of supporting elementary children to make claims justified by evidence and reasoning changed over the two years in the program. The subpractice of supporting elementary children to make claims justified by evidence and reasoning includes supporting students to make a claim and justify this claim in a logical structure. The children drew on the patterns in the data from their investigation to construct their claims.

Compared with their support for analyzing data to reveal patterns and relationships, the interns struggled more with this subpractice. In addition, their knowledge and ability showed greater variation across interns and in each intern's teaching, yet some interns also showed areas of growth in this subpractice over the course of the two years, particularly in the quality of support they provided students. The interns showed the most success in this subpractice during the Science Methods Course, particularly in the highly supported Peer Teaching. Throughout the program, the interns typically supported children to make claims, yet seemed to struggle more in supporting children to use a logical structure for their claims.

In this chapter, as in the previous one, I consider the interns' planning and teaching moves for this subpractice at three time points: (1) before the Science Methods Course, (2) during the Science Methods Course, and (3) after the Science Methods Course. After this chronological depiction, I summarize growth, strengths, and struggles the interns faced in supporting students to make claims justified by evidence and reasoning.

Before Science Methods: Beginning to Support Students to Make Claims

During the first year in the program, the interns showed their knowledge and practice for supporting students to make claims justified by evidence and reasoning in their Children as Sensemakers enactments, end of year one survey, and pre-assessment for the Science Methods Course. These representations of the interns' practice and knowledge suggest that interns had strengths (e.g., supporting students to communicate a claim) and challenges (e.g., explicit connection between claim and evidence).

Children as Sensemakers Enactment: Supporting Children to Make Claims

After supporting students to describe the pattern that the turning of Earth causes day and night during an interactive read-aloud, as described in Chapter 4, the interns returned to the same student to find out how the child described day and night. In this interaction, interns supported their students in answering the focal question, "What causes day and night?" The interns also worked to have the students share their thinking related to their claims. As in their interactive read-aloud with the children, the interns were provided a protocol for investigating student thinking. This protocol included having students describe their answer to the investigation question through speaking, drawing, and, then, writing. In terms of their support for children to make claims justified by evidence and reasoning, the five focal interns used similar teaching moves (see Table 5-1). All of the five interns “partially met expectations” in terms of quality of support for making claims justified by evidence and reasoning.

Table 5-1: Teaching Moves Used and Quality of Support for Making Claims Justified by Evidence and Reasoning during the Children as Sensemakers Enactment

	Ms. Kelly	Ms. Atkin	Mr. Cruise	Ms. Michaels	Ms. Schuster
Supports the student to make claims	X	X	X	X	X
Uses a structure to construct evidence-based claims					
Uses other scaffolds/tools to support construction of claims (sentence stems, etc.)					
Gives feedback on construction of claims					
Follows up on an alternative idea that child gives		X			X
Does not ignore an alternative idea that child puts forth	X	X	X	X	X
Does aspects of the intellectual work of describing the reasoning					
Quality of support	Partial	Partial	Partial	Partial	Partial

All five focal interns supported the students to state claims that answered the investigation question. For example, Ms. Schuster had this interaction with her student:

> Ms. Schuster: Can you tell me … what makes day and night?
> Child: The Earth spins.
> Ms. Schuster: What about the sun?
> Child: The sun is the bright side, and the moon is the dark side. [S_CaSM_Interview]

In this interaction, Ms. Schuster supported her student to share his claim about what causes day and night and followed up with questions about the child’s claim. All five focal interns asked questions that would support their students to make claims about what causes day and night.

All five interns also allowed the students to share their alternative ideas about the scientific phenomenon, and two interns followed up on the children's alternative ideas. When Ms. Michaels's child responded with the idea that the sun moves, Ms. Michaels did not tell the student she was wrong but rather asked additional questions: "Does the Earth move?" and "How does the Earth move?" [M_CaSMInterview]. In this case, Ms. Michaels allowed her student to share her alternative idea and did not simply tell the student she was wrong without finding out more about the student's thinking. The other four focal interns made similar moves to understand the children's thinking. Moreover, Ms. Atkin and Ms. Schuster took this move further by trying to find out more about the children's alternative ideas. For example, Ms. Atkin asked her child to "explain it a little more" when the child replied that the people were on the sun and jumped off, a possible alternative idea of the child.

The interns also showed areas of struggle during their interaction. In particular, all of the focal interns performed aspects of describing the reasoning for the student, either through leading questions or through explicit statements. For example, Mr. Cruise described what the student drew in the picture of day and night rather than allowing the student to explain his reasoning, saying, "The sun goes away" [C_CaSMInterview]. Ms. Kelly, Ms. Michaels, Mr. Cruise, and Ms. Atkin made similar comments to the students.

A few of the interns asked leading questions that may have caused students to give an inaccurate claim. For example, before the students introduced the inaccurate idea that the sun moving causes day and night, Ms. Kelly asked, "Where does the sun go at night? Does it move?" [K_CaSM_Interview]. How Ms. Kelly asked this question seemed to support the student to make an inaccurate claim that the sun moves to cause day and night. Ms. Schuster asked a similar question of her student.

In summary, during the Children as Sensemakers I enactments in the first month of the program, the interns facilitated students to make claims that answer the investigation question but did not often allow the students to share their thinking or justify their claims. The interns were able to handle children's alternative ideas, and some interns asked additional clarifying question about the alternative ideas.

End of Year One Survey: A Range of Knowledge for Supporting Students to Justify Their Claims

The end of year one survey suggested that some of the interns had knowledge of challenges students may face in making claims justified by evidence and reasoning. In response to the question, "What challenges would students have in constructing an explanation in response to the investigation question?" approximately one half of the responses identified challenges related to justifying claims with evidence and reasoning acknowledged in the empirical research, such as using evidence to support claims, making inferences beyond the data, and explaining why (see Table 5-2). Thirty-six percent of the responses discussed challenges children may have in using evidence or data in their explanations. For example, response 65 said, "[The students] may find it hard to pull multiple pieces of evidence together in a scientific explanation" [Survey_QE_R65]. However, other interns named challenges that did not seem as related to the science practice of constructing evidence-based claims but rather to general struggles students have, such as providing detail and using scientific vocabulary.

Table 5-2: Interns' Responses to the Question, "What Challenges Might Students Have in Constructing an Explanation in Response to the Investigation Question?"

Type	Percent of Responses	Examples
Using evidence/data in their explanations	36%	• They may find it hard to pull multiple pieces of evidence together in a scientific explanation [Response 65] • They may find it hard to talk about conflicting data [Response 11]
Reading and interpreting the graph/table/data	13%	• How to read the bar graph [Response 90] • The students would misinterpret the data [Response 86] • Understanding how to read the labels of the x-/y-axis and what the numbers represent (i.e., determining average time/depth) [Response 62]
Making inferences/assumptions about the data	12%	• They may try to incorporate opinions that are not scientific or fact based [Response 57] • They might make incorrect assumptions about the data [Response 19]
Being detailed, specific in their response	12%	• Students might not be specific in their explanations [Response 91] • Using detail to explain results [Response 15]
Knowing what an explanation entails or how to give an explanation	10%	• They might not know what a scientific explanation entails (Response 41) • How to structure a scientific explanation [Response 1]
Explaining why	8%	• They may just write down the facts about what happened and not explain why it happened [Response 23] • The students might not understand how to explain why the organisms had a certain set of results in his scientific explanation [Response 45]
Other	11%	• They might have a hard time putting it into words [Response 93] • Using scientific vocabulary [Response 44]

The end of year one survey also asked the interns to describe strategies they might use to support students with the challenges they named. However, compared with the variety of challenges named, the interns did not name as many different types of strategies. On average, interns named 1.37 strategies (standard deviation = 0.63). The most common response (38%) was to explain or tell students what they may not understand (see Table 5-3). Another 35% of the responses suggested modeling how to construct an explanation for students. These two strategies have been described as effective in supporting students in this science practice (e.g., McNeill, 2009); however, using these strategies by themselves may result in the teacher's doing the intellectual work. However, another 18% of responses described tools or scaffolds that interns would provide for students, such as a checklist or template, and 12% of the responses discussed providing practice or guided practice in constructing explanations. These two strategies are also described in the research as potentially effective and could support students to do the intellectual work (e.g., McNeill, 2009).

Table 5-3: Interns' Responses to the Question, "How Would You Help Students with the Challenges They Might Have with Constructing Explanations?"

Category	Percent of Responses	Example
Explain or tell	38%	• Define what a scientific explanation is. (Response 7) • 1. Explain that a scientific explanation should answer the question being posed. 2. Explain that they should use their data directly in their explanation as evidence. (Response 30)
Model for the students	35%	• I would model numerous scientific explanations along with teaching them what they must include in their explanations. (Response 51) • I would model and coach students through how to write a scientific explanation. (Response 29)
Provide tools or scaffolds for the students	18%	• I would give the students a checklist of what they should have in their scientific explanation, so they can be sure to use evidence and they will choose a side that they support (based on the experiment). (Response 15) • To help the students, we could start with a template that guides the student in the correct format. The template could remind them to only use evidence from the experiments and to look over their work to get rid of opinions/speculation. (Response 41)
Provide practice or guided practice	12%	• Practice creating scientific explanations based on already made data charts. (Response 36) • We would practice using evidence to support claims as well as discuss why we might compare and contrast data. We would practice this with other science material. Once I felt that the students were secure with this information, I would give them this assignment. (Response 6)

Pre-Assessment for the Science Methods Course: Potential in Eliciting Claims Yet Not Supporting Justification of Claims

On the pre-assessment for the Science Methods Course, the interns also showed potential for eliciting students' claims, yet the interns often did not plan for or support students to give a structured evidence-based claim with clear justification. In both the written plans of the 54 interns and the enactments of the five focal interns, interns typically supported students to make claims about the investigation *without* justification. As a reminder, the pre-assessment asked interns to plan for (and, for the focal interns, enact a plan for) supporting a student who struggled with the concept of conservation of matter, with the goal of making sense of the data and answering the investigation question. The five focal interns enacted their plan with a standardized student. (Information on the standardized student protocol is in Chapter 3 and Appendix B.)

Pre-Assessment Plans of the Entire Cohort. On their plans for pre-assessment, only 20% of interns' plans "met expectations" for quality of support for making claims justified by evidence and reasoning, and none of the interns' plans "exceeded expectations." The plans that "met expectations" typically included questions that asked students to answer the investigation question and connect it to evidence or reasoning. For example, Intern 18 planned to "repeat [the] original investigation question" and follow up by asking, "Is the salt still there?" [PreA_18]. Similarly, Intern 43 planned this set of questions:

> What is a general statement you can make about the weight of solutions and the weight of materials used to make [up] the solution? How does this compare to your prediction? How would you answer the investigation question now? Based on your data, does the salt actually disappear? [PreA_43]

This set of questions would support a student to answer the investigation question and support their claim with justification from their investigation.

Forty-three of the interns "partially met expectations." Typically, plans that "partially met expectations" included support for the child to make a claim that did not address the investigation question. These questions often had students make claims about aspects of the data rather than bringing together a complete answer to the investigation question. For example, Intern 20 planned to ask, "How much did the salt weigh that we then added to the water?" and expected the students' response from would be "15 [grams]" [PreA_20]. This question and expected claim supports the student to name an invisible part of the investigation that the dissolved salt still has weight. However, the intern does not use the child's "new understanding" to answer the investigation question or support it with data from the investigation. Intern 33 planned similar questions that did not respond to the investigation question and the concept of conservation of mass: "What happens to [the] weight of water when something is added to it? What can we conclude?" [PreA_33]. These questions do not focus on the investigation question in the same way as the questions from the "meets expectation" group. A few plans from the "partially meets expectations" group did not include a connection between the answer to the investigation question and the evidence or reasoning. For example, after supporting the student to make sense of the data from the investigation, Intern 8 planned to ask, "How can we answer the investigative question?" [PreA_8], but did not plan to facilitate the student to give evidence or reasoning to justify their response.

The final group of plans, 33%, "did not meet expectations." These plans typically had two areas of struggle: telling students the answer or expecting an inaccurate claim for the investigation. In terms of telling students the answer, Intern 44 planned to "explain that … the weight did not disappear. The salt may dissolve, but the weight is maintained." Another intern wrote,

> First, I would explain to the student that we can see that [the] glass [of] water has weight that is 100g. Then, I would tell the student that the salt weights 10g. We know that the salt weighs even though it may dissolve, we are still adding the weight of the salt to the water [PreA_13].

Both of these plans include the teacher telling the student the answer to the investigation question rather than facilitating the student to do the intellectual work of constructing the evidence-based claim.

Interns also sometimes planned for facilitating students to make inaccurate or confusing claims. For example, inaccurate claims included "the weight of a solution increases by the weight of the materials used to make up the solution, which in this case, is the salt” [PreA_29] and “the weight of the solution is less than the materials used to make up the solution" [PreA_19]. These examples suggest that the interns might support the students to make inaccurate claims and confuse students.

Only 4% of interns’ plans included additional follow-up question to facilitate students to name the evidence connected to the claims. For example, Intern 11 planned to ask, “How do you know?” [PreA_11] after the student was asked to answer the investigation question. However, the interns did not plan to support students through other types of tools or scaffolds for construction of claims or to use an explicit structure to construct evidence-based claims.

Pre-Assessment Enactment. In the enactment of the pre-assessment with a standardized student (e.i.an adult acting in the role of a child), the struggles of the five focal interns to support students to make claims justified by evidence and reasoning were similar to those seen in the entire cohort’s lesson plans (see Table 5-4). Four of the five focal interns received a “partially meets expectations” for the quality of their support, and one intern “did not meet expectations.”

The four interns who “partially met expectations,” Ms. Kelly, Ms. Atkin, Mr. Cruise, and Ms. Michaels, supported the students to make a claim about the natural phenomenon, yet these claims often did not directly answer the investigation question. For example, at the end of her interaction with the standardized student, Ms. Atkin asked, “Does the salt go into the water?” Although this question is focused on an implicit aspect of the investigation, it would not, by itself, enable the student to answer the investigation question [A_PreAssess]. Mr. Cruise also did not ask the student to make a claim to answer investigation question. Instead, he asked, “What do you think happened in the investigation?” [C_PreAssess]. Ms. Michaels reviewed the investigation question at the beginning of her interaction but did not have the student give an answer after analyzing data to reveal patterns and relationships. At the end of the interaction, Ms. Kelly asked the student to answer the investigation question. However, she had told the student the answer to this question earlier. In contrast, Ms. Schuster did not support the student to make a claim about the investigation, and, thus, her enactment was deemed to "not meet expectations."

Table 5-4: Teaching Moves Used and Quality of Support for Making Claims Justified by Evidence and Reasoning during the Pre-Assessment Standardized Student Enactment

	Ms. Kelly	Ms. Atkin	Mr. Cruise	Ms. Michaels	Ms. Schuster
Supports the student[s] to make claims	X	X	X	X	
Uses a structure to construct evidence-based claims					
Uses other scaffolds/tools to support construction of claims (sentence stems, peers, etc.)					
Connects students' ideas to each other	X				
Gives feedback on construction of claims					
Follows up on an alternative idea that the child gives	X				
Does not ignore an alternative claim that the child puts forth	X	X	X	X	X
Supports students to describe evidence		X	X	X	
Supports students to describe reasoning			X		
Does not do the intellectual work of naming the evidence for the student		X	X		n/a
Does not do the intellectual work of naming the reasoning for the student		n/a		X	n/a
Does not tell the student the claim ahead of time	X	*X*	X		X
Quality of support	Partial	Partial	Partial	Partial	Does not meet

Although the interns typically supported the standardized student to make a claim, they did not typically use other scaffolds or tools to support the construction of the claim or connect students' ideas to each other. None of the interns provided additional supports or tools to facilitate the construction of evidence-based claims. Only Ms. Kelly connected students' ideas to each other. She read another student's prediction to the student and asked the student, "Do you agree or disagree with what the student said?" [K_PreAssess]. The other interns did not make this type of move. However, this type of move is unexpected in this interaction, because each intern was working with only one (standardized) student.

Except for Mr. Cruise, the interns did not support the standardized student to describe the reasoning and evidence in justification of the claim. Mr. Cruise supported the student to describe the reasoning for the claim by asking, "Can we try and say what we learned from these claims [the statements about a solution from previous classes] and apply it to this investigation?" [C_PreAssess]. The student also provided evidence to support the claim. The other interns did not press for this reasoning, yet Ms. Atkin and Ms. Michaels also supported the students to provide evidence to support the claim.

Ms. Kelly and Ms. Michaels did the intellectual work of connecting evidence to the claim for the student. For example, Ms. Kelly stated the evidence and reasoning for the claim that the weight stays the same, saying that even though "we can't see the weight with our eyes," the weight of the salt is still there. She added, "We still counted the same amount of materials as before, but we just mixed them together" [K_PreAssess]. Ms. Michaels told the student the reasoning and evidence for the claim for the investigation early on, stating that the salt was still there "because it dissolves" [M_PreAssess]. Mr. Cruise also named other aspects of the reasoning for the student. Ms. Atkin and Ms. Schuster did not push for the student to give evidence and reasoning, nor did they state the evidence or reasoning themselves.

The interns typically acknowledged students' alternative ideas about the phenomenon, yet they did not often follow up on the student's thinking. For example, early in the enactment, Ms. Atkin asked, "Do you think that the weight of the salt was in the water?" and the student responded, "I didn't see [it]." Later in the interaction, Ms. Atkin returned to this idea, asking, "Does the salt go into the water?" [A_PreAssess]. This showed Ms. Atkin's recognition of the student's alternative idea. Mr. Cruise, Ms. Schuster, and Ms. Michaels did similar work with students' ideas, and Ms. Kelly probed more about the student's alternative idea. She asked the child to share, asking, "Tell me how you predicted this?" when the child stated that the salt would disappear [K_PreAssess]. This additional probing would enable her to further support the child's thinking about the accurate claim for the investigation question.

In summary, the interns tended to plan to support or did support the standardized student to make claims about the investigation on their pre-assessment. However, they did not often plan to support or did not provide support for students to describe the evidence or reasoning to justify the claim. In their enactments, the focal interns typically acknowledged the alternative ideas of the student, and one intern probed further about this idea. Yet the interns did not typically plan for additional supports for constructing evidence-based claims.

Summary of Pre-Methods Class: Supporting Students to Make Claims

In the first year of the program, the cohort of interns tended to be able to plan for or support students to make claims about the phenomenon. However, they tended to provide the justification of claims for the students on their lesson plans or in their interactions. On their survey, the interns seemed to recognize the importance of justification of claims, yet they did not seem to be able to name teaching moves for supporting students in this work beyond telling or explaining. The lesson plans and enactments showed similar struggles in knowing how to support students.

Science Methods Class: Potential in Supporting Students to Construct Evidence-Based Claims

In contrast to the struggles that interns showed in supporting students to make claims justified by evidence and reasoning during their first year, the interns showed great potential during the Peer Teaching in their science methods class. However, the interns typically struggled to use the potential they showed when they planned for and enacted the Reflective Teaching lesson with an entire class of elementary students.

Peer Teaching: Strengths in Planning for and Enacting Support for Constructing Evidence-Based Claims in Logical Structure

On both their lesson plans and their enactments, the majority of interns "met" or "exceeded" expectations in terms of the quality of support for students to make claims justified by evidence and reasoning (See Table 3-4 in Chapter 3 for more information on the lessons). Although a few still struggled with doing the intellectual work of justifying claims for the students, the interns tended use additional supports for students to make claims and justify these claims with evidence and reasoning.

Peer Teaching Lesson Plans. On their plans for the Peer Teaching lessons, 75% of the interns "met" (54%) or "exceeded expectations" (21%) in terms of quality of support for making claims justified by evidence and reasoning. These interns typically planned for students to make a claim to answer the investigation question and planned to provide supports to answer the claim. For example, Intern 40's plan:

- Generate a claim from the central question:

- What happens when a bag of hot water is placed in a container of cold water? *(I anticipate that my students will discuss that heat energy from the hot water transferred to the cold water until the two water temperatures were even.)*
- Ask students to connect claims to evidence
  - What are your observations?
  - Where do you see the change? How long did it take for you to observe a change in the cold water temperature?
  - How do we know that the two waters did not mix? [PT_40]

This plan included teaching moves to ask the students the investigation question and to have students explicitly justify their claim with multiple pieces of evidence. The other interns who "met" or "exceeded expectations" planned to make similar moves.

Only one plan (2% of the plans) "did not meet expectations." In this plan, the teacher planned to state the answer to the investigation question and lecture about the answer:

> What [scientists] discovered is that heat energy is conducted, or transferred, from a warmer object to a colder object… . This is exactly what happened in our experiment: the heat from the warm water transferred to the cold water, warming it up [PT_32].

Thus, this intern did not plan to support the students to do the intellectual work of constructing a claim with evidence or reasoning to support the claim.

A final group (23%) of the interns "partially met expectations." Those who "partially met expectations" typically had two types struggles: (1) the plan did not explicitly have students answer the investigation question, or (2) the plan did not explicitly link the claim to the evidence. An example of the first struggle is Intern 10's plan. After discussing patterns in the data, the intern planned to "ask some challenging questions that encourage students to think through the process of how heat energy transfers between substances" [PT_10]. This plan seems to skip the step of asking the investigation question and explicitly connecting it to the evidence generated in the investigation. An example of the second struggle is Intern 44, who planned to ask if other students agreed with a student's claim with "thumbs up/down if they agree with others," but did not ask the students to state why they agreed or what evidence they had [PT_44].

Despite the struggles seen in some of the interns' plans, the plans typically showed strengths for supporting students to make claims justified by evidence and reasoning. Ninety-one percent of the interns planned for students to make a claim about the investigation. Seventy-five percent of the interns planned to use a structure to support students to make these claims and justify them with evidence or reasoning (or both), and 65% of the interns planned to provide additional support for constructing these claims. For example, Intern 25 planned to ask students, "Since we have this claim, what evidence can we use from our tables to help us support this claim so other[s] will believe this is true?" and, then, the intern provided the sentence stem, "I think _____ because _____" [PT_25]. In this plan, Intern 25 made it clear that a claim should have evidence to justify the claim and made a logical structure for evidence-based claims apparent to the student. The sentence stem would also serve as an additional support for this structure. In addition to the sentence stem that Intern 25 planned to provide, the interns planned to provide other forms of support or tools for justifying one's claims. Examples of these supports or tools are probing question, such as "*What have we seen or done that makes us think this is the answer to our question?"* [PT_20], and modeling an initial claim with evidence.

Some of the interns included plans for other teaching moves such as supporting students to connect their claims to each other (23% of plans). For example, after a student stated a claim, Intern 6 planned to ask,

> Do you agree/disagree with what student X said? Why? Raise your hand and share what you think if it is different from student X. Do you agree/disagree with student Y? Why? [PT_6].

This set of questions would facilitate students to build on one another's thinking. Two of the interns planned to have students consider the quality of their claims. For example, Intern 1 planned to "clarify claims that are not actually claims" and "have students help pick the important parts" of the claim and evidence "to synthesize" [PT_1]. This move would push the students to more critically consider and analyze their thinking from the investigation.

Peer Teaching Enactment. Like the Peer Teaching plans of the entire cohort, the Peer Teaching enactments of the five focal interns showed several areas of strength in terms of supporting students to make claims justified by evidence and reasoning. In terms of quality, Mr. Cruise and Ms. Michaels "met expectations," Ms. Kelly and Ms. Schuster "exceeded expectations," and Ms. Atkin "partially met expectations" (see Table 5-5).

Table 5-5: Teaching Moves Used and Quality of Support for Making Claims Justified by Evidence and Reasoning during Peer Teaching

	Ms. Kelly	Ms. Atkin	Mr. Cruise	Ms. Michaels	Ms. Schuster
Supports the student to make claims	X	X	X	X	X
Uses a logical structure to construct evidence-based claims	X	X	X	X	X
Uses other scaffolds/tools to support construction of claims (sentence stems, peers, etc.)	X	X	X	X	X
Connects students' ideas to each other	X	X	X	X	X
Explicitly follows up on an alternative idea that the child gives	X	X	X		X
Does not ignore an alternative claim that the child puts forth	X	X	X	X	X
Supports students to describe evidence	X	X	X	X	X
Supports students to describe reasoning	*	X	X	X	X
Does not do the intellectual work of naming the evidence for the student	X		X	X	X
Does not do the intellectual work of naming the reasoning for the student	X	X	X		X
Does not tell the student the claim ahead of time	X	X	X	X	X
Quality of support	Exceeds	Partial	Meets	Meets	Exceeds

*Ms. Kelly ran out of time to finish discussing the reasoning.

All five of the focal interns supported students to make claims and used a logical structure. They also defined the terms *claim* and *evidence* for their students (see Table 5-6). For example, Ms. Michaels stated,

> I want to start thinking about a claim for our investigation question, "How does the water travel from the roots to the leaves of our celery?" Remember, *claim* is how we are going to answer our question. I want you to turn to [your partner] and share with your partner how you could answer the question. [M_PeerTeach]

After a few students shared their claims, Ms. Michaels followed up by saying, "Now that we have our claim, we need to find evidence that backs up our claim" [M_PeerTeaching]. In this interaction, Ms. Michaels both introduced the terms *claim* and *evidence* and allowed her students to share claims with one another and with the class. She also supported her students to use a logical structure by writing the claim on the board and writing the evidence directly under the claim. The other focal interns used similar teaching moves to support their students to make claims justified by evidence and reasoning that were accurate and aligned with the patterns found in the investigation.

Table 5-6: Supports for Constructing Evidence-Based Claims Used during Peer Teaching

	Ms. Kelly	Ms. Atkins	Mr. Cruise	Ms. Michaels	Ms. Schuster
Introduces/defines claim/evidence	X	X	X	X	X
Models how	X				
Gives a worksheet	X	X			X
Checklist for strong claim					
Sentence stem	X	X			X
Work in pairs				X	
Gives feedback on claims	X			X	

In addition to using a logical structure, the focal interns also used other forms of support for making claims justified by evidence and reasoning during Peer Teaching. Ms. Kelly modeled how to make a claim and support it with evidence. After writing this claim with evidence on the board, Ms. Kelly asked, "What was my claim?" and "What was my evidence?" [K_PeerTeach].

These questions would push students to think about these terms and clarify any questions that they might have. Ms. Kelly, Ms. Atkin, and Ms. Schuster also provided their students with worksheets to write down their claims. These worksheets had sentence stems to support students in writing their claim justified by evidence. For example, Ms. Atkin wrote on the board the sentence stem, "I think the stem's function is … because …" and told students to write the answer on their worksheet [A_PeerTeach]. Although Ms. Michaels did not have the students write down their claims and evidence, she did support her students by having them discuss in pairs as described above. This seemed appropriate because Ms. Michaels planned her lesson for kindergarten students. Ms. Kelly and Ms. Michaels also provided feedback on the claims and evidence that their students constructed. For example, Ms. Michaels commented on the list of evidence her students had discussed, saying, "I think that this is good evidence" [M_PeerTeach]. Ms. Kelly pushed her students to clarify their evidence-based claims, saying, "We have to be specific and go to our data in our experiment" [M_PeerTeach]. All of these types of supports that the interns provided have been discussed in the research as productive in the facilitation of the construction of evidence-based claims.

All of the focal interns also worked to connect their students' ideas to each other when discussing claims. For example, after a student shared a claim, Ms. Schuster asked, "Does anyone want to add something to what [the student] said?" [S_PeerTeach]. Mr. Cruise questioned, "Do others agree?" [C_PeerTeach], and Ms. Kelly asked, "Why do you agree with that?" [K_PeerTeach]. These types of questions supported the students to make connections across their thinking.

All five focal interns also did not ignore alternative ideas provided by the students, and four of the five interns (Ms. Kelly, Ms. Atkin, Mr. Cruise, and Ms. Schuster) explicitly followed up on these alternative ideas. Ms. Atkin asked a student who had brought up an alternative idea what she thought of another student's accurate statement that contradicted the alternative idea [A_PeerTeachExplain]. Ms. Schuster also clarified a student's alternative idea by rephrasing the student's statement: "So you think … some of the cold [water] gave some of its energy to the hot [water]" [S_PeerTeach]. These questions that follow up on alternative ideas allowed the interns to clarify the mechanisms involved in the investigations and students' thinking about these mechanisms.

The five interns supported their students to describe verbally the evidence or reasoning for the claims that they made, allowing the students to do the intellectual work of justifying the claim. For instance, after a student shared the evidence of "because it happens," Ms. Kelly pushed further saying, "We need to make the … evidence more specific" [K_PeerTeach]. The student then provided more sufficient evidence for the claim. After introducing a new concept to his students, Mr. Cruise pushed the students to consider how the scientific concept helps support their possible claims, saying, "Now that we know that …., can we apply this to any of our claims?" [C_PeerTeach]. Ms. Michaels and Ms. Schuster made similar moves to facilitate their students to justify their claims with evidence and reasoning.

Although the interns typically supported their students to justify their claims with evidence and reasoning, Ms. Atkin did aspects of the intellectual work by naming the claim and evidence for her students. In attempting to correct a student's inaccurate claim and evidence, she stated the claim for her students ("the tubes suck up most of the water") and gave the evidence for the claim: “the tubes are red”[3] [A_PeerTeach]. Moreover, she did not have students consider why this evidence would justify this claim or support students to extend this claim further, although the students seemed to have the information to do this work.

Summary of Peer Teaching. In summary, the interns’ support for making claims justified by evidence and reasoning during Peer Teaching showed several areas of strength. Most interns planned for using a logical structure for evidence-based claims and providing additional supports for students to construct a claim justified by evidence. In their enactments of their lesson plans, four of the five focal interns used these supports to facilitate their students to do the intellectual work of constructing evidence-based claims and discussing the claims with one another. These many strengths may have resulted from the great amount of support that interns received on this assignment. Despite these strengths during Peer Teaching, a few interns still struggled with planning to explicitly support students to answer the investigation question and provide evidence for their claims.

Reflective Teaching: A Range of Support for Constructing Evidence-Based Claims with an Entire Class

Despite their successes in planning and enacting support for making claims justified by evidence and reasoning during Peer Teaching, the interns’ Reflective Teaching lesson plans and enactment of these lesson plans suggested difficulty in applying their learning to teaching an entire class of students. When asked to plan the Reflective Teaching Lesson on their own, the

---

[3] This investigation involved putting red food coloring in the water for the celery. The red food coloring moved up the tubes (vascular bundles) in the celery. Thus, the tubes’ being red was evidence that there was water in the tubes. See Table 3-4 in Chapter 3 for more information.

interns seemed to struggle more than before. However, high variation existed in the quality of support for this assignment, with a portion of the interns showing great success in this area.

Reflective Teaching Lesson Plans. On their Reflective Teaching lesson plans, the interns showed a range of quality. Forty-two percent of the interns “met” or “exceeded expectations” for the quality of support; 15% “did not meet expectations,” and 43% “partially met expectations.” The interns who “met” or “exceeded” tended to plan for students to make a claim that answers the investigation question and support it with evidence. For example, Intern 15 planned the following:

> The teacher will remind students of the investigation question.… The teacher will ask more questions to push the students toward using evidence. “Why do you think that? What characteristics told you that? What is your evidence?” [RT_15].

This plan required the students to answer the investigation question and give evidence to support their claims. Fifteen percent of the interns “exceeded expectations”; these interns typically went beyond requiring students to state the evidence by having students discuss the mechanism involved (e.g., “so the next part, the final part, is for us to explain using scientific reasoning” [RT_2]), or to evaluate the evidence-based claims of their classmates (e.g., “What do you think about their explanation?” [RT_31]).

In contrast, plans that “did not meet expectations” typically included either the teacher’s telling the students the claim and evidence or they did not plan for anyone to name a claim. Intern 30 planned to tell students the answer to the investigation question “What makes a rock different from other materials?” as follows:

> I will go over the ideas that we have come up with and then explain that a rock is a natural, solid object made of one or more different minerals. Then I will go through each object that was discussed and confirm whether or not it is a rock and why. (RT_30)

In this plan, the teacher would do the work of constructing the evidence-based claim for the first-grade students. Intern 12 did not plan for the investigation question to be answered; rather, she planned to discuss “unusual data” and to “explain again” the big idea of the lesson [RT_12].

The plans that “partially met expectations” typically had one of two challenges: (1) not explicitly answering the investigation question or (2) not clearly identifying evidence that students could use to justify the claim. An example of the first challenge is Intern 48’s plan that asked, “Why is a screw considered to be an inclined plane?” but not the investigation question of “How are the different slopes of an inclined plane related to a screw?” [RT_48]. An example of the second challenge is illustrated by Intern 19, who planned for students to “turn and talk with a partner about a possible claim you can make” but did not plan for students to connect the reasoning or evidence from their investigation to justify this claim [RT_19]. However, the plan did include discussing the evidence when students found a pattern in the data.

Although some of the lesson plans showed struggles, others showed strengths. Ninety-five percent of the plans included a place for students to make a claim, as Intern 15 did above. Sixty-eight percent of the interns planned to provide additional supports for students in constructing the evidence-based claim, such as modeling “an example, if needed” [RT_49] or giving a sentence starter “to show how we are thinking” [23_RT]. Thirty-six percent of the plans included a logical structure for evidence-based claims. For example, Intern 22 planned to tell the first grade students, “We start a claim with ‘I think’ … and then we always must support claims with evidence and you can say ‘I think this because I see…’” [22_RT]. Twenty percent of the plans included ways to facilitate students to connect their ideas to each other, such as “Does everyone agree?” [29_RT] and “Do you agree/disagree and why?” [21_RT].

Reflective Teaching Enactment. As seen with the lesson plans for the entire cohort, the five focal interns' enactment of these plans showed a range of quality for supporting students to make claims justified by evidence and reasoning. Ms. Kelly, Mr. Cruise, and Ms. Michaels "partially met expectations," Ms. Atkin "met expectations," and Ms. Schuster "exceeded expectations" (see Table 5-7). Within this range, similarities and differences existed in how the focal interns provided supports for making claims justified by evidence and reasoning to students in the classroom.

Table 5-7: Teaching Moves Used and Quality of Support for Making Claims Justified by Evidence and Reasoning during Reflective Teaching Enactment

	Ms. Kelly	Ms. Atkin	Mr. Cruise	Ms. Michaels	Ms. Schuster
Supports the student[s] to make claims	X	X	X	X*	X
Uses a structure to construct evidence-based claims		X		X	X
Uses other scaffolds/tools to support construction of claims (sentence stems, peers)	X	X	X	X	X
Connects students' ideas to each other	X	X	X	X	X
Follows up on an alternative idea that the child gives	X			X	
Does not ignore an alternative idea that the child puts forth	X	X	X	X	X
Supports students to describe evidence	X	X		X*	X
Supports students to describe reasoning		X	X	X*	X
Does not do the intellectual work of naming the evidence for the student		X		X	X
Does not do the intellectual work of naming the reasoning for the student		X	X	X	X
Does not tell the student the claim ahead of time	X	X	X	X	X
Quality of support	Partial	Meets	Partial	Partial	Exceeds

*The claim, evidence, and reasoning that Ms. Michaels supported her students to share involved non-normative science ideas.

All five interns supported students to make claims with justification to answer the investigation question posed. In each of the classrooms, the evidence-based claims were co-constructed by the students and intern. Four of the focal interns then had students write individual claims as well. For example, in the transcript below, Ms. Atkin had a student share his thinking about the data with the whole class to build up to making a claim to answer the question, “How does the color affect an organism’s survival?” She then supported the students to write these claims individually by providing a stem sentence.

> Ms. Atkin: What did you notice that was happening [during the investigation]?
> Student 1: I noticed that at the yellow station, the yellow beads they were hard to see. At this [purple] station, these [purple] beads were harder…
> Student 2: and the clear [beads]
> Student 1: and the clear [beads]. It does matter what the habitat in how they blend into the color.
> Ms. Atkin: So, I'm hearing her say that the beads that blended in with their background were much harder to see when you pick them up. I want you to … write a claim.... The claim starts with “the organism that is the same color as its habitat is” and you're going to say what happens. Is it more likely [or] is it less likely to survive? [A_RT]

The other five interns also supported their students to construct a claim about the phenomenon based on the patterns found in the investigation. In four of the five lessons, the co-constructed claim was accurate and complete; however, in Ms. Michaels’s class, the claim was confusing. This claim suggested that weight alone caused objects to sink in water; however, density rather than weight caused objects to sink. Emphasizing weight alone is inaccurate and could result in a common misconception for her students.

Through use of the different tools and questions, the interns also supported students to justify their claims made about the investigation with evidence and reasoning. Ms. Kelly, Ms. Atkin, Ms. Schuster, and Ms. Michaels supported their students to use evidence to justify their claims. For example, Ms. Michaels asked her kindergarteners, “How did we know?” [M_RT]. This facilitated the students to name data that they collected in their investigation to support their claim. Ms. Atkin, Ms. Schuster, Mr. Cruise, and Ms. Michaels supported their students to connect their evidence to their claims. In his lesson on the flow of nutrients, Mr. Cruise asked his students, “What have [we] shown here?” and allowed the students to describe the cycling of nutrients. This facilitated the students to give their reasoning and to connect the evidence of how the organisms interacted in the ecosystem to the claim about the interdependence of living things. In this discussion, the students drew on their understanding of how decomposers cycle nutrients in the soil (a topic of the previous lessons) in order to answer this question. Except for Ms. Kelly, the other interns made similar moves that allowed students to share their reasoning to support the claims.

Three of the interns discussed a logical structure for evidence-based claims with their students. In her fifth grade class, Ms. Schuster explicitly discussed the terms *claim* and *evidence* with her students, describing how including evidence “would make someone else believe the whole thing” [S_RT]. Ms. Schuster asked for a “claim supported with evidence,” asking students to use “scientific definition[s]” to support their claims [S_RT]. In her fourth grade class, Ms. Atkin told students to write a claim, and “then, you have to support it with data, you need to say why based on data” [A_RT]. In this discussion, Ms. Atkin introduced a logical framework for evidence-based claims, although she used the term *data* rather than *evidence*. In her kindergarten classroom, Ms. Michaels asked students the investigation question to support them to make a claim. After students made a claim, she then asked, “Why?” which required the students to justify their claim. Once the students had given their justification, she told them, “So we have evidence” and listed the students’ comments as evidence on the board.

In addition to a logical structure, the interns used a variety of supports to facilitate students in constructing evidence-based claims. Table 5-8 summarizes some of the different supports used by the teachers. Ms. Schuster’s teaching moves showed examples of these supports in the her lesson on healthy cereals. During the lesson, she discussed with students what claim, evidence, and reasoning are, and then she modeled how to make a claim. She emphasized the importance of evidence while modeling her claim, saying, “Do you see what I did there? I used the evidence” [S_RT]. Ms. Schuster provided a sentence stem for students to use when making their claim and a checklist for students to use to give feedback about one another's claims. This checklist included these topics: "1. All 3 cereals are mentioned. 2. A claim is made about which cereal is the best source. 3. There is evidence, 3 numbers supporting each cereal. 4. Explain how this helps the body" [S_RT_LessonPlan]. Ms. Schuster also provided students with an additional worksheet that included the prompt of the scientific question for students to give their answer and allowed students to work in groups before writing another claim individually. As seen in Table 5-8, other interns provided some similar supports but not in all their lessons.

Table 5-8: Teaching Moves Used and Quality of Support for Making Claims Justified by Evidence and Reasoning during Reflective Teaching

	Ms. Kelly	Ms. Atkins	Mr. Cruise	Ms. Michaels	Ms. Schuster
Introduces/defines claim or evidence		X		X	X
Models how					X
Gives a worksheet	X		X		X
Checklist for strong claim					X
Sentence stem	X	X		X	X
Work in pairs/groups					X
Gives feedback on claims					X

All of the interns also worked to connect students' ideas with each other. For example, Ms. Michaels and Ms. Kelly asked their students to give a "thumbs up if you agree with" what another student said, and a "thumbs down if you disagree" [M_RT; K_RT]. Ms. Michaels then followed up with a student, asking why the student did not agree. Mr. Cruise asked other students in the class to answer one another's questions, saying "H____ raised a good question.... Do you have a thought about that?" [C_RT]. Ms. Atkin also facilitated her students to make connections across their ideas with the statement, “As I was walking around, I saw a common theme between most of your claims” [A_RT]. Ms. Schuster had the students evaluate one another’s claims using the checklist she provided.

In terms of considering students’ ideas about the phenomenon, the focal interns showed several strengths. Ms. Kelly followed up on the alternative ideas that the students presented to the class. For example, in their lesson on evaporation, the first graders in Ms. Kelly’s class claimed that the water “disappeared.” Ms. Kelly followed up on this idea by asking, “Where do you think the water went?” This question allowed the students to clarify their claim by saying “into the paper” [K_RT]. Through this interaction, Ms. Kelly learned more about her students’ thinking; she also followed up with other students about their alternative ideas.

Although Ms. Kelly was the only intern to follow up explicitly about alternative ideas, the other interns did not ignore the alternative claims posed by students. For example, Ms. Schuster facilitated her students to claim that different cereals were “healthier” depending on the nutrients considered. Similarly, by asking why a student did not agree, as described above, Ms. Michaels allowed multiple claims to be made about the phenomenon. Ms. Atkin, Mr. Cruise, and Ms. Kelly also facilitated the consideration of multiple alternative claims during their lessons.

Although the interns facilitated students to bring up multiple claims, four of the five interns sometimes did aspects of the intellectual work of justifying the claims with evidence and reasoning for the students. For example, Ms. Kelly told her students that the steam from the kettle evaporated and changed “from the liquid state, which is just water in a cup, to the gas state” without supporting the students to make a claim and use the data from the investigation to describe this process for themselves [K_RT]. She also did not support the students to name the evidence that they saw that would support this claim. Likewise, Mr. Cruise named the evidence from the investigation that showed that the nutrients flowed in a cycle rather than allowing the students to do this. In contrast, the other interns supported their students to do the intellectual work of justifying the claims with evidence and reasoning themselves through the support they provided.

Summary of Reflective Teaching. In summary, the interns' plans for their Reflective Teaching assignment and enactment of these plans showed a range of quality for supporting students to make claims justified by evidence and reasoning. Some interns (e.g., the focal intern Ms. Schuster) planned for and provided a variety of strong supports for students, such as providing sentence stems and feedback on their evidence-based claims. Others struggled. For example, some interns planned to tell children the answers to the investigation question rather than supporting students to do the intellectual work of constructing an evidence-based claim.

Post-Assessment: Showing Growth from the Beginning of Science Methods

The post-assessment plans from the science methods class showed areas of growth for supporting students to make claims justified by evidence and reasoning. Given that the pre-assessment and post-assessment had the same requirements, I compare these two assessments directly in Figure 5-1. As seen in Figure 5-1, the percentage of plans that "did not meet expectations" decreased from 33% on the pre-assessment to 10% on the post-assessment. As seen in the pre-assessment, those plans that "did not meet expectations" typically included the teacher telling the explanation. For example, Intern 41 planned to "explain that ... salt does not disappear" [PostA_26].

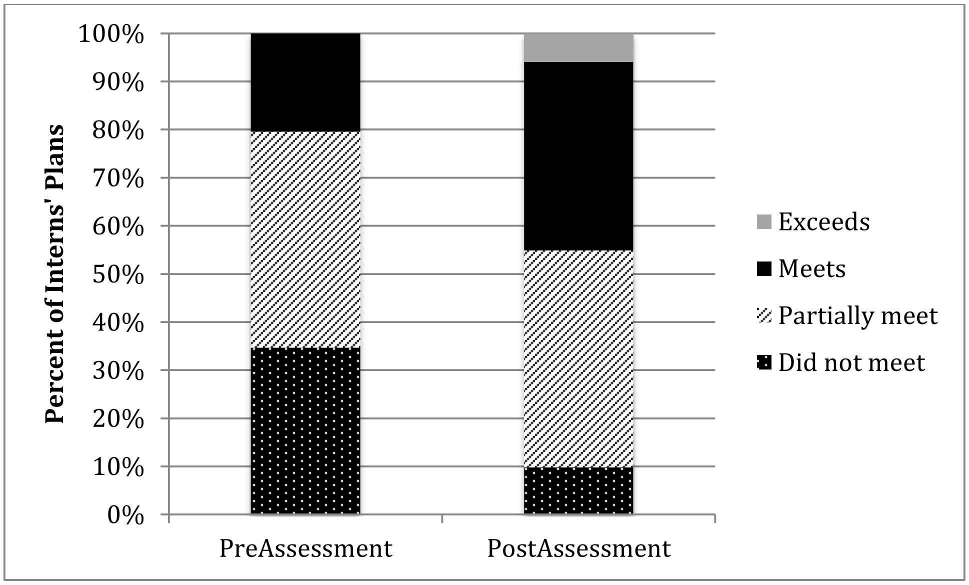


Figure 5-1: Graph of Quality of Support for Making Claims Justified by Evidence and Reasoning during Pre-Assessment and Post-Assessment Plans

The proportion of plans that "partially met expectations" remained fairly consistent from the pre-assessment (43%) to the post-assessment (45%). The post-assessment plans that "partially met expectations" typically did not answer the investigation question, "How does the weight of the materials used to make up a solution compare to the weight of the solution?" An example of this challenge is Intern 21's post-assessment plan that asked, "Did the weight of anything change after mixing the solution?" rather than "How does the weight of the materials that make up a solution compare to the weight of the solution?" [PostA_21].

The proportion of plans that "met expectations" increased from 20% on the pre-assessment to 39% on the post-assessment. The number of plans that "exceeded expectations" also increased from zero to three interns' plans (6%). The post-assessment plans that "met expectations" and "exceeded expectations" included support for students to answer the investigation question and justify their claims. For example, Intern 40 planned to ask, "What do your data tell you about, so that you can answer the question?" after asking the students to describe what they found in the data [Intern 40]. Compared with 4% of the pre-assessment plans that explicitly asked the students to name the evidence for the claims, 20% of the post-assessment plans planned for students to do this work. For example, Intern 22 planned to say, “Remember, our claims need to be supported by evidence: Can you explain [what] … happened to support your claim?” [PostA_22]. In addition to planning for naming the claim and the evidence, the plans that “exceeded expectations” planned for the students to discuss the reasoning involved in the investigation, such as prompting for “scientific reasoning: the science behind the claim and evidence” [PostA_2] or for the class to evaluate the evidence-based claims.

Summary of Supporting Students to Make Claims Justified by Evidence and Reasoning during Science Methods

In summary, the interns showed growth in supporting students to make claims justified by evidence and reasoning during the Science Methods Course. The Peer Teaching lesson plans and enactments showed several strengths, including facilitating students to make claims and justify these claims. The Reflective Teaching lesson plans and enactments showed a range of quality. For example, some plans included multiple tools for supporting students, and others planned to tell students the answer to the investigation question. The post-assessments plans showed an increase in quality as compared with the pre-assessment, yet some interns still struggled to plan for students to make a claim that answered the investigation question and justify this claim.

Post Science Methods Class: The Final Semester of the Program

All four of the interns followed into student teaching seemed to struggle to bring the strengths for supporting students to make claims justified by evidence and reasoning seen during the science methods class into their student teaching semester. (Ms. Schuster did not teach science during student teaching.) Although the interns typically had students make a claim and justify this claim with evidence or reasoning during student teaching, they often did the intellectual work for the students. In this section, I consider the quality of support during the focal interns' student teaching lessons, and their enactments with a standardized student at the end of the year.

Student Teaching: Struggles to Support Students to Construct Claims with Justification Consistently

The focal interns struggled to provide high-quality support for making claims justified by evidence and reasoning during student teaching. Most of the investigations (6 out of 12) "partially met expectations" (see Table 5-9). Six out of 11 of these investigations involved the interns supporting students to make claims about an investigation with justification, but the teachers often did aspects the intellectual work of constructing the evidence-based claims for their students. For example, during Ms. Atkin's second investigation that compared series and parallel circuits, this interaction occurred between Ms. Atkin and the students:

> Ms. Atkin: What are we noticing about what's happening with the parallel circuits?
> Student 1: I see that the parallel circuits are about the same.
> Ms. Atkin: We're seeing that parallel circuits don't … affect the brightness of the bulb, but the series circuits do affect the brightness of the bulb…. When we have 2 batteries in a series, what happens to the brightness of a bulb?
> Student 2: The bulb is brighter.
> Ms. Atkin: When we have two bulbs in a series what happens?
> Student 3: The bulb is dimmer.
> Ms. Atkin: Because we have more resistance [A_Field4].

In this interaction, Ms. Atkin supported Student 1 to make a claim about the investigation, "The parallel circuits are about the same," but Ms. Atkin completed the claim herself by describing how series circuits do affect the brightness of bulbs. Ms. Atkin asked for evidence for this claim with the question, "What happens to the brightness of the bulb," yet the class does not discuss how this evidence helps justify their claims. Ms. Atkin also did the work of connecting the evidence and claims with the reasoning for the students by discussing resistance, yet the students may have been able to do this work themselves because earlier the class had discussed the ideas of resistance and power in series circuits. This doing aspects of the intellectual work of justifying the claims with evidence was common in the focal interns' investigations that "partially met" expectations. Six of the seven investigations that "partially met" expectations involved students making a claim about the phenomenon as Ms. Atkin's students did, and all seven investigations involved students naming reasoning or evidence similar to the students in the example from Ms. Atkin's class. However, in all seven investigations that "partially met expectations," the interns did aspects of the intellectual work of constructing the evidence-based claims for students. Unlike the situation with other investigations that "partially met expectations," Ms. Michaels supported the students to justify their claims with reasoning during her second investigation; however, she did not draw on the evidence collected during the investigation.

Table 5-9: Teaching Moves Used and Quality of Support for Making Claims Justified by Evidence and Reasoning during Student Teaching

Intern	Ms. Kelly			Ms. Atkin		Mr. Cruise				Ms. Michaels	
Investigation	1	2	3	1	2	1	2	3	4	1	2
Supports the student[s] to make claims		X	X	X	X		X	X	X		X
Uses a structure to construct evidence-based claims											
Uses other scaffolds/tools to support construction of claims (sentence stems, peers, etc.)				X				X			
Connects students' ideas to each other		X	X	X	X	X	X	X	X	X	X
Gives feedback on construction of claims											
Follows up on an alternative idea that the child gives	X	X			X				X		X
Does not ignore an alternative idea that the child puts forth	X	X	X	X	X	X	X	X		X	X
Supports students to describe evidence		X	X	X	X		X	X	X	X	
Supports students to describe reasoning			X			X	X	X	X		X
Does not do aspects of the intellectual work of naming the evidence for the student				X	X	X	X			X	
Does not do aspects of the intellectual work of naming the reasoning for the student			X			X	X		X	X	
Does not tell the student the claim ahead of time		X	X	X	X	X	X	X	X	X	X
Meets or exceeds expectations								X			
Partially meets expectations			X	X	X	X	X		X		X
Did not meet expectations	X	X								X	

Only one of the investigations from student teaching "met" expectations for supporting children to construct evidence-based claims. In this investigation, Mr. Cruise supported the students to construct claims that were supported by multiple pieces of evidence. He did this by giving students worksheets with a prompt for students to write their claims with evidence. To support their claims about the most common pollutant found on the playground, the students provided evidence from their investigation. Mr. Cruise also pushed for the reasoning for why a particular item observed in the playground is a pollutant, asking "someone with a raised hand" to "support" the claim that "air pollution can become water pollution" [C_Field4].

For three of the investigations (two of Ms. Kelly's investigations and one of Ms. Michaels' investigations), the interns' support for making claims justified by evidence and reasoning "did not meet expectations." In these three investigations, Ms. Michaels and Ms. Kelly told students the claim rather than allowing the students to do this work. Ms. Kelly's Investigation 1 is an example of how the interns told students the answer to the investigation question. During an investigation on "what is a fruit?" Ms. Kelly said, "A fruit is the part of a plant with seeds" before allowing the students to investigate their fruits to find the seeds [K_Field1]. At the end of the lesson, the students did not return to make additional claims about how each of the fruits they investigated had seeds. Thus, only the intern made claims about the investigation question, and she did so before the students had an opportunity to investigate for themselves.

Although the interns often struggled to support students to make claims justified by evidence and reasoning during student teaching, the interns connected students' ideas to each other in 10 of 11 investigations. In her first investigation, Ms. Michaels asked students to show that they also noticed a similar sound with a "thumbs up" [M_Field2]. Likewise, in his first investigation, Mr. Cruise marked what a student said earlier in the investigation when saying a student "presented that our list disproportionately represented fresh water [rather than salt water]…, what's a reason that we listed so many fresh water ideas?" [C_Field1]. All of the interns made similar moves to help students make and see connections across their ideas.

During student teaching, the interns sometimes followed up explicitly with students about their alternative ideas (5 of the 11 lessons) and often did not ignore the students' alternative ideas (10 of 11 lessons). For example, Ms. Kelly discussed with students why they might think that cucumbers are vegetables, not fruits [K_Field1]. When a student provided an alternative explanation for how batteries in a parallel circuit works, Ms. Atkin asked the student to come to the board to show what she meant [A_Field4]. Only in one of the 11 investigations did an intern ignore a student's alternative idea. During the investigation on filtering pollutants, Mr. Cruise ignored the students' claim that the coffee ground pollutant "might be safe to drink" [C_Field5].

Unlike the Peer Teaching and Reflective Teaching enactments, the interns did not use a logical structure for evidence-based claims. In addition, the interns rarely provided additional tools or scaffolds for constructing evidence-based claims; only two tools were seen in the 11 investigations. These included a worksheet with a prompt for students to write their claims that Mr. Cruise provided during his third investigation, and prompts to explain why on an exit ticket in Ms. Atkin's first investigation. The use of sentence stems, checklists, and other tools was not seen during the student teaching lessons.

In summary, the interns typically supported students to make claims about their investigation during student teaching; however, a few of the investigations did not involve students making claims. Interns used some productive teaching moves such as connecting students' ideas to each other and attending to students' alternative ideas. Yet interns also used some less productive teaching moves; for example, they often named the evidence or reasoning themselves, rather than having students do this intellectual work. In contrast, one intern did sometimes facilitate students to construct claims supported by evidence and reasoning.

End of the Year Standardized Student Interaction: Growth Only for One Intern

As a result of time constraints at the end of their school year, only three of the five focal interns completed the end of the year standardized student enactment. This interaction had the same script for the standardized student as the pre-assessment enactments, allowing comparison across the two time points. Using this comparison, Ms. Schuster showed substantial growth, moving from “does not meet expectations” on the pre-assessment enactments to “exceeds expectations” on end of the year enactment in terms of quality of support for making claims justified by evidence and reasoning (see Table 5-10). On the other hand, Ms. Kelly and Ms. Atkin did not show change and “partially met expectations” for the pre-science methods enactment and end of the year enactment.

Table 5-10: Teaching Moves Used and Quality of Support for Making Claims Justified by Evidence and Reasoning during End of the Year Standardized Student Enactment

	Ms. Kelly	Ms. Atkin	Ms. Schuster
Supports the student to make claims	X	X	X
Uses a structure to construct evidence-based claims			X
Uses other scaffolds/tools to support construction of claims (sentence stems, peers, etc.)			X
Connects students' ideas to each other	X		
Follows up on an alternative idea that the student gives	X	X	X
Does not ignore an alternative idea that the student puts forth	X	X	X
Supports students to describe evidence	X		X
Supports students to describe reasoning	X		X
Does not do the intellectual work of naming the evidence for the student	X		X
Does not do the intellectual work of naming the reasoning for the student			X
Does not tell the student the claim ahead of time	X	X	X
Quality of support	Partial	Partial	Exceeds

Ms. Schuster used several teaching moves to support the standardized student in constructing an evidence-based claim. She supported the student to make a claim that would answer the investigation question. She also introduced a logical structure for evidence-based claims and defined evidence, saying, "Sometimes scientists say that is evidence [when] we used our data … to prove" our claim [S_Interview4]. Ms. Schuster pushed the student to use their prior understandings to help support their claim. This facilitated the student to make a claim and justify the claim with evidence and reasoning. Ms. Schuster also supported the student to evaluate their thinking in light of the prediction made and the evidence from the investigation:

> Student: [In my prediction,] I said it would go down, but now, I think will be the same.
> Ms. Schuster: What makes you think that?
> Student: Because we found that the weight of the materials equals the weight of the solution.
> Ms. Schuster: Did you learn anything differently this time? [S_Interview4]

This interaction would facilitate a student to be able to notice how their thinking changed as well as to evaluate the claim on the evidence from the investigation.

Ms. Atkin and Ms. Kelly used some of the same teaching moves as Ms. Schuster to support the students in constructing an evidence-based claim, but not all of the moves (see Table 5-10). Ms. Atkin also supported her student to make a claim about what occurred in the investigation. Likewise, after the student discussed the investigation, Ms. Kelly asked, “Why do you think that?” [K_Interview4]. This question facilitated the student to name justification for her thinking. However, Ms. Atkin and Ms. Kelly also did aspects of the intellectual work for the students, whereas Ms. Schuster did not. Ms. Kelly did the intellectual work of naming the reasoning of connecting the evidence (the weights of the materials to the solution) to the claim (the weight was the same), saying, “We still counted the same amount of materials as before, but we just mixed them together” [K_Interview4]. Ms. Atkin did the intellectual work of justifying the claims with evidence and reasoning and did not give the student the opportunity to show that she understood this justification.

Unlike Ms. Schuster and Ms. Atkin, Ms. Kelly made an explicit connection between the student’s thinking and the thinking of other students. Ms. Kelly asked the student to comment on other students’ prediction with the question, “Why do you think your answers are different?” [K_Interview4]. Making this connection enabled Ms. Kelly to give the student additional ideas to consider and to learn more about the student’s thinking.

Despite these differences, all three interns explicitly followed up with students' alternative ideas. For example, Ms. Schuster used a follow-up question when the student claimed that the salt would disappear in a solution, asking, "How would the weight change?" [S_Interview4]. Likewise, Ms. Kelly also probed further about the same alternative idea with the question, "Why do you think that the mixture would [weight the same?" [K_Interview4]. These questions enabled the interns to learn more about the students' thinking in order to facilitate the students' construction of an evidence-based claim.

In summary, the three focal interns who participated showed variation in their end of year standardized student enactments. Ms. Schuster used a variety of teaching moves to support the student to construct a claim justified by evidence and reasoning, whereas Ms. Atkin and Ms. Kelly supported the students to make a claim but did aspects of justifying the claim for the standardized student. Ms. Schuster showed growth from the similar interaction during the pre-assessment before the Science Methods Course, but Ms. Atkin and Ms. Kelly did not.

I turn next to an illustration of the changes over time in how interns supported students to make claims justified by evidence and reasoning.

Change over Time in Supporting Students to Make Claims Justified by Evidence and Reasoning

The interns showed strength in their ability to support students to make claims justified by evidence and reasoning during the Science Methods Course. This seemed to suggest growth from the first year in the program. However, without the help provided in the Science Methods Course, the interns struggled to provide high-quality support for students to make claims justified by evidence and reasoning during student teaching. Similar to the case of their support for analyzing data to reveal patterns and relationships, the interns had consistently stronger enactments or plans when given extensive support to do this work during the Science Methods Course.

Change over Time in Lesson Plans

I analyzed four lesson plans from the entire cohort intended to support students to make claims justified by evidence and reasoning: the pre-assessment from the beginning of year two, Peer Teaching during the science methods class, Reflective Teaching near the end of the science methods class, and the post-assessment at the middle of the second year. Figure 5-2 shows the quality of support for the four different assignments. From the pre-assessment to Peer Teaching plans, the percentage of plans meeting or exceeding expectations increased from 20% to 75%. However, the proportion of plans "meeting" or "exceeding expectations" decreased for the Reflective Teaching assignment (42%) and the Post-Assessment (45%). Similarly, the percentage of students who "did not meet expectations" decreased from 33% on the pre-assessment to 2% on the Peer Teaching. However, this number increased on the Reflective Teaching assignment (15%) and post-assessment (10%). Thus, the plans showed the greatest strengths during Peer Teaching, but there was also an overall increase in quality from the pre-assessment to the post-assessment.

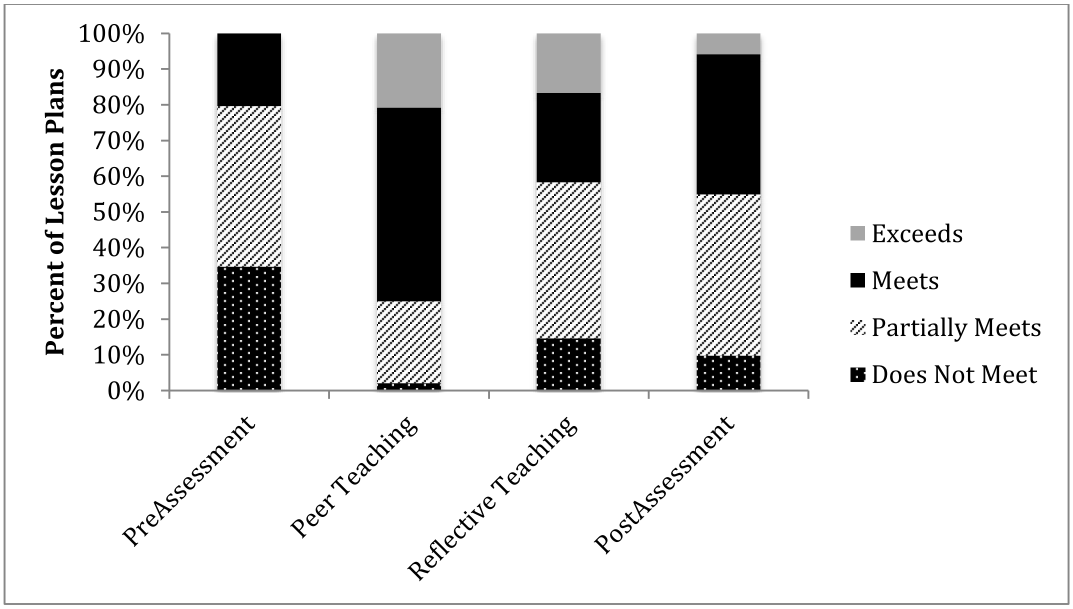


Figure 5-2: Graph of Quality of Support for Making Claims Justified by Evidence and Reasoning in Lesson Plans

Consistent with the trend in the quality of the supports, the interns also planned to give students additional support during Peer Teaching. Compared with 4% of interns planning to facilitate students to state claims with evidence on the pre-assessment, 75% of interns planned to do this in their Peer Teaching Lessons. However, this proportion declined for Reflective Teaching Lessons (36%) and the post-assessment (20%). In the Peer Teaching and Reflective Teaching lessons, about a fourth of the interns also planned to connect students' ideas to each other; interns did not commonly plan to make this move on the pre- and post-assessment. This may be because interns were planning to interact with one student rather than a classroom of students.

In summary, the interns showed the greatest strengths for supporting students to make claims justified by evidence and reasoning during Peer Teaching. This is not unexpected because interns co-planned for this assignment with peers and had more scaffolding for this assignment than for others. The interns continued to show some of these strengths in the Reflective Teaching and post-Assessment that followed Peer Teaching; however, a few interns continued to plan to tell students the claims and evidence rather than support the students to do the intellectual work.

Change over Time in Enactments

The five focal interns' enactments showed a pattern for quality of support that was similar to that of the lesson plans of the entire cohort. The greatest success in supporting students to make claims justified by evidence and reasoning typically occurred during the Science Methods Course, as seen in Table 5-11. Ms. Schuster continued to "exceed expectations" during the end of the year Standardized Student Enactments, yet Ms. Kelly and Ms. Atkin did not continue to keep up the quality of their support during the same enactments. The interns showed the greatest struggle during student teaching, when the interns typically "did not meet" or "partially met" expectations.

Table 5-11: Quality of Support for Constructing Evidence-Based Claims over Time

	Children as Sensemakers	Pre-assessment	Peer Teaching	Reflective Teaching	Student Teaching	End of Year
Ms. Kelly	2	2	4	2	1.5	2
Ms. Atkin	2	2	2	3	2	2
Mr. Cruise	3	2	3	2	2.5	n/a
Ms. Michaels	2	2	3	2	1.5	n/a
Ms. Schuster	2	1	4	4	n/a	4

Does not meet = 1; partial = 2; meets = 3; exceeds = 4.

In a manner similar to the trends in the quality of support, the interns also used more teaching moves to support students to make claims justified by evidence and reasoning during Peer Teaching than with the other enactments. Table 5-12 shows the different moves that the interns used to support construction of evidence-based claims over time. As seen in the table, the interns typically supported students to make claims and did not ignore alternative claims that students made, throughout their enactments during the program. In contrast, the interns did not often use a logical structure or other supports to facilitate the construction of claims. The interns sometimes connected students' ideas to each other or facilitated students to justify their claims with evidence or reasoning. The use of these teaching moves was more common during the Peer Teaching and Reflective Teaching enactments.

In summary, the interns' enactments were strongest during Peer Teaching, yet some of the interns continued to use teaching moves to support students to construct evidence-based claims during Reflective Teaching, Student Teaching, and the end of the year standardized student enactment. Ms. Schuster showed the most growth over the two years, yet she was not given the opportunity to teach science during Student Teaching, so interpreting her trajectory in comparison to the other interns' is challenging. The other interns seemed to struggle in providing quality support during student teaching, but sometimes they facilitated students to make claims and justify them with evidence or reasoning during these investigations.

Table 5-12: Teaching Moves Used to Support Making Claims Justified by Evidence and Reasoning over Time

	Children as Sensemakers (*n* = 5)	Pre-assessment (*n* = 5)	Peer Teaching (*n* = 5)	Reflective Teaching (*n* = 5)	Student Teaching (11 investigations)	End of Year (*n* = 3)
Supports the student[s] to make claims	XXXXX	XXXX _	XXXXX	XXXXX	XXXXXXX _ _ _ _	XXX
Uses a structure to construct evidence-based claims	_ _ _ _ _	_ _ _ _ _	XXXXX	XXX _ _	_ _ _ _ _ _ _ _ _ _ _	X_ _
Uses other scaffolds/tools to support construction of claims (sentence stems, peers, etc.)	_ _ _ _ _	_ _ _ _ _	XXXXX	XXXXX	XX_ _ _ _ _ _ _ _ _	X _ _
Connects students' ideas to each other	n/a	X_ _ _ _	XXXXX	XXXXX	XXXXXXXXXX _	X _ _
Follows up on an alternative idea that the child gives	XX	X_ _ _ _	XXXX _	XX _ _ _	XXXXX _ _ _ _ _ _	XXX
Does not ignore an alternative idea that the child puts forth	XXXXX	XXXXX	XXXXX	XXXXX	XXXXXXXXXX _	XXX
Supports students to describe evidence	n/a	X X X _ _	XXXXX	XXXX_	XXXXXXXX _ _ _	XX_
Supports students to describe reasoning	n/a	X _ _ _ _	XXXX _	XXXX_	XXXXX_ _ _ _ _ _	X X _
Does not do the intellectual work of naming the evidence for the student	n/a	XX _ _	XXXX_	XXX_ _	XXXX _ _ _ _ _ _ _	X X _
Does not do the intellectual work of naming the reasoning for the student	_ _ _ _ _	XX _ _	XXXX_	XXXX_	XXXXX_ _ _ _ _ _	X _ _
Does not tell the student the claim ahead of time		X X X X _	XXXXX	XXXXX	XXXXXXXXXX _	XXX

X=an intern used this move; _ = an intern did not use this move_

Conclusion

This chapter described strengths, struggles, and change of the entire cohort in the subpractice of supporting children to make claims justified by evidence and reasoning. Similar to the subpractice of supporting children to analyze the data to reveal patterns and relationships, the interns showed the most success in the subpractice of supporting children to make claims justified by evidence and reasoning during the Science methods Course, particularly in the highly supported Peer Teaching. The interns tended to support children to make claims throughout the program, yet they seemed to struggle more in supporting children to use a logical structure for their claims than in supporting children to analyze the data to reveal patterns and relationships. The next chapter, Chapter 6, considers the interns' science knowledge for teaching associated with the teaching practice of supporting children to construct evidence-based claims.

.

CHAPTER 6

CHANGES OVER TIME IN SCIENCE KNOWLEDGE FOR TEACHING

This chapter considers the changes over time in the interns' science knowledge for teaching connected to the teaching practice of supporting elementary students to construct evidence-based claims. Building on Shulman's (1986) work, the science knowledge for teaching discussed in this chapter includes subject matter knowledge and pedagogical content knowledge (Ball, Thames, & Phelps, 2008). The subject matter knowledge considered includes both the *syntactic knowledge* of how knowledge is constructed in the field and *substantive knowledge,* or the body of knowledge in science. Drawing on Abell's (2007) framework, I also consider three of the four components of science pedagogical content knowledge: *knowledge of science learners*, *knowledge of science instructional strategies*, and *knowledge of the science curriculum*. Although knowledge of science assessment is another important component, I did not have access to enough of the interns' assessments to consider this area.

As in Chapters 4 and 5, this chapter outlines the evidence of the quality of the interns' science knowledge for teaching seen in their lesson plans, enactments of teaching, surveys, and other class assignments by following the interns throughout the program. The analyses suggest that the interns had science subject matter knowledge for writing accurate claims justified by evidence regarding natural phenomena, yet this accuracy seemed to vary across science topics. The interns struggled with connecting the claims to scientific principles. The interns' pedagogical content knowledge seemed to improve throughout the program, with the strongest quality of this knowledge seen in the interns' enactment of lessons during student teaching.

This chapter first considers the evidence of the interns' subject matter knowledge by examining their ability to construct accurate evidence-based claims at various time points in the program. Then, the chapter considers evidence of the interns' pedagogical content knowledge as seen in their lesson plans and enactments with students.

Interns' Subject Matter Knowledge: Constructing Accurate Evidence-Based Claims

Throughout the program, the interns constructed evidence-based claims about different natural phenomena. Typically, the interns were able to accurately explain the mechanism behind the natural phenomena, yet the claims varied in quality. The interns sometimes struggled to include the justification in terms of evidence or reasoning to support their claims based on analyses of the data.

Before Science Methods

The interns typically wrote accurate, complete, and clear claims during the first year of the program. However, some interns wrote inaccurate claims, suggesting that these interns may struggle with the subject matter knowledge needed for elementary teaching. The claims also suggested struggles with providing sufficient evidence that aligned with the claim.

Children as Sensemakers. The interns were asked to construct an evidence-based claim for the question, "What causes day and night?" at the beginning of the Children as Sensemakers I Course. This assignment occurred before the interns had prepared for interaction with a child about this phenomenon. Approximately two thirds of the interns (69%) wrote accurate claims, and 62% of the claims were accurate, complete, and clear. An example of an accurate, complete, and clear response follows:

> We have day and night because the earth rotates on its axis once every 24 hours. The side of the earth facing the sun is in daytime while the opposite side of the earth (in darkness, facing away from the sun) is in night. [CaSM_WS7].

Some interns also included representations to support their claims (22%) and discussed the revolution of Earth as well as the rotation of Earth (42%), which facilitated the clarity of their explanation.

The most common inaccurate claim was that the revolution or orbit (not the rotation) of Earth caused day and night. For example, response 9 said the following:

> An entire day lasts 24 hours. In this 24 hours, the earth completes an orbit around the sun. Orbit means that the earth goes around the sun… For about half of the day, there is daytime, which means "where we are located on the earth" is facing the sun. When the area that we live on ... is not facing sun, we have night, which is about half of a day. And the cycle continue[s]. [CaSM1_WS9].

This response is both inaccurate about the mechanism that causes day and night and unclear, using language such as "we have night which is about half of a day." Other common struggles included confusing the terms "rotation" and "revolution" (20%), including an inaccurate representation (17%), and claiming that the side of Earth in nighttime always faces the moon (8%).

Survey. On the end of the year survey, the interns showed levels of content knowledge and ability to construct evidence-based claims that were similar to those seen in the Children as Sensemakers assignment. This survey provided data from an investigation of diving time and depth of pupa and larva after a disturbance to answer the question, "What are the differences in diving behaviors of between the pupa and larva when disturbed?" (see Appendix I). On the survey, 98% of interns selected the appropriate claims that matched the evidence provided.

However, when asked why they selected the particular claims, most of the interns (87%), but not all interns, provided evidence that would justify their claims. A majority of the interns (54%) provided evidence that aligned with the claim, but not all of the evidence to sufficiently support their claims. In contrast, a third (33%) provided sufficient evidence that aligned with the claim. An example of sufficient evidence aligned with the claim that "the pupa dives deeper and stays underwater longer than the larva" is the following:

> The larva reached an average depth of 22 cm while the pupa reached an average depth of 38 cm. Therefore, the depth reached by the pupa is greater than the depth reached by the larva. Furthermore, the larva's average time underwater was 90 sec while the pupa's average time underwater was 120 sec. Therefore, the pupa's average time underwater is greater than the larva's average time underwater. [SurveyEvidence_Response 9]

This response includes all of the pieces of evidence given to support the claim and clearly details this evidence. An example of evidence aligned with the claim but not sufficient is "Out of 5 trials, the average depth AND time for the pupa was larger than the larva" [SurveyEvidence_Response 10]. This response does not provide a detailed description of the evidence found during the investigation.

A final group of interns (13%) did not include evidence that justified the specific claims. The statement in Response 5, that the intern "selected the statements based on the data provided on the table" [SurveyEvidence_Response 5], is an example of this struggle. The survey also asked the interns to select the appropriate representation to make sense of the data, and 85% of the interns selected a representation that would highlight the pattern in the data to answer the investigation questions.

The end of the year survey also considered the interns' content knowledge in the area of ecosystems. This survey showed a range in the interns' content knowledge from all answers correct to half of answers correct. Out of 30 questions, the average was 24 questions answered correctly, with a standard deviation of 3.10. This average is slightly higher than the average for in-service teachers in the surrounding area who took the test (Smith, personal communication, April 24, 2012).

Pre-Assessment. On the pre-assessment for the Science Methods Course, interns were asked to answer the investigation question, "How does the weight of a solution compare to the weight of the materials that make up the solution?" A majority of the interns (78%) gave an accurate, complete claim to answer the question. An example of an accurate, complete claim is Intern 44's response: "The weight of the solution is equal to the weight of the materials used to make up the solution" [PreA_44]. Another 14% of the interns gave accurate claims that were not as clear or complete, such as "The weight of the materials will remain consistent while moving from the solution to the separate components" [PreA_47]. A final 8% of the interns wrote inaccurate or confusing claims, such as, "The weight of the solution is less than the materials used to make up the solution" [PreA_19]. Thus, most of the interns were able to provide an accurate claim to answer the investigation question, but a few interns still struggled with interpreting clearly the data provided.

The pre-assessment asked interns to describe how they made sense of the data to answer the investigation question. The interns' responses to this question gave insight into how the interns analyzed the data to reveal patterns and relationships and could justify their claims. Most of the interns, 84%, described a clear, accurate pattern in the data that would lead to the claim given. For example, Intern 10's response (whose claim is above) stated,

> The weight of the water before the salt was [added] was 400g. The salt was 25g. After mixing [salt in the water], the water [with the salt] weighted 415 g and the cup holding the salt originally weighed 10g. 400g(water) + 25g (salt) = 425 g; 425g (water + salt) – 10 g (salt cup) = 415g (mixture). [PreA_10]

A portion of the interns (18%) who named a clear, accurate pattern also used all of the data provided to show the pattern rather than just one group, as Intern 10 did above. A final 16% of the interns gave answers that were either unclear or unspecific for supporting the claims they made, such as, “I used the information from each of the group’s data” [PreA_28].

A group of interns (16%) provided support for their claim with reasoning based on scientific principles, although this was not specified in the assessment. An example of this is Intern 44’s addition to the claim given above: “The water is combined but no matter is created or destroyed so the mass remains the same” [PreA_44].

Summary of before Science Methods Science Knowledge for Teaching. In summary, the majority of interns wrote accurate, complete claims for the Children as Sensemakers, end of the year survey, and pre-assessment for science methods. The interns seemed to struggle to provide sufficient evidence aligned to the claim on the end of the year survey. However, the interns were able to describe how they could justify their claims by analyzing data to reveal patterns and relationships on the pre-assessment.

Science Methods Course

During the Science Methods Course, the interns’ struggles and strengths in constructing evidence-based claims seemed to be similar to those seen during the first year. Their strengths included writing accurate claims. Their struggles centered on justifying these claims with evidence and reasoning.

Peer Teaching. The Peer Teaching Lesson Plan assignment required interns to write an evidence-based claim to answer the investigation question. The interns typically wrote accurate claims; 92% of the claims on the lesson plans were accurate. Approximately one fifth of the lesson plans (21%) included complete, accurate claims, such as, “I think when the warm water is placed into the cold water, the warm water will become colder and the cold water will become warmer. The temperatures of both waters will be the same” to the question, “When a bag of warm water is placed into a container of cold water, what happens to the temperature of the water in each container over time?" [PT_25]. An example of an accurate, complete claim for the investigation question, "What role does the stem play in the plant?" is "I think that the role that stems play in a plant is to provide support and structure for the plant, and to pass nutrients and water to the rest of the plant" [PT_47].

Of the four of interns who did not write accurate claims, two interns did not include a claim on their lesson plan, and two interns wrote confusing claims. One example of a confusing claim is, "I think the object with more temperature will move to the object with less temperature" [PT_20]. Although most of the claims were accurate, 71% of the claims did not completely answer the investigation questions. An example of an accurate, incomplete claim is, "I think that the water will travel up the celery stem" in answer to the question, "What will happen to the celery (both the firm and the flexible) if you stick it in water?" [RT_13]. This claim does not include a description of what would happen to both types of celery, such as mentioning that the flexible celery becomes firmer in the water.

The interns also typically justified their claims with evidence; 88% of the interns wrote evidence that aligned with the claim. Of the seven interns who did not write evidence that would align with their claim, three interns did not write any evidence. The other four interns wrote evidence that would not justify their claims, such as the evidence of "I think this because I've seen … warm water melt ice cubes (hot chocolate)" for the claim "I think the warm water will get colder and cold water will get warmer" [PT_31]. Three-fourths of the interns (75%) justified the claim with evidence that aligned with the claim, but the evidence the interns provided was not sufficient for justifying the claim. For example, for the claim, "I think the temperature of the water in both containers will eventually be the same," the intern wrote the evidence, "I think this because I've seen the cold water’s temperature increase and the warm water’s temperature decrease until they reached the same temperature” [RT_8]. The evidence does not include the specific data from the investigation, such as the exact temperatures, which would more sufficiently justify the claim made. A final group of interns (13%) did plan for sufficient evidence that would justify the claim, such as, “I think this because the bag with warm water went from a temperature of [initial temperature at t = 0] to [final temperature at t = 10 minutes] and the bottle with the cold water went from a temperature of [initial temperature at t = 0] to [temperature at t = 10 minutes]” for the claim, “When a bag of warm water is placed into a container of cold water, the temperature of the water in the bag decreases and the temperature of the water in the bottle increases until the water in both containers have the same temperature.”

In contrast to including accurate claims with evidence to justify the claim, the interns did not typically use reasoning, such as describing a mechanism to justify their claims. Approximately a third of the interns’ plans (29%) included this reasoning. An example of this reasoning is, “We also learned warmer object transfer their energy (heat) to cooler objects” for the claim that “I think the object heat energy will be transferred from a warm object to a cooler object until the two objects are the same temperature (claim)” [PT_19]. The interns may have not included the reasoning because the lesson plan template that the interns used did not explicitly ask for reasoning.

Reflective Teaching. Like the Peer Teaching lesson plans, the interns’ Reflective Teaching lesson plans typically included an accurate claim; 89% of the claims were accurate. Approximately one half (54%) of the claims were both accurate and complete. An example of an accurate, complete claim is, “I think more rigorous physical activity (like jogging or jumping jacks) will raise your heart rate” for the investigation question, “What types of activities raise your heart rate?" [RT_49]. Another third of the claims (35%) were accurate but not complete. These claims did not answer all aspects of the investigation. For example, the claim "I think plants are living things, and some things about them are the same as animals, while other things are different" does not answer all parts of the investigation question, "Are plants living things? What makes plants and animals different?" [RT_6].

The interns' plans also typically included evidence that would justify their claims. More than four fifths (82%) of the plans included evidence that would align with the claims—for example, "I think this because I've done more rigorous and less rigorous physical activities, and the more rigorous activities resulted in an elevated heart rate" as evidence for the claim "I think more rigorous physical activity (like jogging or jumping jacks) will raise your heart rate." However, as seen in this example where the details of the evidence are not included, the evidence was typically not sufficient; 56% of the interns' plans included evidence that aligned with the claim but was not sufficient. A quarter of the plans did include sufficient evidence, such as the following claim and evidence:

> I claim that [L]ife is a better source of iron compared to [L]ucky [C]harms and [F]rosted [F]lakes. I claim this because when comparing food labels [L]ife has 8.95mg of iron and [F]rosted [F]lakes has 7.13mg and [L]ucky [C]harms has 4.5mg. Because [L]ife is the best source of iron it will help transport iron to the rest of the body. [RT_39].

This evidence-based claim includes multiple pieces of specific evidence to justify the claim. This claim also includes reasoning to justify the claim, describing why it is important to have iron in one's diet. Approximately a fifth of the lesson plans (20%) included similar reasoning. As in the Peer Teaching Lesson Plans, the template for the Reflective Teaching Plans did not ask explicitly for the reasoning.

Post-Assessment. The post-assessment for the Science Methods Course matched the pre-assessment for the class, so I present a comparison of the interns' content knowledge at these two points in the program. As seen in Table 6-1, the interns typically wrote accurate, complete claims for both the pre-assessment and post-assessment, with a few more interns writing complete claims on the post-assessment than on the pre-assessment. In the other categories listed in Table 6-1, the interns' responses were similar, suggesting that their science content knowledge did not change in this area.

Table 6-1: Interns' Evidence-Based Claim and Description for Revealing a Pattern in the Data for the Pre- and Post-Assessment

	Claim				Analyzing Data to Reveal Patterns and Relationships		
Chapter 2	Accurate, complete	Accurate, not complete	Inaccurate	Connects to scientific principle	Accurate, includes all data	Accurate, does not include all data	Either inaccurate or unclear
Pre-assessment	78%	14%	8%	14%	18%	67%	15%
Post-assessment	85%	8%	7%	14%	16%	67%	17%

Summary of Science Methods Course. In summary, the interns typically wrote accurate and complete claims during the Science Methods Course. These claims usually included evidence aligned with the claim. However, most did not write reasoning that linked the evidence to the claim.

Comparisons over Time

Throughout the program, the interns tended to write accurate claims (see Table 6-2). Over two thirds of the interns wrote accurate claims on all of the assignments. However, the interns' ability to identify or write accurate claims seemed to vary depending on the context or topic. For example, closer to two thirds of the interns wrote an accurate claim about "what makes day and night" for the Children as Sensemakers Course, but almost all interns selected an accurate claim based on the graph for the end of the year survey. These differences could result from the difficulty of the task (e.g., writing their claim versus selecting from a list), the interns' difficulty with the science topic, or other aspects of the context. Because the accuracy of the interns' claims does not seem to increase consistently over time, I would not suggest that this is a sign of an increase in their knowledge. The proportion of accurate, complete claims also seemed to vary in a similar respect.

Table 6-2: Quality of Interns' Evidence-Based across the Program

	Complete, Accurate Claim	Accurate Claim	Connected to Principle	Evidence/Pattern Aligned with Claim	Sufficient Evidence, Includes All Data
Children as Sensemakers	62%	69%	n/a	n/a	n/a
End of Year One Survey	98%	98%	n/a	54%	33%
Pre-Assessment	78%	92%	14%	67%	18%
Peer Teaching	71%	92%	33%	88%	13%
Reflective Teaching	54%	89%	20%	82%	26%
Post-Assessment	85%	92%	14%	67%	16%

The interns typically aligned the evidence or patterns identified in the data with their claims; however, this also showed variation over time. The interns seemed to struggle to include sufficient evidence for their claims. They also typically did not connect their claims to a larger scientific principle or mechanism. However, the assignments did not ask for the interns to do this work.

Pedagogical Content Knowledge as Seen in the Planning and Enactments of Lessons

The interns' pedagogical content knowledge, including the areas of their knowledge of science learners, knowledge of science instructional strategies, and knowledge of the science curriculum, is considered in this section. As in Chapters 4 and 5, I follow the cohort and focal interns through the program, drawing on evidence for the science pedagogical content knowledge from the lesson plans and enactments of the science lessons.

Before Science Methods: Providing Accurate Descriptions

Before the Science Methods Course, the interns typically accurately represented the phenomenon in an appropriate manner for an elementary student. However, at times, interns introduced potentially confusing ideas about the science content because of the imprecise use of words. Interns sometimes discussed the mechanism or principle involved in the phenomenon, and the interns usually connected the science concept or phenomenon to students' lives.

Children as Sensemakers. During the Children as Sensemakers I Course, the focal interns supported students to answer the investigation question, "What causes day and night?" through an interactive read-aloud activity. During this activity, the interns showed strengths in providing an accurate description of the phenomenon and in making connections to the mechanisms involved in the phenomenon. However, some interns encouraged confusing ideas. With these strengths and struggles, two interns "met expectations" in their science knowledge for teaching and three interns "partially met expectations" (see Table 6-3).

Table 6-3: Evidence of Use of Science Knowledge for Teaching during Children-as-Sensemakers Read-Aloud

	Ms. Kelly	Ms. Atkin	Mr. Cruise	Ms. Michaels	Ms. Schuster
Uses accurate description of the phenomenon that is appropriate for elementary students	X	X	X	X	X
Does not encourage confusing ideas			X	X	X
Connects the phenomenon to child's lives	X	X	X	X	X
Connects the claims to the scientific principle or mechanism	X	X	X	X	X
Quality of science knowledge for teaching	Partially meets	Partially meets	Meets	Meets	Meets

As seen in Table 6-3, all five of the focal interns used an accurate, age-appropriate description of the phenomenon. For example, Mr. Cruise turned the model of Earth with green and yellow toothpicks representing people on different sides of Earth. He built on what the student noticed about which toothpicks would be in day and which in night, and he said, "If I keep turning [Earth] around and around, you see how 'green' has daytime and 'green' goes to 'nighttime'… and the earth just keeps spinning around" [C_CaSMReading]. Mr. Cruise, then, asked the child, "What do you think about what makes day and night?" to check that the student understood that Earth turns around. This description accurately represented the rotation of Earth as the cause of day and night, and used child-friendly language such as "turning" to help the child understand this concept. The other interns used similar terms with their students.

Although the interns used an accurate description of the phenomenon, two of the interns (Ms. Kelly and Ms. Atkin) encouraged confusing ideas. Ms. Kelly told her student that Earth "spins very, very slowly around and around," yet Earth actually spins very fast (1,040 miles/hour) relative to other speeds a child might experience [M_CaSMReading]. Similarly, Ms.

Atkin stated that an inaccurate claim was correct. In contrast, Ms. Michaels, Ms. Schuster, and Mr. Cruise did not encourage confusing ideas. However, Ms. Schuster and Mr. Cruise did not correct a child's possible misunderstanding. For example, Ms. Schuster's student stated, "When [Earth] is moving it is sunny, and when it stops, it is dark," and Ms. Schuster did not clarify the student's confusion about this concept [S_CaSMReading]. These struggles suggest that the interns were able to give mostly accurate explanations of the phenomenon yet seemed to confuse (or ignore) some of the details, suggesting challenges with explaining the science content.

Despite some of their struggles in explaining the science content, all of the interns connected their explanations of the scientific phenomenon of day and night to the mechanism of Earth spinning. As exemplified in Mr. Cruise's description, all of the interns discussed how Earth spins or turns. The interns also emphasized the role of Earth in blocking the sun during nighttime. For example, Ms. Michaels asked the student, "Can you explain Earth's shadow to me?" and highlighted which part of Earth is in the shadow during nighttime [M_CaSMReading].

All of the interns also connected the scientific phenomenon to their students' lives. An example of this is Ms. Atkin's question, "Have you been outside and seen your shadow before?" The subsequent discussion seemed to support the child to connect her experiences of shadows with how Earth's shadow creates darkness in nighttime. Other interns made other connections to students' lives, pointing to their pedagogical content knowledge of science learners.

The week after the interactive read-aloud, the interns returned to the students to elicit their thinking about day and night. Although all of the interns made explicit connections to the mechanism in their interactive read-aloud, some of the interns struggled to explicitly ask students to explain the mechanism involved in this phenomenon during their interview. Only Ms. Atkin and Ms. Schuster explicitly followed up with the child about the mechanisms involved. When the student she was working with stated that Earth spins, Ms. Atkin asked, “Do you think that has anything to do with day and night?” [A_CaSMInterview]. Although the child responded, “No,” this question was pushing the child to give her explanation of the mechanism involved in the phenomenon. In contrast, Ms. Michaels, Ms. Kelly, and Mr. Cruise did not follow up on students’ statements to find out their explanation of the mechanism.

In summary, the interns tended to use accurate, age-appropriate explanations of what causes day and night during the interactive read-aloud. The interns also connected these explanations to the mechanism of the phenomenon and the students’ lives. However, some interns struggled with introducing or encouraging confusing ideas. Also, some of the interns did not push the students to give mechanistic explanations during their follow-up interviews with the students.

Pre-Assessment. The pre-assessment lessons and enactment of these lesson plans by the focal interns suggested that the interns had a range of science knowledge for teaching. The assessment asked interns to develop a plan to support students to answer the investigation question, “How does the weight of the solution compare to the weight of the materials used to make up the solution?” and focused on the conservation of mass. Some of the interns showed strong understanding of the science content and how to support students to understand this science content in their plans and enactments. In contrast, other interns struggled to plan or enact lessons that would make clear the mechanisms involved in the phenomenon of salt dissolving in water or that would help students understand the scientific principle of conservation of mass.

Pre-Assessment Lesson Plans. The pre-assessment lesson plans from all 54 interns in the cohort showed a range of evidence for quality science knowledge for teaching. A majority of the lesson plans “met” (57%) or “exceeded” (10%) expectations for the quality of the science knowledge for teaching. These plans would support the interns to give an accurate, age-appropriate explanation of the investigation and would connect this explanation to the mechanism involved in the investigation. For example, Intern 3 planned to "determine how the weights of the materials used to create a solution compare [equal] to the solution final weight." Recognizing possible student struggles, the lesson plan also included the following:

> If misconceptions remain, I would explicitly explain that although our eyes no longer perceive the salt molecules when they are mixed with the water to form the saltwater solution, the salt continues to be part of the solution. [PreA_3]

This lesson plan shows the interns' plans to support the student to give an accurate explanation and to handle possible struggles that the student might have. The plans (10%) that "exceeded expectations" also made clear connections to the scientific principle involved in the investigation in addition to discussing accurate, age-appropriate explanations. An example of connecting to the scientific principle is Intern 16's plan to discuss "whether or not the total weight of the matter is conserved" [PreA_16].

Although a majority of the interns "met" or "exceeded expectations" for science knowledge for teaching, a group of interns struggled with planning accurate, age-appropriate explanations of the phenomenon. A fifth of the interns "partially met" expectations; these plans typically did not include a plan to connect the claim with the mechanism involved. For example, Intern 31 planned to focus on "Why does the weight of the cup matter?" [PreA_31] rather than noticing the conservation of mass from before to after mixing. This suggests that the intern may not see the importance of highlighting the mechanism involved in the phenomenon or the additional support a student may need to see this. A final 12% of the interns "did not meet expectations." These plans typically included inaccurate or confusing explanations, such as, "The weight of the solution is more than the what it was before" [PreA_17].

A few of the interns' plans also showed additional strengths in terms of their science knowledge for teaching, such as connecting the evidence-based claim for the investigation to information discussed in previous lessons (provided in the assessment write-up) or to the students' previous thinking. Eight percent of the interns made connections to ideas discussed in previous classes. For example, Intern 39 planned to "refer to claims of [what] a solution is from the class claims" already discussed [PreA_39]. This move might help students make connections across lessons, and it suggests that the intern had an awareness of the importance of making these connections. Thirty-five percent of the interns planned to connect to the students' prior knowledge or thinking about the investigation. An instance of this is Intern 45's plan to "ask if [the child's] hypothesis [made before the investigation occurred] was correct and why/why not" [PreA_45]. These questions might support children to consider their prior knowledge and think metacognitively about changes in their thinking.

Pre-Assessment Enactments. As seen in the lesson plans of the entire cohort, the enactments of the five focal interns showed a range of quality in their science knowledge for teaching. The interns showed some similar strengths as well as individual struggles. Table 6-4 outlines the evidence of use of science knowledge for teaching during the focal interns' pre-assessment enactments.

Table 6-4: Evidence of Use of Science Knowledge for Teaching during the Pre-Assessment Enactment

	Ms. Kelly	Ms. Atkin	Mr. Cruise	Ms. Michaels	Ms. Schuster
Uses accurate description of the phenomenon that is appropriate for elementary students	X	X	X	X	X-
Does not encourage confusing ideas		X	X		X
Connects the claims to the scientific principle or mechanism			X	X	X
Connects the phenomenon to child's life or prior knowledge	X		X	X	X
Quality of Science Knowledge for Teaching	Partially meets	Partially meets	Exceeds	Partially meets	Meets

All of the interns used an accurate description of the phenomenon that seemed appropriate for elementary students. For example, Ms. Kelly stated, "We still counted the same amount of materials before, we just mixed them together" and emphasized that the weight of the materials equaled the weight of the solution. Other interns also discussed a similar accurate, age-appropriate answer to the investigation question.

Although the interns typically used age-appropriate, accurate language, a few interns struggled, using imprecise or complex language. Two of the interns (Ms. Kelly and Ms. Schuster) introduced complex terms such as *dissolved* and *solute* to the student without explaining what these terms meant. An instance of this is when Ms. Schuster told the student, "The salt dissolved, so we can't tell the difference" between the salt and the water, without clearly defining this unfamiliar term. Although such terms would be age-appropriate for students, a teacher might need to check for students' understanding of these terms. Two of the interns also encouraged confusing ideas during the interaction. For example, Ms. Michaels confirmed the students' idea that the salt disappeared by saying the salt "disappears because it dissolves" [M_PreA]. This statement might have encouraged the misconception that the weight of the salt also disappears rather than is conserved. Ms. Kelly also confirmed that the salt disappeared in a similar manner. The other interns did not encourage confusing ideas in the same way.

A few of the interns connected the claims to the scientific principle or mechanism involved in the investigation. Ms. Michaels and Ms. Schuster discussed the mechanism of salt dissolving. However, as discussed above, both of these interns struggled with providing a clear definition of *dissolving* for the student. Mr. Cruise connected the claim to the larger scientific principle of conservation of mass. By asking, "Is any of the weight from the salt being lost?" and "Is the water gaining mass?" he underscored that the conservation of mass is occurring. Ms. Atkin and Ms. Kelly did not connect the claim to a scientific principle or mechanism.

Most of the focal interns (Ms. Kelly, Mr. Cruise, Ms. Michaels, and Ms. Schuster) also connected the claim to the children's everyday life or prior knowledge. Ms. Kelly, Mr. Cruise, Ms. Michaels, and Ms. Schuster reviewed the prior claims that the class had made about solutions and mixture, which might support a child to make connections across lessons. These interns asked the students to discuss the predictions they made before conducting the investigation. Ms. Kelly also had the students consider their prediction after they had made sense of the data by asking, "Does what you predict match the data that we collected?" [K_PreA]. This question might support a student to reconsider their earlier thinking and adjust their understanding.

Summary of Pre-Assessment. The interns showed a range of science knowledge for teaching in their lesson plans and enactments of the pre-assessment. On the lesson plans, some interns planned to use an inaccurate description of the phenomenon, whereas others planned for an accurate, age-appropriate description that connected to the scientific principle of conservation of mass. The focal interns' enactments showed a similar range. Some of the focal interns encouraged confusing ideas in their enactments or did not connect to the mechanism or principle involved in the investigations. On the other hand, one intern showed strength in his science knowledge for teaching by using an accurate, age-appropriate explanation that connected to the principle of conservation of mass and the child's prior knowledge.

Summary of Pre-Science Methods. In summary, the interns showed a range of science knowledge for teaching in their lesson plans and enactments before the Science Methods Course. Although most interns used accurate, age-appropriate descriptions of the phenomena, some interns struggled with preciseness in their language. Similarly, some interns connected their descriptions to the mechanism or principle involved in the investigation, and others did not.

Science Methods Course: Providing Accurate Descriptions But Struggling to Make Connections

During the Science Methods Course, the interns' lesson plans and enactment suggested areas of strength in their science knowledge for teaching, such as providing accurate, age-appropriate descriptions of the phenomenon. However, some interns continued to struggle to make connections between the accurate claims and the mechanism or students' prior knowledge.

Peer Teaching. The interns' Peer Teaching lessons and enactments showed several strengths in terms of the interns' science knowledge for teaching. These strengths included using an accurate, age-appropriate description of the phenomenon and connecting the description to the mechanism or principle involved in the lesson. The interns had a high level of support through co-planning the lessons and working with their instructors for this assignment.

Peer Teaching Lesson Plans. The 54 interns in the cohort planned lessons that provided an accurate, age-appropriate description of the phenomenon. Almost all interns (94%) connected the description to a mechanism or principle; of these interns, 52% “met expectations” and 42% “exceeded expectations” for science knowledge for teaching. For example, Intern 40’s plan included asking this investigation question to her students: “What happens when a bag of hot water is placed in a container of cold water?” and the Intern wrote, “I anticipate that my students will discuss that heat energy from the hot water transferred to the cold water until the two water temperatures were even” [PeerTeach_40]. This plan exemplifies how the plans typically included an accurate, age-appropriate description of the phenomenon and a connection to the mechanism involved, which in this case is the transfer of heat energy.

The plans that “exceeded expectations” also included a connection between the mechanism or principle and the students’ everyday lives. For example, Intern 31 planned to ask, “What are some other real-life examples of heat energy transfer? What would happen to the temperature of ice cream if I dropped it on the blacktop in the middle of summer?” [PeerTeach_31]. This discussion of heat energy might support students to continue considering the mechanism involved in the investigation and to make connections to what they experience in the world.

Although most of the interns connected the description of the phenomenon to the mechanism or principle involved, three interns (6%) did not make this clear connection and “partially met expectations.” An example of this struggle is Intern 9’s plan, which included the claim, “I think that the stem helps to carry water and nutrients through the plant,” based on the evidence, “After the limp celery sat in the colored water, the stems and leaves of the celery turned the color of the water” [PeerTeach_9]. However, the plan did not include discussing the "tubes" (vascular bundle) in the celery that function to pull the water up. Discussing these tubes might support students in understanding the mechanism involved in the phenomenon of water transport in plant stems.

Despite the struggles of a few, the lesson plans of the entire cohort suggested other areas of strength in their science knowledge for teaching, including making connections to students' prior knowledge or everyday lives and extending the thinking to a new situation or application. All of the interns made connections to students' prior knowledge or experiences with the investigations. Examples of these connections included the following: "review[ing] what we knew before starting the experiment" [PeerTeach_17]; using an example from students' experiences, such as holding a snowball to help explain the mechanism [PeerTeach_37]; and reminding students what they did during the "last class" [PeerTeach_45]. A majority of the interns (66%) planned to extend the thinking to a new situation or application. For example, Intern 14 planned to pose the following thought experiment: "What … would happen to the leaves of our celery plant if there was not a stem? Why do we think this would happen?" [PeerTeach_14].

Peer Teaching Enactments. The five focal interns' enactments of the Peer Teaching lessons suggested that their strengths in science knowledge for teaching were similar to those of the entire cohort. However, some areas of struggle also arose in the enactments. Three of the five interns (Ms. Kelly, Ms. Atkin, Mr. Cruise) "met" expectations and one (Ms. Schuster) "exceeded" expectations for the science knowledge for teaching seen in their enactments. These interns used an accurate description of the phenomenon and connected this description to the mechanism or principle involved in the phenomenon (see Table 6-5). Ms. Michaels "partially met" expectations; she did not use an accurate description of the phenomenon.

Table 6-5: Evidence of Science Knowledge for Teaching Seen in the Peer Teaching Enactments

	Ms. Kelly	Ms. Atkin	Mr. Cruise	Ms. Michaels	Ms. Schuster
Uses an accurate description of the phenomenon that is appropriate for elementary students	X	X	X		X
Does not encourage confusing ideas		X	X		X
Connects the phenomenon to the child's life	X	X	X	X	X
Connects the claims to the scientific principle or mechanism	X	X	X	X	X
Quality of Science Knowledge for Teaching	Meets	Meets	Meets	Partially Meets	Exceeds

Four of the five of the interns used accurate, age-appropriate descriptions of the phenomenon. For example, Ms. Atkin emphasized an accurate, age-appropriate description of the function of a stem. She underscored a student's point that the tubes (vascular bundle) of the plant "suck up most of the water." Moreover, she clarified what the word "function" means, saying, "Function is how it supports the rest of the plant" after another student's claim of, "The stem's function is to turn red" [A_PeerTeach]. In this conversation, Ms. Atkin supported her students to give an accurate and age-appropriate description of the function of a stem, the phenomenon being investigated. The other interns also used similar descriptions of the phenomenon being investigated. One intern did not use an accurate description of the phenomenon. Ms. Michaels claimed, "I think our initial thinking that our tubes feed our celery plant is still true" [M_PeerTeach]. This claim suggests that plants receive their food from the stem rather than the leaves making the food for the plant.

Although the interns typically used accurate descriptions, one intern did not clarify confusing ideas brought up during the lesson. Ms. Kelly did not follow up with a student who stated, “The tubes [vascular bundle in the celery stem] are there to drink the water” [M_PeerTeach]. By not following up on this statement, Ms. Kelly may have encouraged students to think that stems can purposefully drink water like humans do, anthropomorphizing the plant. Ms. Atkin, Ms. Schuster, and Mr. Cruise did clarify confusing ideas brought forward, such as Ms. Atkin’s clarification of the word *function* discussed above.

All of the interns connected the claims made to students’ prior knowledge or everyday experiences. Examples of these connections include Ms. Schuster asking, “What would be examples [of heat energy transferring]?” [PeerTeach_S] and Ms. Michaels discussing “what we [she and the students] initially thought” would happen in the investigation. Both of these moves would facilitate students to make links between their prior knowledge and experiences and what they were learning in the investigation.

In addition to connecting the claims to students’ prior knowledge, four of the five interns also connected the claims to mechanisms or principles involved in the phenomena. For example, Mr. Cruise discussed with student how heat energy flows in their investigation of “what happens when a bag of hot water is placed in a container of cold water.” He underscored how heat energy is transferred and then asked the students to apply what they learned to another situation. A student was able to describe “that the flow of heat energy is from hot to cold” [PeerTeach_C]. This discussion facilitated students to see the mechanism involved in the investigation, the transfer of heat energy. Ms. Kelly, Ms. Atkin, Ms. Michaels, and Ms. Schuster had similar discussions with students about the mechanism or principle involved in their investigations.

Peer Teaching Summary. In summary, the interns’ lesson plans for Peer Teaching suggested several strengths in their science knowledge for teaching. Almost all of the plans typically had accurate, age-appropriate descriptions of the phenomenon that connected to a mechanism or principle. The enactments of the five focal interns showed similar strengths, yet one intern made a claim during the enactment that could be confusing to students and result in inaccurate scientific thinking.

Reflective Teaching. In comparison to the Peer Teaching lesson plans and enactments, the Reflective Teaching lesson plans and enactments suggested more problematic areas of the interns' science knowledge for teaching. However, the interns also continued to show strengths, such as connecting the science content to students' lives.

Reflective Teaching Plans. Approximately three fourths of the entire cohort's plans (77%) used accurate, age-appropriate descriptions of the scientific phenomena with connections to the mechanism or principle involved. For example, in a first-grade lesson investigating the similarities and differences between plants and animals, Intern 6 planned to underscore how both plants and animals "are alive, need water, [and] grow" [RT_6]. This list supports students to notice similar characteristics of living things, underscoring the biological principle of the needs of living things. Other Reflective Teaching plans had similar age-appropriate, accurate descriptions; these Reflective Teaching plans either "met expectations" (56%) or "exceeded expectations" (21%) for science knowledge for teaching. The plans that exceeded expectations also planned to discuss explicitly the mechanism or principle involved in the investigation and connected the mechanism or principle to students' everyday experiences. An example of these connections is Intern 11's lesson plan that supported students to investigate what causes day and night using models. The intern planned to ask students:

> When we went outside and looked at where the sun was in the sky, it seemed to be moving throughout the day. Was the *sun* actually moving? What was really happening? How do you know? How did our model here help us see that? [RT_11].

These questions might support the students to consider their everyday experiences with the sun and explicitly discuss the mechanism of Earth turning.

Another approximately one fourth of the interns' plans "partially met" expectations for science knowledge for teaching. These plans typically had two struggles: (a) not including a discussion of the principle or mechanism involved in the investigation, and (b) introducing confusing ideas. An example of the first struggle is Intern 49's plan for fifth graders that investigated how certain activities increase heart rate. The plan included an accurate claim and evidence, "I think that jumping jacks increased my heart rate the most because at rest, my heart rate was 70 bpm, but after doing 15 seconds of jumping jacks, my heart rate increased to 80 bpm" [RT_49]; however, the plan did not include a discussion of why increased activity causes a faster heart rate, an idea important to understanding the cardiovascular system. An example of the second struggle is Intern 5's plan, which asked students "to write what you noticed as the water disappeared out of the kettle [that was boiling water]" [RT_5]. The use of the word *disappear* might encourage the common alternative idea that when water evaporates, it disappears rather than becomes water vapor.

Despite the struggles seen in some of the plans, the Reflective Teaching plans suggested other strengths in the science knowledge for teaching, including the following: (a) connecting to students' prior knowledge and experiences (77%) and (b) extending the claims to a new application (73%). Examples of connecting to students' prior knowledge and experience are "review[ing] some of the things we thought … and wanted to know" [RT_21] and questions that required students to apply knowledge from previous lesson, such as Intern 18's question, "Do you think most fossils are made from sedimentary, metamorphic, or igneous rock?" [RT_18]. The latter, coming at the end of an investigation of fossils, would require students to use the knowledge of rocks they had learned in previous lessons. An example of extending the claims to a new application is Intern 22's question to first graders, "Is a tomato a fruit? Why or why not?" [RT_22], after students made claims about what a fruit is based on their investigation. This question would require students to apply the class definition of a fruit to a new item that they did not investigate in class.

Reflective Teaching Enactments. The focal interns' enactments of the Reflective Teaching lessons showed strengths and challenges similar to those seen in the Reflective Teaching lesson plans of the entire cohort. In four of the five lessons, the interns used an age-appropriate and scientifically accurate description of the phenomenon (see Table 6-6). These interns either "met" (Ms. Schuster, Ms. Atkin) or "partially met" (Ms. Kelly, Mr. Cruise) expectations for science knowledge for teaching. For example, in an investigation of how an organism's environment affects its ability to survive, Ms. Atkin supported students to accurately describe that "if a bug is the same color as the background, it's more likely to blend in" [RT_A]. Ms. Kelly, Mr. Cruise, and Ms. Schuster similarly used age-appropriate, accurate descriptions of the phenomenon. In contrast, Ms. Michaels used an inaccurate claim during the investigation she conducted with her kindergarten students. She told her students that their "leaf sank [when they placed the pennies on top] because the pennies are heavier [than the leaf]" [RT_Ms. Michaels]. This claim suggests that weight alone causes an object to sink, a common alternative idea.

Table 6-6: Evidence of Science Knowledge for Teaching Seen in Reflective Teaching Enactments

	Ms. Kelly	Ms. Atkin	Mr. Cruise	Ms. Michaels	Ms. Schuster
Uses an accurate description of the phenomenon that is appropriate for elementary students	X	X	X		X
Does not encourage confusing ideas		X			X
Connects the phenomenon to child's life	X	X	X	X	X
Connects the claims to the scientific principle or mechanism	X	X	X	X	X
Meets or exceeds expectations	Partially Meets	Meets	Partially Meets	Does not meet	Meets

Although Ms. Kelly and Mr. Cruise typically used accurate, age-appropriate descriptions of the phenomena, these two interns sometimes used imprecise language or introduced ideas that could confuse students. When Ms. Kelly connected the class's claim that the water turned into steam to the scientific phenomenon of evaporation, she reinforced a common alternative conception that the water "disappears" as it evaporates. Ms. Kelly stated,

> "When something evaporates it changes from the liquid state, which is just water in a cup, to the gas state, which is what happened when our steam ***disappeared*** into the air" [RT_K – emphasis added].

This quote shows how Ms. Kelly's use of language for describing the scientific phenomenon might cause confusion for students who think that the water molecules disappear completely. A more scientifically accurate description might underscore the mechanism behind the change of state from liquid to gas. Ms. Kelly used this language throughout her lesson. Similarly, in a fifth-grade lesson on the cycling of nutrients in an ecosystem, Mr. Cruise described that the arrow in the simple food chain represented "the flow of nutrients in a system" [RT_C], whereas the arrows conventionally represent the flow of energy. This might confuse students' understanding of the conventional use of arrows in food chains and food webs; however, in this case, the nutrients did move through the system in a similar manner.

All of the interns connected the investigation and claims made about the scientific phenomena to students' lives or prior experiences. For example, in their investigation of "what is the best cereal?" Ms. Schuster discussed with students why looking for nutrients is important for their health; for example, fat "helps [the] brain and … nervous system form" [RT_S]. In the investigation of how an organism's environment affects its ability to survive, Ms. Atkin connected the students' prior knowledge about camouflage and presented additional common examples of animals blending in with their background. In her lesson on evaporation, Ms. Kelly reminded students of when the class "put water in the freezer" and the water became a solid [RT_K]. Each of these examples would connect the investigation and claims made to students' prior knowledge and experiences.

All five focal interns also connected the claims made during the investigation to a scientific principle or mechanism. For example, Mr. Cruise accurately connected the students' claims about the individual roles that organisms play in the movement of nutrients in the ecosystem to the larger concept of the cycling of matter and nutrients, with the statement, "There is this cycle that goes over and over" [RT_C]. Ms. Kelly, Ms. Atkin, and Ms. Schuster would also discuss an accurate mechanism or principle. Ms. Michaels also discussed the mechanism behind floating or sinking in her investigation; however, the mechanism she discussed was inaccurate, as described above.

Reflective Teaching Summary. In summary, the interns' Reflective Teaching lesson plans and enactments typically included accurate, age-appropriate descriptions of the phenomena that connected to a mechanism or scientific principle. The interns also commonly made connections to students' prior knowledge or experiences. However, some interns struggled with using accurate descriptions or avoiding confusing ideas during their teaching.

Post-Assessment. The pre-assessment and post-assessment for the Science Methods Course had the same requirements and investigation question: "How does the weight of the solution compare to the weight of the materials used to make up the solution?" As seen in Figure 6-1, the quality of the interns' science knowledge for teaching seemed similar on the pre- and post-assessment for the Science Methods Course, although a slight shift in the proportion of interns in each category occurred. There was no significant different between the two assessments (paired t-test: $t = 0.3806$; $p = 0.71$; $df = 46$). On both the pre- and post-assessment, the majority of interns "met" or "exceeded" expectations in terms of quality of science knowledge for teaching. These lessons included an accurate, age-appropriate description of the phenomenon and a connection to the mechanism or principle involved. For example, Intern 14 planned to "show how the weights [of the solution and the materials] are equal …[and] discuss why they're equal, and even though in the solution we can't see the salt, it is still there" [PostA_14]. This plan would support students in making an accurate claim and considering the mechanism involved in the claim.

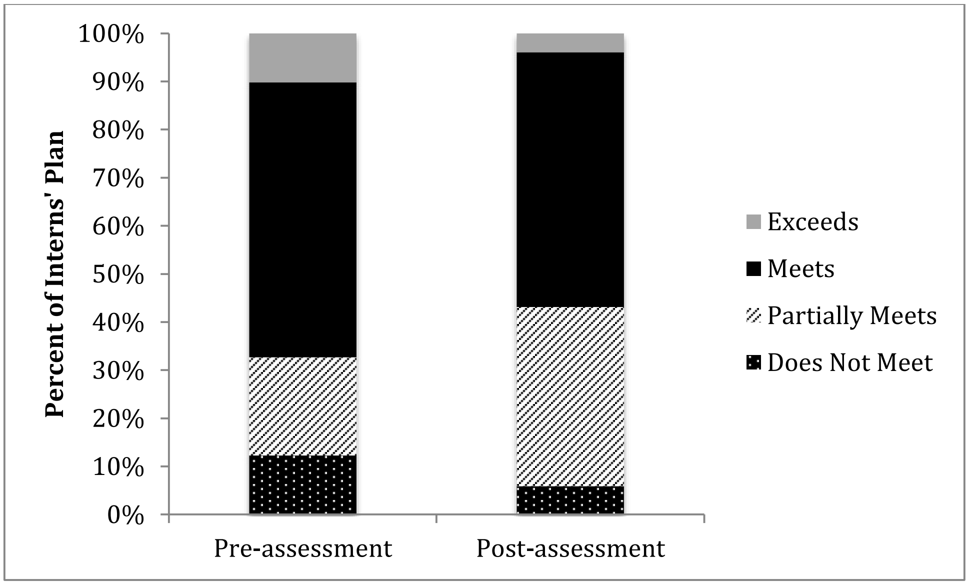


Figure 6-1: Quality of Interns' Science Knowledge for Teaching as Evidenced by the Pre-Assessment and Post-Assessment

Some interns showed struggles in terms of science knowledge for teaching on the pre- and post-assessment. On the post-assessment, fewer plans "did not meet expectation" (6%) than on the pre-assessment (12%). These plans inaccurately described the phenomenon, such as claiming, "the solution weighs more" than the materials that make up the solution [PostA_9]. A few more plans "partially met expectations" on the post-assessment (37%) than on the pre-assessment. These plans typically did not connect to the mechanism involved in the investigation.

Science Methods Summary. In sum, the interns showed strengths in their science knowledge for teaching on the Peer Teaching lesson plans and Reflective Teaching lesson plans in terms of including accurate, age-appropriate descriptions. Similarly, the quality of science knowledge for teaching remained similar on the pre- and post-assessment lesson plans for the course; these plans typically provided an accurate, age-appropriate description of the phenomena. In the enactments of the lesson, focal interns typically connected the accurate descriptions to students' lives and the mechanism involved in the phenomena. However, some of the focal interns struggled with encouraging or introducing confusing ideas about the scientific phenomena during their enactments.

After Science Methods: Continued Growth over Time

After the Science Methods Course, the interns' enactments of their lessons suggested growth in their science knowledge for teaching. The focal interns accurately described the scientific phenomena and made connections to the scientific principle or mechanism. The interns also regularly made connections to children's prior knowledge or experiences, particularly connections to previous lessons or learning.

Student Teaching. The focal interns' enactments during student teaching suggested several areas of strengths in their science knowledge for teaching. (Ms. Schuster did not teach science during student teaching.) All four of the focal interns' enactments "met" or "exceeded expectations" in the quality seen in the science knowledge for teaching (see Table 6-7). In each of the 11 lessons, the interns used an accurate description of the phenomena that would be appropriate for an elementary student. For example, in their investigation of pollutants found on the school grounds, Mr. Cruise discussed with students if birdseed is a pollutant. He accurately described how "both the apple core and birdseed can decompose, so [he is] not sure if [he] would consider them pollutants" [C_Field4]. However, Mr. Cruise also considered the students' response, "What if the birdseed was dumped into the river?" [C_Field4] and added, "All of these questions do not have answers" [C_Field4]. This discussion depicted the complex problem of pollutants and how materials can sometimes cause damage to other living things in an accurate and age-appropriate manner. In the other investigations, all four of the focal interns used similar, age-appropriate descriptions of the phenomena.

Table 6-7: Evidence of Science Knowledge for Teaching Seen in Student Teaching Enactments

	Ms. Kelly			Ms. Atkin		Mr. Cruise				Ms. Michaels	
Investigation	1	2	3	1	2	1	2	3	4	1	2
Uses an accurate description of the phenomenon that is appropriate for elementary students	X	X	X	X	X	X	X	X	X	X	X
Does not encourage confusing ideas		X	X	X		X	X	X	X	X	X
Connects the phenomenon to children's prior knowledge or experiences	X		X	X	X	X	X	X	X	X	X
Connects the claims to the scientific principle or mechanism	X	X	X	X	X	X	X	X	X	X	X
Meets or exceeds expectations	X	X	X	X	X	X	X	X	X	X	X

The interns typically used clear language in describing the phenomena; however, in two of the 11 investigations, an intern used a question or explication that could introduce confusion. In her first investigation of what is a fruit, Ms. Kelly asked, "Do all fruits grow from the ground up?" [K_Field1]. This question seemed confusing to the students and resulted in students' considering items that grow in the ground, such as carrots, to be fruit. Similarly, Ms. Atkin explained that the difference between series and parallel results from "the way that electricity is going through" [A_Field4], without clearly explicating how electric current moves through the circuit. Without this additional information, the students may not have been able to understand what Ms. Atkin meant. These are the only two instances of encouraging confusing ideas during the student teaching enactments that were video-recorded. This suggests that the interns typically used clear, age-appropriate explanations of the phenomena.

The interns typically connected the investigation and description of the phenomena to students' prior knowledge or everyday experiences. For example, Ms. Michaels reviewed what students had learned in their previous lessons about the senses, reminding students, “We have been talking about your senses” [M_Field1]. Ms. Kelly required students to apply their understanding of forces from the investigation to an everyday experience of playing with a toy car by asking, “What causes the car to spin out of control?” [K_Field3]. These types of connections to students’ prior knowledge from previous lesson and to students’ everyday experiences occurred throughout the interns’ lessons, except for Ms. Kelly’s second investigation, which she did not connect to prior knowledge or experiences.

The interns also typically made connections between the claims made in the investigation and the mechanism or principle involved. An example of a connection to the mechanism is Ms. Atkin’s discussion of what caused the light to be brighter during an investigation of “what happens when you add more batteries to a circuit?” During this investigation, Ms. Atkin discussed that “the more power, the brighter [the light bulb] is getting” and underscored the mechanism involved in the phenomenon. An example of a principle is Ms. Kelly’s second investigation of “what causes objects to move?” where she emphasized the scientific principle that “objects cannot move all by themselves” rather that they need a force, which “is a simple push or pull” [K_Field2]. The interns made similar connections in the other investigations during student teaching.

End of the Year Standardized Student Enactment. In contrast to the enactments during student teaching that suggested high-quality science knowledge for teaching, the interns’ end of the year Standardized Student Enactments of the three focal interns who participated in the standardized student interview showed a greater range in the quality of the science knowledge for teaching. The three enactments ranged from “exceeds expectations" to “partially meets expectations.” However, the interns also showed some similar strengths (see Table 6-8).

For example, with the investigation question, “How does the weight of the solution equal the weight of the materials used to make up the solution?” all three interns supported students to make the claim that the weight of the materials is equal to the weight of the solution. Thus, they used an accurate, age-appropriate description of the phenomena.

Table 6-8: Evidence of Science Knowledge for Teaching during the End of the Year Standardized Student Enactment

	Ms. Kelly	Ms. Atkin	Ms. Schuster
Uses an accurate description of the phenomenon that is appropriate for elementary students	X	X	X
Does not encourage confusing ideas		X	X
Connects the phenomenon to students’ prior knowledge or everyday experiences	X	X	X
Connects the claims to the scientific principle or mechanism	X		X
Quality of science knowledge for teaching	Meets	Partially meets	Exceeds

Ms. Schuster “exceeded expectations” by using an accurate, age-appropriate description of the phenomenon that connected to students’ prior knowledge and everyday experiences and the scientific mechanism. She supported the students to connect the accurate claim to the mechanism of making a solution. She asked the students, “Why does [the concept of] a solution support” our claim? [S_SS2]. This question facilitated the students to describe their prior knowledge that in a solution, one cannot tell the solid from the liquid. She also used the example of “cookie dough,” a typical everyday experience, to distinguish between a mixture and a solution.

Ms. Kelly used a similar accurate, age-appropriate description of the phenomenon that connected to the scientific mechanism and students' everyday experiences. Like Ms. Schuster, she used the everyday experience of a "smoothie" to help explain how the solution is made up of pieces that do not go away when mixed together. However, she encouraged a confusing idea by describing the salt as "disintegrating" and "disappearing" into the water [K_SS2].

In contrast, Ms. Atkin "partially met expectations" and did not discuss a mechanism or scientific principle involved in the investigation, yet she did use an accurate, age-appropriate description of the phenomenon that connected to the students' prior knowledge. However, Ms. Atkin did not make other connections to everyday experiences as Ms. Kelly and Ms. Schuster did in their enactments.

After Science Methods: Summary. In summary, the focal interns showed several strengths in their science knowledge for teaching in their enactments of lessons after the Science Methods Course. The interns consistently used accurate, age-appropriate descriptions of the phenomena and connected the descriptions to the mechanism or principle involved. The interns also typically made connections to students' prior knowledge or everyday experiences.

Change over Time

The focal interns' enactments of their lessons seemed to suggest growth in science knowledge for teaching over the two years in the program. However, the lesson plans of the entire cohort did not seem to show the same growth from the pre-assessment to the post-assessment during the Science Methods Course. In this short section, I consider the changes over time in both the lessons plans of the entire cohort and the enactments of lessons by the focal interns.

Changes over Time Seen in the Lesson Plans. The quality of science knowledge for teaching seen in interns' pre- and post-assessment plans did not show change; however, the interns showed higher quality of science knowledge for teaching during the Peer Teaching and Reflective Teaching assignments (see Figure 6-2). For the Peer Teaching lesson plans, almost all (94%) of the interns either "met" or "exceeded expectations" for quality of the science knowledge for teaching. For the Reflective Teaching assignment, three-fourths (77%) of the interns met this mark. This means that the lesson plan included an accurate, age-appropriate description of the phenomenon and a connection to the mechanism or scientific principle. In the Reflective Teaching and Peer Teaching plans, more than three fourths of the interns also planned to make connections to students' prior knowledge or everyday experiences.

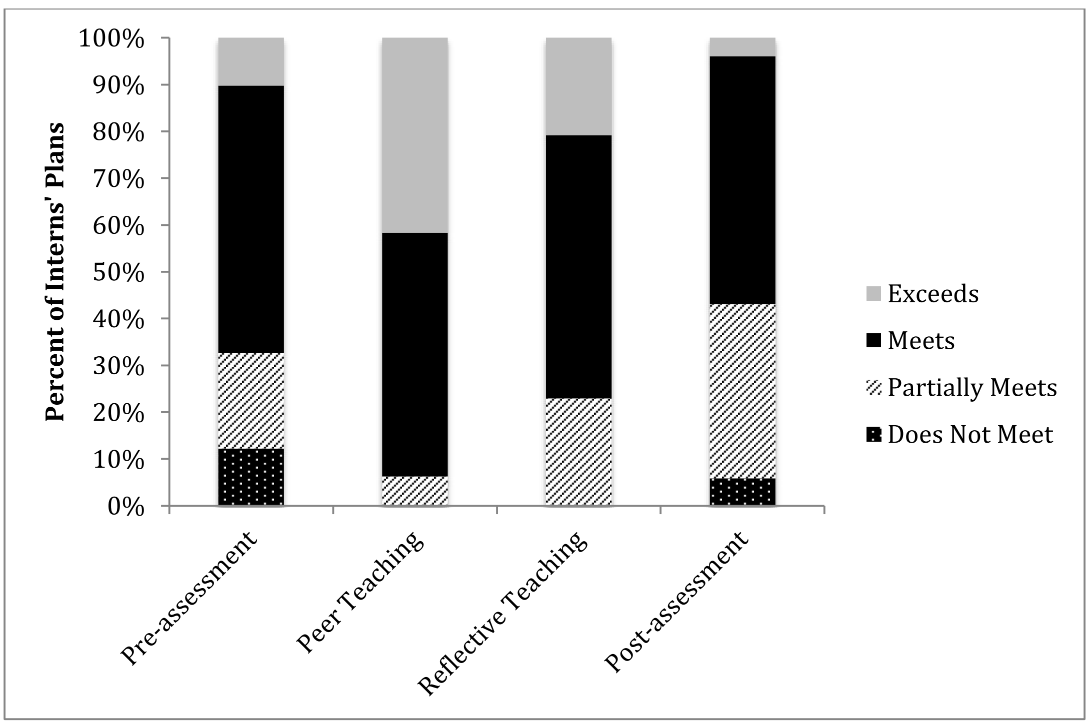


Figure 6-2: Quality of Science Knowledge for Teaching of Interns' Lesson Plans across Assignments

In contrast, fewer interns "met" or "exceeded expectations" for the pre-assessment (67%) and post-assessment (57%). The struggle to "meet" or "exceed expectations" on the pre- and post-assessment may result from the directions of the task, which required the interns to support students to answer the investigation question but did not explicitly require interns to address the mechanism or principle involved. For each set of lesson plans, most of the interns "met" or "exceeded expectations," suggesting strength in this area. However, a portion of the interns "partially met" or "did not meet expectations," suggesting that some interns struggled to present the science content clearly and connect to the mechanism or principle involved in the phenomena.

Change over Time Seen in the Enactments. The focal interns' enactment showed the highest quality of science knowledge for teaching during student teaching, as seen in Table 6-9. The interns also showed strengths during their Peer Teaching enactments. This strength is not surprising, given the additional support interns had in co-planning these lessons with peers.

Table 6-9: Quality of Science Knowledge for Teaching Seen in Enactments over Time

	Children as Sensemakers	Pre-Assessment	Peer Teaching	Reflective Teaching	Student Teaching	End of Year
Ms. Kelly	2	3	3	2	3.3	3
Ms. Atkin	2	2	3	3	3	3
Mr. Cruise	2	4	4	3	3	n/a
Ms. Michaels	2	2	2	1	3.5	n/a
Ms. Schuster	3	3	4	3	n/a	4

Does not meet = 1; partial = 2; meets = 3; exceeds = 4

The interns' enactments also showed particular areas of strength or struggle throughout the program in terms of science knowledge for teaching. As seen in Table 6-10, the interns typically used an accurate, age-appropriate description of the phenomenon and connected this to a scientific principle or mechanism. In addition, the interns often connected the phenomenon or investigation to students' prior knowledge or everyday lives. However, the interns struggled with introducing or encouraging confusing ideas about the content in their lessons, yet this occurred less often during student teaching.

Table 6-10: Evidence of Science Knowledge for Teaching Seen in the Enactments throughout the Program

	Children as Sensemakers (*n=5*)	Pre-Assessment Standardized Student (*n=5*)	Peer Teaching (*n=5*)	Reflective Teaching (*n=5*)	Student Teaching (*n*=11)	End of the Year Standardized Student (*n*=3)
Uses an accurate description of the phenomenon that is appropriate for elementary students	XXXXX	XXXXX	XXX _ _	XXXX _	XXXXXXXX XXX	XXX
Does not encourage confusing ideas	XXX _ _	XXX _ _	XXX _ _	XX _ _ _	XXXXXXXX X _ _	XX _
Connects the phenomenon to child's life	XXXXX	XXX _ _	XXXXX	XXXXX	XXXXXXXX XX _	XXX
Connects the claims to the scientific principle or mechanism	XXXXX	XXXX _	XXXXX	XXXXX	XXXXXXXX XXX	XX_

X = evidence found in an interns' enactment; _ = evidence not found

Conclusion

This chapter summarized the interns' science knowledge for teaching. First, the chapter examined the interns' subject matter knowledge as seen in their evidence-based claims. The interns' evidence-based claims seemed to remain at the same quality throughout the program. However, the proportion of accurate claims varied depending on the discipline (e.g., life science versus earth science) or topic. This chapter also considered the interns' pedagogical content knowledge for supporting students to construct evidence-based claims. The interns' pedagogical content knowledge seemed to improve throughout the program. The strongest quality was seen in the interns' enactment of lessons during student teaching. This trend in quality of the interns' science knowledge for teaching differed from the quality of the subpractices of supporting students to analyze the data to reveal patterns and relationships and supporting students to make claims justified by evidence and reasoning. As described in Chapters 4 and 5, the interns' quality of support for these two subpractices was strongest during the Science Methods Course. In the next chapter, I consider the individual focal interns' trajectories for learning to support elementary children to construct evidence-based claims, including all three dimensions discussed thus far: the two subpractices and the science knowledge for teaching.

CHAPTER 7

TRAJECTORIES OF INDIVIDUAL FOCAL INTERNS OVER TIME

Chapters 4, 5, and 6 considered the entire cohort's trajectory of learning in the program for the teaching practice of supporting students to construct evidence-based claims. This chapter examines the individual learning trajectories of the focal interns as well as the focal interns' self-report of their change over the course of the program. In this chapter, I focus on four of the five focal interns, Ms. Atkins, Ms. Kelly, Mr. Cruise, and Ms. Schuster. Ms. Michaels was unavailable for the final two interviews, making it difficult to consider her self-report of change over time.

The individual trajectories highlight the strengths, struggles, and growth that could occur for interns over the course of the program. Figure 7-1 summarizes the individual trajectories of these four focal interns over the two years in the program. Each row represents one focal intern's teaching practice and knowledge for supporting students to construct evidence-based claims. Each row contains up to four large rounded boxes, which represent an intern's teaching practice and knowledge at particular time points in the teacher education program. From left to right, these time points are as follows: the first year, the Science Methods Course, student teaching, and the post-assessment. Each larger rounded box contains four smaller boxes, which represent components of the teaching practice: supporting students to *analyze the data,* supporting students to *share their thinking* about the patterns and relationships, supporting students to *use a logical structure to justify their claims*, and supporting students to *communicate a claim*. The shading of the small boxes represents the quality of the support that the intern provided at this time in the program. A darker shade represents higher quality. The shading of the larger rounded boxes represents the interns' science knowledge for teaching at particular points in the program. The darker shading of these boxes represents evidence of higher quality of science knowledge for teaching at a particular point in the program.

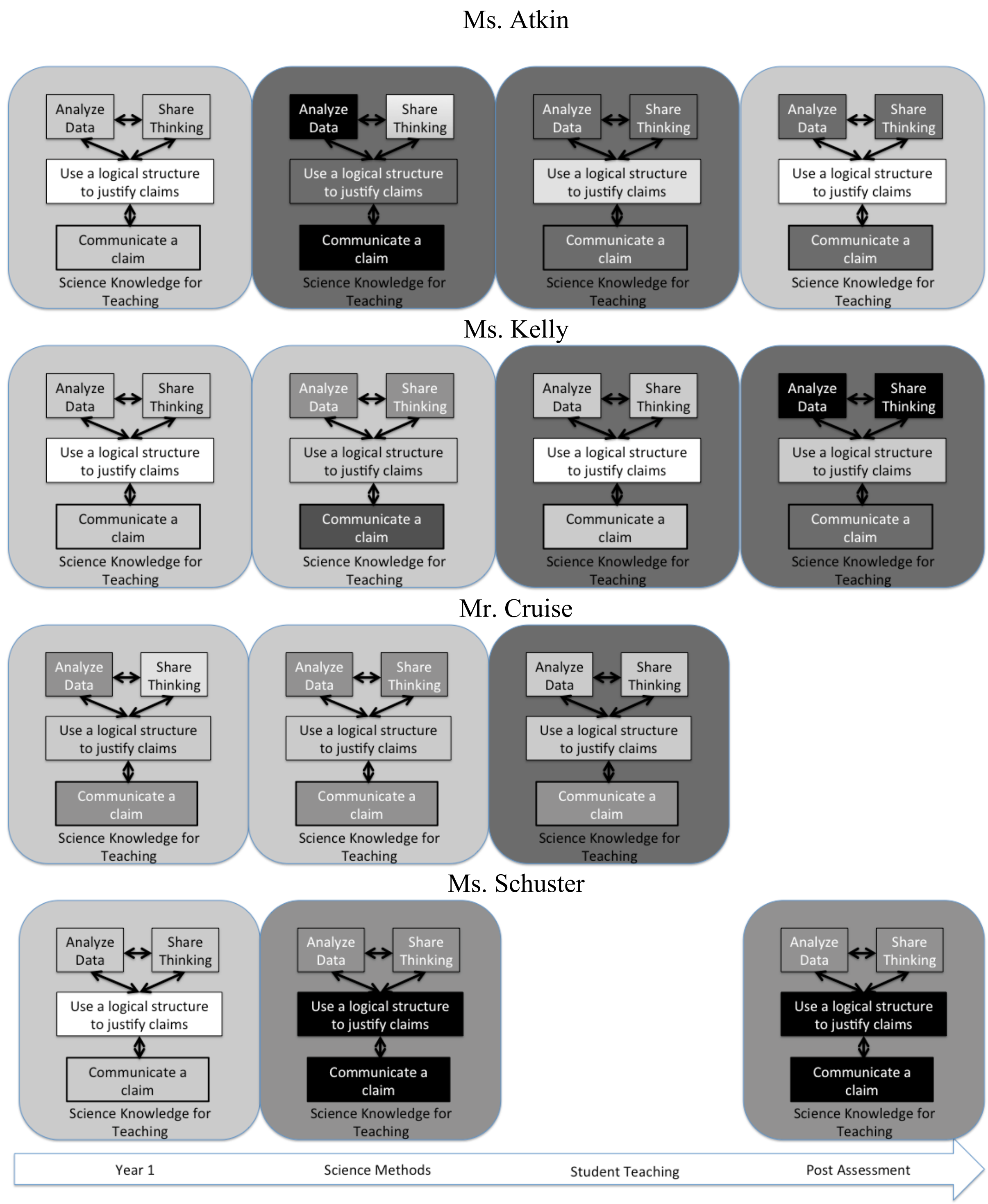


Figure 7-1: The Focal Interns' Practice and Knowledge for Supporting Students to Construct Evidence-based Claims over the Program.

As seen in Figure 7-1, variation existed in the interns' trajectories. The individual trajectories also showed growth over time, particularly in the science knowledge for teaching and the teaching subpractice of supporting students to analyze data to reveal patterns and relationships, yet the interns typically continued to struggle in other areas, such as using a logical structure to justify claims. In interviews, the interns connected their learning to support students to construct evidence-based claims of natural phenomena to several factors in the program (e.g., the EEE framework and approximations of practice) and outside of the program (e.g., prior experiences with students, science content courses). This chapter focuses in on the individual trajectories of the focal interns and finishes with a comparison across their trajectories.

Ms. Atkin's Practice and Knowledge for Supporting Students to Construct Evidence-Based Claims

Ms. Atkin's interviews suggested that she was excited about and had a strong foundation for teaching elementary science. Before the first year in the program, Ms. Atkin transferred from a nearby university to enter the teacher education program as an integrated science major. Ms. Atkin had taken 10 science courses as an undergraduate. This number of courses is more than taken by most interns in the cohort, who typically took three science content courses, but it was similar to the number taken by the other focal interns, Mr. Cruise and Ms. Schuster, who were also integrated science majors. In her first interview, Ms. Atkin described science teaching as "fun." She also described how the most exciting part of teaching was the students' "growth throughout the year both academically and socially" [A_Interview1]. Her experiences with students prior to the program (e.g., tutoring students, volunteering in a kindergarten classroom) seemed to position Ms. Atkin as comfortable and excited about her teaching.

As seen in the first row in Figure 7-1, Ms. Atkin showed growth in supporting students in analyzing the data to reveal patterns and relationships and share their thinking. Her science knowledge for teaching also seemed to grow over time, although this was not evidenced in the post-assessment. Throughout the program, Ms. Atkin seemed to struggle with supporting students to use a logical structure to justify claims. She attributed this to her learning teaching in the field, approximations of practice in difference courses, and an explicit emphasis on discussions. In this section, I consider Ms. Atkin's trajectory over the course of the program, as well as how she described her learning.

Ms. Atkin's Support for Analyzing Data to Reveal Patterns and Relationships and Sharing Thinking

An area of growth for Ms. Atkin was supporting students to analyze the data to reveal patterns and relationships. Table 7-1 outlines the teaching moves Ms. Atkin used in the subpractice of supporting students to analyze the data to reveal patterns and relationships throughout the program, as well as the quality of support Ms. Atkin provided for this subpractice.

Table 7-1: Ms. Atkin's Teaching Moves and Quality of Support for Analyzing Data to Reveal Patterns and Relationships

	Before Science Methods	Science Methods	Student Teaching	Post-Assessment
Creates an additional clear representation to show the pattern	_	X _	X X	X
All of the data are considered	X _	X X	X X	
Makes implicit features of the representation clear	X X	X X	X X	X
Connects representations to each other	X X	X X	X X	X
Does not do the intellectual work involved in analyzing and interpreting the data	_ X	X X	X X	
Does not ask leading questions that provide the reasoning	_ _	X X	X X	
Quality of Support (average)	2.5	3.5	3.5	3

X = teaching move was used; _ = teaching move was not used; 1 = did not meet expectations; 2 = partially met expectations; 3 = met expectations; 4 = exceeded expectations

As seen in Table 7-1, Ms. Atkin's quality of support improved over time. At the beginning of the program, Ms. Atkin did aspects of the intellectual work of analyzing and interpreting the data for the student during the Children as Sensemakers Course. For example, while investigating how the model of Earth turned to cause day and night, she told the child the pattern of "it turned clockwise" rather than allowing the child to name the pattern, although the student seemed capable of realizing this pattern [A_CaSMReading].

Ms. Atkin also used representations that seemed confusing for her students throughout the first year and into the second year of the program. For example, she guided the standardized student to use negative numbers to see the pattern of conservation of mass during the pre-assessment standardized student enactment. The use of negative numbers might make it difficult to conceptualize that the weight of the solution was equal to the weight of the materials that made up the solution, which was the object of the lesson [A_PreAssess]. Ms. Atkin discussed her own struggle to support students to use graphs to analyze the data to reveal patterns and relationships during her reflective teaching assignment during science methods. She commented that she “noticed it wasn’t going well” while teaching the lesson [A_Interview3: 286]. She commented that this experience helped her learn how to support students in analyzing data to reveal patterns and relationships: “I've realized that you need to have multiple approaches to how to … analyze the data with the students” [A_Interview3:278-279].

As she moved into student teaching after this experience, Ms. Atkin provided additional support for students and used clearer representations for revealing patterns. For example, she designed a table to compare different types of circuits and supported the students to use the table during the lesson. As the class completed the chart, Ms. Atkin asked the students to describe the patterns they noticed and compare their observations to each other. She also had students share their thinking about the patterns they noticed, asking questions such as, “Why do you think [this circuit] was about the same [brightness as the other circuit]?” These interactions about the chart seemed to support the students to name the pattern [A_Field4]. In other lessons during student teaching, Ms. Atkin also supported the students to analyze and interpret the data with the aide of a representation and facilitated students to describe the pattern. In her interviews, Ms. Atkin also commented that she felt she had more strategies to support students to analyze the data to reveal patterns and relationships, saying, “I’ve learned more about what to do help students … identify patterns in the data” [A_Interview4: 181-183]. However, during the end of the year enactment with a standardized student, Ms. Atkin showed struggles in supporting students to analysis data that were similar to those she had earlier in the program.

Ms. Atkin also showed areas of strength throughout the program, including making implicit features of representations more explicit and making connections across representations. For example, during the Peer Teaching Lesson, she explicitly circled patterns that students named in the table. She also connected the students' representations of their observations to the table they created as a group, telling students, "Now, we're going to look at our observations and make one big T chart [to show what we found]" [A_PeerTeach]. Similar teaching moves were seen throughout Ms. Atkin's lessons in the two years of the program (see Table 7-1).

Ms. Atkin's Support for Making Claims Justified by Evidence and Reasoning

In the subpractice of supporting students to make claims justified by evidence and reasoning, Ms. Atkin showed growth in connecting students' ideas to each other and working with students' alternative ideas. As seen in Table 7-2, Ms. Atkin attended to students' alternative ideas and connected students' ideas to each other more frequently during science methods and student teaching than in her interactions with students before science methods. At the beginning of the two years, during the read-aloud with the child, Ms. Atkin ignored the child's alternative idea and instead affirmed the student's inappropriate reasoning.

> Ms. Atkin: Which one is showing sunrise?
> Student pointed to the appropriate representation.
> Ms. Atkin: Why did you choose that one?
> Student: …They are walking into the light.
> Ms. Atkin: Good. [A_CaSMReading]

Ms. Atkin's affirmation that the child's answer was "good" suggests that Ms. Atkin did not recognize that the child had possibly misunderstood the representations and thought that people walked into the light during sunrise. Ms. Atkin also did not connect students' ideas to each other during her pre-science methods enactments.

Table 7-2: Ms. Atkin's Teaching Moves for Support Students to Make Claims Justified by Evidence and Reasoning

	Pre-Science Methods	Science Methods	Student Teaching	Peer Teaching
Supports the student to make claims	_ X	X X	X X	X
Uses a structure to construct evidence-based claims	_ _	X X	_ _	
Uses other scaffolds/tools to support construction of claims (sentence stems, peers, etc.)	_ _	X X	X _	
Connects students' ideas to each other	_ _	X X	X X	
Gives feedback on construction of claims	_ _	X _	_ _ _	
Follows up on an alternative idea that the child gives	_ X _	X _	X _	X
Supports students to describe evidence	X	X X	X X	
Supports students to describe reasoning	_	X _	_ _	
Does not ignore an alternative idea that the child puts forth	_ X	X X	X X	X
Does aspects of the intellectual work of describing the evidence	X	X X_	X X	
Does not do the intellectual work of naming the reasoning for the student	_ _	X X	_ _	
Quality of Support	2	2.5	2	2

X = teaching move was used; _ = teaching move was not used; 1 = did not meet expectations; 2 = partially met expectations; 3 = met expectations; 4 = exceeded expectations

In contrast to her enactments before the science methods course, during science methods and student teaching, Ms. Atkin seemed to recognize and follow up on students' alternative ideas more frequently. She also more consistently connected students' ideas to each other. For example, when a student offered an alternative idea about how electricity flowed in a circuit, Ms. Atkin asked the student, "Can you go up to the board and point?" to facilitate the student to explain her thinking. After the student further explained her thinking, Ms. Atkin asked the other students, "Does anyone want to resay what she said or add to it?" At this point, other students shared their thinking about the flow of electricity in the circuit [A_Field3]. This example illustrates how Ms. Atkin followed up on students' alternative idea and connected students' ideas to each other during student teaching and science methods.

In her interviews, Ms. Atkin noted how she grew in her ability to consider students' alternative ideas and connect the students' ideas to each other. After the science methods class, she described how she had greater awareness of students' alternative ideas and how to use this knowledge in her teaching than she had had at the start of the program: "I've been more aware of alternative ideas…. I've learned that … sometimes you just have to let alternative ideas go and try to think about it later … and then come back to the student" [A_Interview4]. Ms. Atkin also commented on this change in her teaching at the end of the program: "I think I'm more willing to go and explore those alternate ideas than I probably was at the beginning of the year" [A_Interview4: 218-219]. In this interview, Ms. Atkin also discussed her growth in using discussion moves that connect students' ideas. She described how "students … building off of one another's thoughts to help come up with a collaborative idea … has been a big thing." When asked to give an example, she described how she supported students to "restat[e] one another or try … to explain adding on to one another's thoughts" [A_Interview4: 189-193]. In this interview, Ms. Atkin named some of the teaching moves seen during her student teaching. The interviews suggest that she was using these moves with students purposefully and able to see her own growth in this area over time.

Throughout the program, Ms. Atkin showed strength in supporting students to make claims, yet she continued to struggle to facilitate the students in justifying their claims with both evidence and reasoning. As seen in Table 7-2, the quality of Ms. Atkin's support for making claims justified by evidence and reasoning typically "partially met" expectations. Ms. Atkin supported students to make claims and justify their claims throughout the program. However, she regularly did aspects of the intellectual work of justifying the claims with reasoning and evidence for the students. For example, Ms. Atkin had students make a claim about how to make a complete circuit. Then, a student shared the evidence based on her observations from the investigation. Rather than allowing the students to reason through how this claim was true on the basis of the mechanism discussed earlier in the class, Ms. Atkin did this work, saying, "Remember, we want the electricity to go all of the way through … to complete the circuit" [A_Field1]. Ms. Atkin commonly did the intellectual work of justifying the claim for the students throughout the program. Only during Peer Teaching did Ms. Atkin support the students to share both the evidence and reasoning that supported the claim. For Peer Teaching, Ms. Atkin had additional support from co-planning the lesson and was teaching adults in the class.

In summary, Ms. Atkin improved in her ability to consider students' alternative ideas and connect students' ideas to each other. In addition, Ms. Atkin regularly supported students to make claims about the patterns in the data. Over time, she supported students to justify these claims with either evidence or reasoning, yet she continued to provide either the evidence or reasoning for students.

Ms. Atkin's Science Knowledge for Teaching throughout the Program

Throughout the program, Ms. Atkin's lesson plans and written work suggested she had strong science content knowledge. For example, on her pre-assessment for the science methods class, Ms. Atkin planned to underscore the "big idea" of conservation of mass with additional examples: to "use other substances to show the mass of an object or substances can not be destroyed" [A_LP_PreAssess]. Similarly, in her reflective teaching plan for her fourth-grade classroom, Ms. Atkin described how her lesson underscored the principle of natural selection:

> This lesson focuses on natural selection. Students will observe how characteristics of an organism (beads) affect the organism's ability to survive in its habitat. During the lesson, students will learn about predators and preys and actually take on the role of being a predator. They will simulate natural selection through an interactive investigation where the students have twenty seconds at each station to collect beads (prey). [A_LP_RT]

This description suggests that Ms. Atkin understands the scientific principles and mechanisms underlying the lesson she planned for her students.

Although Ms. Atkin's lesson plans and prior experiences suggested that she had strong content knowledge and ability to link lessons to the big ideas, her early enactments of lessons showed her struggle to connect students to the "big ideas" and mechanisms involved in natural phenomena. In her enactments of the pre-assessment lesson described before, she did not discuss with the standardized student the "big idea" of conservation of mass, although she had planned to do so in her lesson plan. Likewise, during a read-aloud with a first-grade child about "what makes day and night," Ms. Atkin did not clarify the student's confusion about how people "walk" into the sunlight rather than that Earth turns into the sunlight. Later in the lesson, Ms. Atkin did tell the child that "Earth turns" but did not have the child explain this mechanism; this was a missed opportunity [A_CaSMReading].

During the second year in the program, Ms. Atkin seemed to grow in her ability to make the mechanisms and "big ideas" more apparent to her students. For example, in her Reflective

Teaching lesson about natural selection described above, she discussed with her students why being camouflaged might be an advantage for survival. After Ms. Atkin summarized the finding that bugs of the same color as their background are more likely to survive, she asked a student to explain "why [the bug] …was more likely [to survive]." The student gave a comment, and Ms. Atkin rephrased this comment, saying, "I like what [Student A] said, if the bug's the same color as their background, it's more likely to blend in" [A_RT]. These comments highlighted the mechanism involved in the phenomenon they were investigating in their simulation.

During student teaching, Ms. Atkin also discussed the mechanisms underlying the phenomenon the students were investigating. After students investigated how to light a bulb with a complete circuit, Ms. Atkin discussed the movement of electric current in a complete circuit. She also used an analogy and additional representation to help students understand what occurs in a short circuit [A_Field1]. In other lessons, the class discussed how resistance and power affect the brightness of a bulb. Ms. Atkin also made connections across the lessons in her unit to support students to understand the big idea. At the beginning of her fourth lesson during student teaching, she asked students to recall the evidence-based claim from a previous lesson, asking, "When we had two batteries, was the bulb brighter or dimmer?" [A_Field4]. In this lesson, she also discussed with students how they could apply this knowledge to wire a house. Use of these discussions and teaching moves suggest that Ms. Atkin helped her students to see the mechanisms and big ideas underlying their investigations during student teaching.

How Ms. Atkin Described Why Her Practice and Knowledge Changed

In her interviews, Ms. Atkin identified three reasons why her practice changed over the course of the program: (a) her opportunities to teach in the field, (b) her experiences in the approximations of practice during the Children as Sensemakers and the Science Methods Course, and (c) the emphasis on leading discussions during math methods.

First, Ms. Atkin explicitly described her experiences in the field as most influential to her learning. In particular, she described her opportunity to teach a science unit as being influential, saying,

> I've had the most interaction with really doing science lessons consecutively and … each day pulling out data or pulling out different observations that they're making and trying to create a claim at the end [A_Interview4: 347-350].

This quote highlights how teaching science in the field enabled Ms. Atkin to practice the work involved in supporting her students. In her interviews, she seemed to connect her many experiences teaching in the field with being more flexible to "go … off course" and explore students' alternative ideas [A_Interview4: 220]. She also discussed how being in the field throughout the program facilitated her understanding of the range of ideas that students might have.

Second, Ms. Atkin described how the approximations of practice during the Children as Sensemakers Courses and Science Methods Course also supported her to consider students' alternative ideas and scaffold student learning. Ms. Atkin described how interacting with individual students in the field during the Children as Sensemakers Courses allowed her to develop a deeper understanding of student thinking. She emphasized that "to see how a student interprets … information was really helpful" [A_ Interview4: 408-409]. Ms. Atkin also emphasized the influence of analyzing her experiences during the course. She explained that the analysis of these experiences helped her realize that she should not assume students "understood it." Rather than thinking that "they're fine," she discussed learning the importance of reviewing students' work and probing their thinking [A_Inteview1:388- 397]. The experiences and new knowledge enabled her to develop her ability to "ask a lot more whys" [A_Interview1: 337-386].

Ms. Atkin seemed to build on this knowledge about students' thinking as she moved through the program. She discussed how the Peer Teaching in the Science Methods Course, another approximation of practice, supported her to notice students' alternative ideas, and then to learn to use additional teaching moves. Ms. Atkin described how particular interactions with her colleagues during Peer Teaching allowed her to handle students' ideas flexibly by "let[ting] alternative ideas go" or "reguid[ing] [students] to the right" direction. [A_Interview3: 231-254]. To deal with these alternative ideas, Ms. Atkin pointed to receiving "feedback" from her peers who acted in the role of a student during Peer Teaching. Ms. Atkin described how her colleagues were "experienc[ing] some of the difficulties" in their role as a student. Discussion of these struggles allowed the group to work "together and create an idea of how [they] would approach it" [A_Interview4: 411-418]. Ms. Atkin marked this experience from the Peer Teaching as influential in multiple interviews.

Ms. Atkin also described how Peer Teaching allowed her to incorporate new teaching moves into her practice. For example, she commented,

> We had to think about how we would analyze the data…. Then, seeing how your lesson went, and then seeing how somebody doing the exact same lesson analyzed their data was just nice to see different ways. You could reflect on yours and [say,] "Well, that would have been great if I had done that. I really like that move." [A_Interview3: 340-348].

One example of a teaching move that Ms. Atkin discussed learning was "being specific with science terms" [A_Interview2: 302]. In addition to her peer's lesson, Ms. Atkin also described the other representations in the Science Methods Course that were influential. For example, she said that watching videos of a science lesson "was helpful … to see [how] other teacher[s] … [supported] analyzing data and how they set it up" [A_Interview3: 373-382]. Discussing lessons in science methods also seemed influential to Ms. Atkin because these "break down the segment of the lesson" and allowed her to hear "multiple perspectives" [A_Interview3].

Third, Ms. Atkins shared that the Mathematics Methods Course's emphasis on leading discussions influenced her learning. Ms. Atkin described how her mathematics methods professor encouraged the use of discussion moves. She pointed out how using these discussion moves "help prolong the discussion [about looking at the data and constructing claims] and make it more in depth" [A_Intervivew4: 176-185]. Ms. Atkin described how she continued to practice these discussion moves during her student teaching and thus developed her teaching practice.

Summary of Changes

As illustrated in the first row of Figure 7-1, Ms. Atkin showed growth in supporting students to analyze the data to reveal patterns and relationships, to share their thinking, and to communicate claims. In each of these elements of the teaching practice, the quality of Ms. Atkin's support seemed to improve over time. For example, she probed students' alternative ideas and connected students' ideas to each other more regularly at the end of the program. Ms. Atkins also improved in her use of science knowledge for teaching during the enactments of her lessons. She made more explicit connections to the mechanisms involved in the scientific phenomena students were investigating and making connections across lessons. However, Ms. Atkins struggled with highlighting the big ideas during the end of the year standardized student enactment. This struggle did not occur during the lessons she taught during student teaching. Ms. Atkin discussed how time in the field, the approximations of practice in difference courses, and explicit emphasis on discussions facilitated her learning.

In contrast to this growth, Ms. Atkin continued to struggle with supporting students to use a logical structure to justify their claims. Although she grew in facilitating students to justify their claims with either reasoning or evidence, she did aspects of justifying the claim with evidence and reasoning rather than allowing students to do this work. In addition, Ms. Atkin used sentence stems to support students in constructing evidence-based claims in a logical structure during science methods; however, she discontinued this use and the emphasis on a logical structure for claims after the course.

Ms. Kelly's Practice and Knowledge for Supporting Students to Construct Evidence-Based Claims

Ms. Kelly, entered the teacher education program as a traditional undergraduate. Unlike the other focal interns who were integrated science majors, she was a language arts major and could remember taking only two science content courses during her undergraduate career. When Ms. Kelly was asked to describe science teaching during her interview, she used the word "fun" [K_Interview1]. However, throughout the interviews, Ms. Kelly described her lack of confidence in her science knowledge. For example, in her fourth interview, she commented, "I'm not comfortable in my science teaching because I've never considered myself to be someone who's good at science and who understands science" [K_Interview4: 680-683]. Despite this concern, Ms. Kelly seemed committed to teaching science, explaining that "I chose to [teach] my [student teaching] unit in science … because … I wanted to challenge myself" [K_Interview4:680; 683]. Ms. Kelly's interviews also suggested her commitment to teaching at the elementary level and particularly "early education" [K_Interview1: 67]. An example of this commitment is seen in her description of the challenge of "balancing the need of every student." She commented how she wanted to "find … a way to reach every student and make sure everyone's achieving and has the support they need" [K_Interview1: 104-105]. In addition, she named how elementary students are "so full of life and so of knowledge in different ways that you just never really know what's going to happen" as the most exciting part of teaching elementary students [K_Interview1:96-98].

As seen in the second row of Figure 7-1, Ms. Kelly showed variation across time in terms of the quality of her support for constructing evidence-based claims. She showed strengths in supporting students to analyze data to reveal patterns and relationships and communicate claims during the Science Methods class and end of the year standardized student enactment, yet she was inconsistent during student teaching. Her science knowledge for teaching seemed to grow over time. Ms. Kelly attributed the change in her practice to experiences in the science methods class and other courses as well as her experiences teaching students. This section further elaborates on Ms. Kelly's practice and knowledge seen during two years in the program, as well as in her own description of her learning.

Ms. Kelly's Support for Analyzing the Data to Reveal Patterns and Relationships and Share Their Thinking

Overall, Ms. Kelly's practice for supporting students to analyze the data to reveal patterns and relationships and share their thinking suggested possible growth throughout the two years in the program. However, the quality of her support was inconsistent over time, as seen in Table 7-3.

Table 7-3: Ms. Kelly's Teaching Moves and Quality of Support for Analyzing Data to Reveal Patterns and Relationships

	Before Science Methods	Science Methods	Student Teaching	Post-Assessment
Creates an additional clear representation to show the pattern	X	X _	X _ _	X
All of the data are considered	_	X X	X X _	X
Makes implicit features of the representation clear	X X	X _	X _ _	X
Connects representations to each other	X X	X X	X X _	X
Supports the child(ren) to analyze and interpret the data	X X	X X	X _ _	X
Probes student thinking	X _	X _	X _ _	X
Does not do the intellectual work involved in analyzing and interpreting the data	X _	X _	X _ _	X
Does not ask leading questions that provide the reasoning	X _	X X	X X X	X
Quality of support	2	3	2.5	4

X = teaching move was used; _ = teaching move was not used; 1 = did not meet expectations; 2 = partially met expectations; 3 = met expectations; 4 = exceeded expectations

Areas of inconsistency for Ms. Kelly included supporting students in doing the intellectual work involved in analyzing and interpreting the data and using a representation to show a pattern (see Table 7-3). During her interaction with the standardized student during the pre-assessment, Ms. Kelly did the intellectual work of analyzing and interpreting the data, including doing the calculations for the students as she created a representation to analyze the data for only one of the three groups. Ms. Kelly asked, "Why are we adding the weight of the cup [that had salt in it] in order to compare the weight of the materials and the solution?" This question might support the students to describe their thinking about what had occurred in the investigation. However, Ms. Kelly gave the answer to this question, saying, "We need to remain consistent" and did not allow the standardized student to share their thinking [K_Pre-Assess]. These interactions show how Ms. Kelly sometimes did the work of naming the pattern for her students and struggled with using representation to support analyzing data to reveal patterns and relationships.

In contrast to her struggles during the pre-assessment enactment, during Peer Teaching, during one of her student teaching lessons, and at the end of the year standardized student enactment, Ms. Kelly facilitated the students to do the work of finding and naming the pattern in the data using an additional clear representation. For example, during the second investigation in student teaching that used toy cars to investigate forces, Ms. Kelly created a representation with her first-grade students of "ways that you could move your car." As the students shared their ideas, such as "blew through a straw" and "pull[ed] a string," Ms. Kelly asked, "Is that a push or pull force?" and recorded their ideas on the board. The students were able to describe what type of force it was, such as "[blowing through a straw is] a push force because … the air will push the car" [K_Field2]. Ms. Kelly used similar representations and supported the students to name patterns during the Peer Teaching and end of the year standardized student enactment. Thus, throughout the program, including during student teaching, Ms. Kelly sometimes provided high-quality support for analyzing data to reveal patterns and relationships, whereas at other times, she did the work for students. This is also seen in the quality of support provided, where Ms. Kelly ranged from "did not meet expectations" to "exceeded expectations" throughout the program.

Another area of inconsistency for Ms. Kelly was probing student thinking. At the beginning of the program during the Children as Sensemakers interactive read-aloud with a first-grade student, Ms. Kelly did not ask probing questions to follow up on what the child said. At other times in the program, Ms. Kelly asked probing and open-ended questions, and she allowed the students to do the intellectual work. For example, during her Peer Teaching enactment, Ms. Kelly asked probing questions such as, “Can you say more?” to clarify a pattern that a colleague-student noticed. Her open-ended question, “Looking at our observation before and after, what changed?” facilitated the colleague-students to name patterns from their investigation [K_PeerTeach]. During her second investigation in her first-grade student placement, Ms. Kelly did similar work, asking open-ended questions such as what is “one of the ways that you could [get] your car to move?” and probing questions, such as “Why?” [K_Field2]. These enactments suggest that Ms. Kelly sometimes asked probing questions and open-ended questions, whereas at other times she struggled supporting students to share and justify their thinking.

Although the quality of Ms. Kelly’s support for analyzing data to reveal patterns and relationships was inconsistent and did not seem to show growth in terms of averages (as seen in Table 7-3), comparing her first (the pre-assessment of the Science Methods Course) and second (the end of the program) Standardized Student enactments suggested growth in this subpractice. For example, during the pre-assessment enactment, Ms. Kelly used only a portion of the data and described the pattern in the data for the student. She also did the work of writing the data into the chart and calculating the differences. In contrast, at the end of the program, Ms. Kelly used all of the data and had the standardized student do the intellectual work of completing the chart. During this interaction, Ms. Kelly also used several representations to help the student understand the pattern, including a chart for the data of all three groups. She used an example of a “smoothie” to facilitate the concept that the “weight [of the salt] is still in the cup,” even if one cannot see the salt, an implicit aspect of the phenomenon [K_SSEndoftheYear]. Ms. Kelly asked probing questions throughout both interactions, such as, “Tell me about how you predicted this” [K_Pre-assess] and “Why do you think that?” [K_SSEndoftheYear].

Adding to the evidence of growth in supporting students to share and justify their thinking from the Standardized Student Enactments, Ms. Kelly described how she learned to probe student thinking and ask students “why” in her interviews. For example, in her first interview, Ms. Kelly commented, “I guess in general you do hear teachers say, ‘Why? Why? Why?’ They ask that question a lot,” and she connected this question to “pushing [kids] to explain” [K_Interview1:595-598]. In her fourth interview, Ms. Kelly described how she “pushed [students] to be able to tell me why” during her student teaching lessons [K_Interview4:552]. However, the lesson that Ms. Kelly described was not observed.

Ms. Kelly’s Support for Students to Make Claims Justified by Evidence and Reasoning

In the subpractice of supporting students to make claims justified by evidence and reasoning, Ms. Kelly showed several challenges in terms of allowing students to do the intellectual work of naming the evidence and reasoning. However, she also had a few areas of strength around connecting students’ ideas to each other and considering alternative ideas. Table 7-4 outlines the teaching moves Ms. Kelly used and her quality of support for this subpractice.

Table 7-4: Ms. Kelly's Teaching Moves and Quality of Support for Supporting Students to Make Claims Justified by Evidence and Reasoning

	Before Science Methods	Science Methods	Student Teaching	Post-Assessment
Supports the student to make claims	X X	X X	X X _	X
Uses a structure to construct evidence-based claims	_ _	X _	_ _ _	_
Uses other scaffolds/tools to support construction of claims (sentence stems, peers, etc.)	_ _	X X	_ _ _	_
Connects students' ideas to each other	X	X X	X X _	X
Gives feedback on construction of claims	_ _	X _	_ _ _	_
Follows up on an alternative idea that the child gives	_	X X	X X _	X
Does not ignore an alternative idea that the child puts forth	X	X X	X X X	X
Supports students to describe evidence	_ _	XX	X X _	X
Supports students to describe reasoning	_	X _	X _ _	X
Does not do the intellectual work of naming the evidence for the student	_	X _	X _ _	X
Does not do the intellectual work of naming the reasoning for the student	_ _	X _	X X _	X
Does not ask a leading question that provides the reasoning	_ _	XX	X X _	X
Quality of Support	2	3	1.5	2

X = teaching move was used; _ = teaching move was not used; 1 = did not meet expectations; 2 = partially met expectations; 3 = met expectations; 4 = exceeded expectations

Throughout her enactments in the program, as seen in Table 7-4, Ms. Kelly typically supported students to make claims, yet she often did aspects of justifying the claim with reasoning and evidence for the students. For example, during her second investigation of student teaching, Ms. Kelly asked her first-grade students to make claims about how objects move after their investigation with small toy cars. She asked students, “Did anyone’s car start moving all by itself?” and allowed students to point out how they used a push or pull force to move the car. However, Ms. Kelly justified the class claim of “objects cannot move all by themselves, that with evidence,” saying, “Every successful method [of moving the toy car] used a push or pull.” She also connected this claim to the principle of force with “a force is simple push or a pull” [MK_FieldLesson3]. In this case, Ms. Kelly supported the students to name the claims and made the evidence and reasoning clear for the students, yet she did the intellectual work of making the connections between the claim, evidence, and reasoning rather than allowing her students to do so. She also did not use any additional supports or the structure of evidence-based claims to do this work. This type of support for students to name the claim but not the evidence or reasoning was typical during Ms. Kelly’s lesson. During her first investigation of student teaching, Ms. Kelly told the students the answer to the investigation question before allowing them to investigate or name their own claims.

In contrast to her other lessons, during Peer Teaching, Ms. Kelly used additional supports and the structure of evidence-based claims for the colleague-students to make their own claims connected to evidence and reasoning. She supported students with the structure of evidence-based claims by asking, “Can someone tell me why we always have to have evidence for the claim?” [K_PeerTeach]. She also modeled this structure and provided a sentence stem to support the work. This type of additional support for students did not occur in other enactments, especially those in her placement classroom. This was on the lesson where Ms. Kelly "exceeded expectations" in terms of quality of support; in her other lessons, Ms. Kelly either "did not meet" or "partially met" expectations.

In her interviews, Ms. Kelly commented on wanting to provide more support for students to construct evidence-based claims; however, she felt it would be counter to the way that science was taught in the classroom. Ms. Kelly highlighted how "this claim-evidence thing is really helping [the students] find that purpose" for the investigations that they do [K_Interview4], yet she struggled with implementing it into the classroom. For example, Ms. Kelly commented,

> I didn't explicitly have kids make a claim [in the claim-evidence framework] … just because I didn't think that was going to be appropriate with what they were used to doing … not in that exact pattern. [K_Interview4: 543-544]

In this quote, Ms. Kelly seems to present the challenge of recognizing that the students do not regularly do the work of constructing evidence-based claims in her placement classroom and feeling comfortable introducing this idea herself in the classroom. Ms. Kelly pointed out that in the "curriculum that they use in my classroom … there's no mention for doing claim and evidence type stuff" [K_Interview 3: 300-303], and how her mentor did not follow the framework either. Given the experiences of the students in her class, Ms. Kelly described how she "didn't really feel comfortable throwing [an emphasis on an investigation and making claim with evidence] at [her students] for one unit" [K_Inteview4: 459-472].

In contrast to the challenges that Ms. Kelly seemed to face with introducing the structure of evidence-based claims, she showed strengths in connecting students' ideas to each other and considering students' alternative ideas throughout the program. For example, during the pre-assessment enactment with a standardized student, Ms. Kelly supported the standardized student to consider how her own ideas contrasted with other students' ideas on the paper, asking, "Do you agree or disagree with what the student said?" [K_PreAssess]. This question encouraged the student to make connections between her own ideas and those of the other student even though Ms. Kelly was working an individual student. In this same interaction, Ms. Kelly also followed up on an alternative idea that the student stated with the question, "Can you tell me a little about how you came up [with your prediction]?" [K_PreAssess]. Ms. Kelly used similar questions and probes to connect students' ideas to each other and to find out more about students' alternative ideas throughout almost all of her lessons. In interviews, Ms. Kelly discussed how she learned to ask these questions, including "Do you agree with them? Why?" [K_Interview3: 915].

Ms. Kelly's Science Knowledge for Teaching Connected to Supporting Students to Construct Evidence-Based Claims

Ms. Kelly showed growth in describing science content accurately and connecting the mechanism to students' everyday experiences. Early in the program, Ms. Kelly sometimes introduced confusing language or ideas about the science content. For example, during her Children as Sensemakers read aloud, she told her first-grade student, Earth "spins very slowly … around and around" although Earth actually spins quickly [K_CaSMReadAloud]. Likewise, she used the word *disappear* to describe salt dissolving in water during her pre-assessment enactment, as well as water evaporating into the air during her Reflective Teaching enactment [K_Pre-Asssess, K_RT]. Using the term *disappear* might not allow students to understand that matter cannot be create or destroyed. In contrast, during her student teaching, Ms. Kelly regularly introduced accurate descriptions of the science content to her students. For example, in her third investigation, she asked the first-grade students, "If you put a small force on something, how will it move?" and students responded, "A little" [K_Field3]. The class continued to think in an accurate, age-appropriate way about the link between the amount of force and the amount of movement. Ms. Kelly's other enactments during student teaching and her end of the year standardized student enactment showed similar accurate, age-appropriate descriptions of the content.

Throughout the program, Ms. Kelly regularly highlighted the mechanism or scientific principle involved in the phenomena. For example, during her first investigation of student teaching, Ms. Kelly told the first-grade students, “A fruit is the part of the plant with seeds,” which was the principle students were working on during the investigation [K_Field1]. During her last student teaching investigation and the end of the year standardized student enactment, Ms. Kelly began to extend the classes’ understanding of the mechanism or scientific principle by considering another everyday experience. For example, during her third investigation of student teaching on force described in the previous paragraph, Ms. Kelly asked a question to support students to apply the idea the class was discussing to a new everyday experience of having their toy cars spin out of control. She asked, “If I have a car, what causes the car to spin out of control?” The students were able to make the link to creating a stronger force, saying, “You push so hard.” Ms. Kelly connected the students’ ideas back to the idea of force with the comment, “I used a *force* that is hard” [K_Field3, emphasis added]. Ms. Kelly made similar extension of the scientific principle during the end of the year standardized student enactment.

In her interviews, Ms. Kelly described how she felt she had developed science knowledge for teaching around the purpose of scientific practices in science, the reasons for teaching science to her students, and her students’ abilities to engage in the science practice of constructing evidence-based claims. In the fourth interview, Ms. Kelly commented that, from her previous experiences in science courses, “I never really understood why we do science” [K_Inteview4: 404]. In the same interview, Ms. Kelly summed up the new knowledge she had for science teaching:

> I just never really realized the importance of science teaching before I came into this program. Now, I understand it on so many different levels, instructionally, what it does for kids, and … why we teach it. [K_Interview4:418-420]

In her third interview, Ms. Kelly emphasized learning what constructing evidence-based claims are and why supporting students to construct evidence-based claims is important. She said, "I actually think having a chance to learn what those things [doing claim and evidence] are and understanding why they're important make it easer" to teach these to her students.

In addition to developing understanding of science and science teaching, Ms. Kelly also described how she learned more about what her young students are able to do in science. In particular, she commented on how all her students were able to engage in the work:

> The majority of the kids in my class are struggling learners, and I've never seen every single kid in my class excel the way they do in science.… They get so excited, and it's evident in the work that they produce. [K_Interview4: 408-420]

Throughout her interviews, she described how she realized that "my kids can do it" in terms of constructing evidence-based claims, whereas "that might've been something that initially" she thought the students could not do [K_Interivew3: 335-338].

How Ms. Kelly Described Why Her Knowledge and Practice Changed

In her interviews, Ms. Kelly attributed changes in her knowledge and practice for supporting students to construct evidence-based claims to three areas: (a) developing an understanding of what science teaching is and how to engage in science teaching throughout the Science Methods Course, (b) enacting science teaching in the methods course and in her placement classroom, and (c) developing her teaching practice across the courses she took throughout the elementary education program. As she described the changes and why they occurred, Ms. Kelly often pointed to particular frameworks, such as the EEE framework in the Science Methods Course.

In discussing how her teaching practice changed, Ms. Kelly pointed to developing her understanding of science, what science teaching is, and how to teach science from the Science Methods Course. For example, Ms. Kelly stated, "I think that having science methods was really important … because I know what the triple E framework is, and I know what it looks like in a high-quality classroom" [K_Interview4:482-485]. This quote shows how Ms. Kelly typically considered the aspects of science teaching in light of the EEE framework introduced in the Science Methods Course. Ms. Kelly also pointed out how the Science Methods Course facilitated her understanding of the purpose of science practices and why to engage students in these practices, which contrasted to her previous experiences of science learning. She commented,

> What I remember of chemistry was basically just we're doing this because the teacher told us to do it. What we learned in science methods was that there's a purpose for every single experiment that your kids do. I think that part of … claim evidence … is really helping them to find that purpose. I believe that when kids understand the purpose, they're way more motivated and willing to do it because they understand why they're doing it. It no longer just feels like a task they've been given. I never really understood that difference until I saw that science isn't just, "Here. Do it because the teacher told you to." [K_Interview4: 427-445]

In this quote, Ms. Kelly emphasizes learning the purpose for engaging in scientific investigations and constructing evidence-based claims through the Science Methods Course. She also discusses her belief that she should share this purpose with her students. This theme of developing her understanding of the purpose of science and science teaching during the science methods appeared in all three of her interviews after the start of the course.

Ms. Kelly pointed to particular aspects of the Science Methods Course as particularly supportive in her developing understanding of science and science teaching, including making connections between the EEE framework, videos of science lessons, class discussions, and readings. Ms. Kelly discussed how the class watched videos "that highlighted each section of the triple E framework" [K_Interview3: 440-463]. She found the videos "really, really helpful because you can talk about good teaching as much as you want, but … actually see[ing] it … makes a big difference [K_Interview3:467-469]. The videos seemed to support Ms. Kelly in visualizing the work of science teaching. She particularly commented on videos of a lower elementary class engaged in investigating and constructing evidence-based evidence as proof that her students could also do this work, saying, "Some of the videos we watched were actually from a first-grade class, and they were able to do it, so I was [thinking], 'Okay, if they can do it, my kids can do it'" [K_Interview3: 335-336].

Ms. Kelly pointed out how class discussions allowed her to make sense of these representations of science teaching in the videos by talking "about the things we saw and why they were important, which our teacher [educator] connected back to what we had been talking about previously" [K_Interview3: 422-426]. These discussions along with watching the videos seemed to help Ms. Kelly understand "what it means to be a triple E science teacher" [K_Interviwer4:626]. She also discussed how class readings about "why do claim and evidence" and "how to do it" "paired with the ability and chance to talk about it is what made [the readings] actually meaningful to me" [K_Interview3: 872-883; 558- 572]. Thus, Ms. Kelly seemed to appreciate having a chance to discuss the ideas in the readings and videos in the context of the EEE framework.

In addition to the representations and discussions of science teaching, Ms. Kelly also named the opportunities to enact science teaching as influential in her learning. She pointed to how the enactments of assignments in the methods course built on the work from the Science Methods Course, commenting, "Having the chance to see it first, do it in peer teaching, and then do it in the classroom just gives you so many more opportunities" to learn [K_Interview4: 636-637]. Ms. Kelly highlighted how she felt Peer Teaching allowed her to consider how to support student learning and develop her practice for responding to unexpected student ideas in this comment:

> There are so many … everyday ideas [of students] that can come out of nowhere to the teacher … having the opportunity to teach … peers where there's no pressure … and nothing's going to happen to you if you mess up is really beneficial. [K_Interview2]

She later commented that having three iterations of Peer Teaching allowed her to "know what didn't go so well [during Peer Teaching], how to fix it here, and then having another chance to fix [her struggles], which "gave [her] a chance to understand what I was doing and why I was doing it" [K_Interview4: 655-668]. In these quotes, Ms. Kelly pointed out how struggling in the safe environment of peers facilitated her ability to reflect and develop an understanding of how and why to use particular teaching moves. In addition to discussing the Peer Teaching Assignments, Ms. Kelly described how completing the methods course assignments in the field also enabled her to improve her practice, saying that these assignments "gave me the chance to get feedback from my instructor and understand how I could change … what I was doing to do it better" [K_Interview4: 670-680]. Ms. Kelly also cited enacting lessons in the field as a place for understanding the success all students can have in this work, pointing how she "was actually so surprised" to see how "all of the kids" used evidence to support their claims [K_Interview3:523-541]. These successful interactions seemed to facilitate Ms. Kelly in realizing the importance of teaching science in her elementary classroom.

Beyond the Science Methods Course, Ms. Kelly made connections to the other courses in the teacher education program as facilitating learning the teaching moves for supporting students in constructing evidence-based claims. For example, Ms. Kelly discussed how the Children as Sensemakers Courses facilitated her ability "to be able to push kids to explain their thinking," such as "what kinds of questions to ask kids, what kind to facial expressions to have" [K_Interview4: 690-700] and "not validate a student['s claim]" [K_Interview1:680-686].

Multiple courses, including the Facilitating Classroom Discussions course, literacy course, social studies methods, and the Mathematics Methods Courses, supported her in making connections across students' ideas and probing student thinking. In particular, Ms. Kelly discussed how having evidence to support a claim "is actually a skill that's used across a lot of different disciplinary areas" that she had worked on in multiple courses [K_Interview1:588-590]. This discussion points out how Ms. Kelly seemed to make connections to multiple courses in the program in learning to support students to construct evidence-based claims of natural phenomena.

Summary of Changes

The second row in Figure 7-1 illustrates the changes in Ms. Kelly's practice and knowledge for supporting students to construct evidence-based claims over the two years in the program. As seen in Figure 7-1, Ms. Kelly's science knowledge for teaching seemed to improve over the course of the teacher education program. Toward the end of the program, Ms. Kelly tended to use accurate, age-appropriate descriptions of the natural phenomenon connected to a scientific principle, whereas she had sometimes introduced confusing language or ideas earlier in the program. She also tended to apply the mechanism to an everyday experience later in the program. Ms. Kelly also showed a few areas of consistent growth, including probing student thinking and connecting students' ideas to each other. These were teaching moves that Ms. Kelly made throughout the teacher education program.

Ms. Kelly seemed to show variable growth in supporting students to analyze the data and share their thinking, and to communicate a claim in a logical structure of evidence-based claims. For example, Ms. Kelly supported students to name the evidence and reasoning for the claim in a logical structure during Peer Teaching. However, she did not do all of these pieces during

Reflective Teaching, student teaching, or the end of the year standardized student enactment. She also, however, tended to do the intellectual work for the students, and she did not often create an additional representation to analyze the data to reveal patterns and relationships. Yet, during the End of the Year standardized student enactment, Ms. Kelly did allow the students to do the intellectual work of sharing their thinking. Ms. Kelly discussed feeling uncomfortable introducing some of the work of constructing evidence-based claims in her placement class, given the established culture in the room.

In describing changes in her knowledge and practice for supporting students to construct evidence-based claims, Ms. Kelly emphasized the science methods class as influencing her ability to understand what science is, what science teaching is, and how to teach science. She seemed to use the EEE framework to define science teaching, and she pointed out how the videos, discussions, reading, and Peer Teaching allowed her to understand and practice this framework. Teaching in the field seemed to convince Ms. Kelly of the importance of having students support their own claims with evidence. She often cited other classes as supportive in developing particular teaching moves for facilitating this work, such as pushing students to explain why.

Mr. Cruise's Knowledge and Practice for Supporting Students to Construct Evidence-Based Claims of Natural Phenomena

Throughout his interviews, Mr. Cruise showed an enthusiasm for science learning and teaching as well as a strong vision of how to teach science. He discussed his hope to become a teacher in the environmental school he had attended as a middle-school student, or a similar school. He described how at this school, "They teach out of … the natural text or the living textbook" [C_Inteview1:107-108]. As an integrated science major, Mr. Cruise estimated that he had taken about eight science courses at the university and attended one summer at the

University's biostation. He pointed out that "as much as I like being a teacher, I also love learning" [Interview4: 578]. In addition to his experience in science courses, Mr. Cruise had experience with elementary students in science education. For example, he went on backpacking trips with students to support "learning how to [be] self-reliant … while teaching natural history and some other writing curriculum" [C_Interview1: 133-135]. He highlighted that this experience influenced his teaching philosophy of supporting students "to feel empowered and impassioned by what they're seeing and doing" [C_Inteview4: 521-530]. His commitment to this teaching philosophy was a theme throughout his interviews.

In supporting students to construct evidence-based claims, Mr. Cruise showed strengths in supporting students to analyze the data to reveal patterns and relationships, and supporting students to make claims justified by evidence and reasoning throughout the two years in the program. Like the other interns, he showed growth in his science knowledge for teaching. Mr. Cruise attributed his learning to support students to construct evidence-based claims to experience outside the program, the decomposition focus in the program courses, and having the opportunity to plan, teach, and reflect on lessons. This section considers the strengths, struggles, and growth seen in Mr. Cruise's practice and knowledge for supporting students to construct evidence-based claims.

Mr. Cruise's Support for Analyzing Data to Reveal Patterns and Relationships and Sharing Thinking

Throughout the two years in the program, Mr. Cruise typically showed a high quality of support and used several teaching moves for the subpractice of supporting students to analyze the data to reveal patterns and relationships (see Table 7-5). For example, during his Reflective Teaching lesson focused on how nutrients cycle through an ecosystem, Mr. Cruise co-

constructed a representation of the movement of nutrients through the ecosystems that the fifth-grade students had investigated. During this construction, Mr. Cruise highlighted implicit features of the representation, such as asking, “What does the arrow represent?” He also highlighted similarities and differences between representations with the question, “What is similar between … the food chain and the food web?” Through discussion of this question, Mr. Cruise underscored that they contained some pieces of similar information. As students commented on what to add to the representation, Mr. Cruise pushed the students to name the patterns that they saw, asking, “Where would the nutrient transfer be taking place?” [C_RT]. The students were able to name aspects of this pattern, including that the movement of nutrients “goes over and over” [C_RT]. Throughout his enactments, Mr. Cruise created an additional representation of all the data, connected the representations to each other or to the investigation, and supported students to analyze and interpret the data to reveal the pattern, as he did in the Reflective Teaching Lesson. In his other enactments, Mr. Cruise sometimes highlighted implicit features of the representations for students; however, this teaching move was less common during his student teaching investigations, as seen in Table 7-5.

Table 7-5: Mr. Cruise's Teaching Move and Quality of Support for Analyzing Data to Reveal Patterns and Relationships over Time

	Before Science Methods	Science Methods	Student Teaching
Creates an additional clear representation to show the pattern	X	X X	X X X _
All of the data are considered	X	X X	X X X X
Makes implicit features of the representation clear	X X	X X	X _ _ _
Connects representations to each other or to the investigation	X X	X X	X X X X
Supports the child(ren) to analyze and interpret the data	X X	X X	X X X X
Probes student thinking	X X	X X	X X X _
Does not do the intellectual work involved in analyzing and interpreting the data	X X	X X	X X_ _
Does not ask leading question that provides the reasoning	_ X	X X	X X X X
Quality of Support	3.5	3.5	3

X = teaching move was used; _ = teaching move was not used; 1 = did not meet expectations; 2 = partially met expectations; 3 = met expectations; 4 = exceeded expectations

In addition to the teaching moves that Mr. Cruise used to support students to analyze the data to reveal patterns and relationships, Mr. Cruise typically supported students to share their thinking. Throughout each of the enactments during the two years in the program, Mr. Cruise probed student thinking. An example of this probing is asking a student to share more of his thinking with the question, “How is the sun in space?” when the child had stated only that the sun was “in space” during the Children as Sensemakers final interview [C_CaSMInterview].

Although Mr. Cruise regularly probed student thinking, he sometimes did aspects of the intellectual work for the students. For example, during a lesson considering the use of coffee filters in removing pollutants, Mr. Cruise interpreted the patterns across the groups for the students rather than allowing the fourth-grade students to do this work.

Throughout his interviews, Mr. Cruise highlighted the importance of analyzing data to reveal patterns and relationships and described his experiences with this work prior to the program. He emphasized how science involved "identifying trends that other scientists are studying at the same time" and being "able to discuss" these patterns [C_Interview4:557-573]. Throughout his interviews, he emphasized how students in classrooms should also have the opportunity to do this work. In terms of his previous experiences, Mr. Cruise described how on his backpacking trips, he took the "initiative to ask students questions about why they thought what was going on if they made some kind of observation" [C_Inteview1:747-757]. This description of how he supported students during these trips seems to match some of the ways that Mr. Cruise supported students to analyze the data to reveal patterns and relationships during his enactments. After the Science Methods Course, he said, "I think [the program] made me more aware of how it is to allow students to come to their conclusions in science" rather than doing the intellectual work for the students [C_Interview3: 391-392].

Mr. Cruise's Support for Making Claims Justified by Evidence and Reasoning

Mr. Cruise's quality of support for supporting students to make claims justified by evidence and reasoning remained fairly consistent over the program. As seen in Table 7-6, Mr. Cruise typically supported students to make claims and name either the evidence or the reasoning. He also connected students' ideas to each other during student teaching and the Science Methods Course. However, he usually did not use a logical structure for supporting students to make their evidence-based claims. In addition, he typically did aspects of the intellectual work for students by justifying the claim with the reasoning and evidence during student teaching.

Table 7-6: Mr. Cruise's Use of Teaching Moves and Quality of Support for Making Claims Justified by Evidence and Reasoning over the Course of the Program

	Before Science Methods	Science Methods	Student Teaching
Supports the student to make claims	X X	X X	X X X _
Uses a structure to construct evidence-based claims	_ _	X _	_ _ _ _
Uses other scaffolds/tools to support construction of claims (sentence stems, peers, etc.)	_ _	X X	X _ _ _
Connects students' ideas to each other	_	X X	X X X X
Gives feedback on construction of claims	_ _	_ _	_ _ _ _
Follows up on an alternative idea that the child gives	_ _	X _	X _ _ _
Does not ignore an alternative idea that the child puts forth	X X	X X	X X X _
Supports students to describe evidence	X X	X _	X X X _
Supports students to describe reasoning	X X	X X	X X X X
Does not do the intellectual work of naming the evidence for the student	X	X X	X X__ _
Does not do the intellectual work of naming the reasoning for the student	_ _	X X	X X X _
Quality of Support	2	2.5	2.5

X = teaching move was used; _ = teaching move was not used; 1 = did not meet expectations; 2 = partially met expectations; 3 = met expectations; 4 = exceeded expectations

An example of Mr. Cruise's support for making claims justified by evidence and reasoning occurred during an investigation modeling the movement of water through the ground during student teaching. During this investigation, Mr. Cruise asked the fifth-grade students, "Did you see water accumulating anywhere in your model?" This supported the students to make a claim about where water accumulates as the water moves through the soil. A student also provided evidence from his model for this claim. Next, Mr. Cruise asked the students to "raise your hand if [accumulation of water] happened" in their model as well. Rather than allowing the other students to discuss the evidence they had for their investigation, Mr. Cruise told students the evidence from his observations, saying that the accumulation of water "was one of my observations." The class did not discuss why the water might accumulate, the reasoning behind the claim being made. Rather, Mr. Cruise went on to define the terms *porous* and *percolation* for the students and told them that the "water [in his cup] … has percolated through the ground" [CB_Field2]. Students were not given the opportunity to make these connections themselves. As seen in this interaction, Mr. Cruise supported students to make a claim and provide a piece of the evidence, yet he named most of the evidence and reasoning. Mr. Cruise also did not provide any other type of supports for evidence-based claims. This type of interaction was typical of Mr. Cruise's teaching, which "partially met expectations."

During his Peer Teaching Lesson and two of his student teaching lessons, Mr. Cruise supported students to provide the evidence and reasoning for the claim and used additional tools and scaffolds to support this work (see Table 7-6). For example, during the Peer Teaching Lesson enactment of an investigation of the transfer of heat energy, Mr. Cruise asked his colleague-students to make a claim from their investigation and encouraged them to "use evidence to back up the claim." He also had this colleague-students connect their answer to “what we know about the transfer of heat energy.” Throughout these interactions, Mr. Cruise clearly wrote the claims, evidence, and reasoning that students stated on the board, supporting the students to see the connections [C_PeerTeach]. As seen in these interactions, Mr. Cruise was able to facilitate students to construct an evidence-based claim with the evidence and reasoning explicitly named. Mr. Cruise did similar elements of this work during two of his student teaching investigations. All three of these enactments “met expectations” in terms of quality of support.

In addition to his work on supporting students to make claims from their data, Mr. Cruise typically connected students’ ideas with each other and sometimes followed up on students’ alternative ideas, as seen in Table 7-6. An example of connecting students’ claims is asking, “What do you think about his [answer]?” and allowing students to comment on a student’s claim [C_Field4p3]. An example of following up on an alternative idea is asking the class about the students’ question of whether or not birdseed is pollution, allowing students to give reasoning for how birdseed “could be either way” [C_Field4p3]. In two of his enactments, Mr. Cruise ignored a student’s alternative idea. For example, during the investigation on filtering pollutants in student teaching, Mr. Cruise ignored the students’ claim that the coffee ground pollutant “might be safe to drink” [C_Field5]. Mr. Cruise also ignored a student’s claim during his Reflective Teaching enactment.

During his interviews, Mr. Cruise emphasized pieces of the subpractice of supporting students to make claims justified by evidence and reasoning. For example, he described how it is important to “mak[e] sure that students have opportunities to regroup and explain their findings, talk about they’ve found” after they have an investigation [C_Interview3: 622-626]. As seen in his thinking about analyzing data to reveal patterns and relationships, Mr. Cruise connected explaining findings to what scientists do and emphasized the importance of allowing students to do the intellectual work.

Mr. Cruise's Science Knowledge for Teaching for Supporting Students to Construct Evidence-Based Claims

Mr. Cruise's science knowledge for teaching for supporting students to construct evidence-based claims seemed strong throughout the program and appeared to grow during student teaching. He typically described the phenomenon under investigation in an accurate, age-appropriate manner and connected these descriptions to the scientific principle or reasoning and to students' everyday lives. For example, during the fifth-grade students' investigation of pollution during student teaching, Mr. Cruise accurately described how the air pollution that students noticed in their investigation might affect the water, saying:

> All of those gasses that go off into the atmosphere, can turn into … smog. That smog can build up and build up until when it rains, that water is fairly acidic. It can erode types of paint. It can even harm some of the trees. [C_Field4p3]

Mr. Cruise's question, "Does this pollutant affect water around [the children's school]?" connected to the unit's larger principle of water pollution and to the students' lives [C_Field4p3]. This type of accurate description and connection appeared in almost all of Mr. Cruise's enactments. These enactments "met" or "exceeded" expectations for the quality of knowledge for science teaching, with three out of four of his student teaching enactments "exceeding expectations."

In contrast to the accurate description and connections that Mr. Cruise made during most of his enactments, in his Reflective Teaching Lesson during the methods course, Mr. Cruise presented a confusing idea about the science. In his Reflective Teaching enactment lesson, Mr. Cruise claimed that the arrows in a food chain represent "the flow of nutrients in a system," when the convention is that the arrow represent the flow of energy. This might cause confusion for students when they see this common representation of the food chain later in their careers as students.

In his interviews, Mr. Cruise described how his science knowledge for teaching improved in four ways during the program: (a) he learned how to use a framework for science lessons, (b) he learned how to plan science lessons and units, (c) he now understood the realities of how science can work in elementary classrooms, and (d) he learned how to be equitable in his teaching. In his third and fourth interviews after the Science Methods Course, Mr. Cruise emphasized how the EEE framework provided a more formal way of organizing his thinking about supporting science learning, saying, "I think I had a fairly good understanding of what students need to know in terms of [science learning]. Having [the Triple E Framework] in a formal [format] I think helps" [C_Interview3: 384-387]. In summarizing the framework, he emphasized "making sure that your students have opportunities to connect their [learning] to things they experience, … planning carefully for the investigation, ... then, of course doing the Explain portion" [C_Interview3: 750-769]. He pointed out how this helped him adapt the science curriculum for students: "As I was thinking about what [the EEE framework was] having me do, I thought I can make [the lesson] more relevant to my students" [Interview3: 326-372].

In his fourth interview at the end of the program, Mr. Cruise also discussed learning about planning and adapting curriculum for science lessons, particularly emphasizing the idea of backward planning. When asked, "How has your knowledge about how to support elementary students to make sense of data and construct claims changed?" Mr. Cruise commented,

> I would say the most significant difference for me from the beginning has been learning about backwards design ... to create an assessment, and then to give students a pre-assessment, to evaluate that pre-assessment, and then to use all of that information with

> the learning goals from the district and from myself, to plan out a series of lessons, and to have that big picture idea or directionality was really helpful. [C_Interview4]

This quote suggests that the idea of planning with backward design facilitated his ability to think about how to focus on his unit and lessons and connect to the larger big ideas in science.

In addition to discussing his learning around framing and planning for science learning, Mr. Cruise also discussed learning more about doing this work in science classrooms. Throughout his interviews, he commented on how the program grounded his idealized understanding of what should happen in science classrooms in the realities of schools. For example, he said,

> I think it was hard for me at the beginning of the program because I wanted to be very theoretical about education, and I still am.… Being in the program has exposed me to some of the realities that are in the classroom. [C_Interview1:602-609]

Some of the realities of the classroom that Mr. Cruise named included classroom management such as distributing materials. He also commented on seeing how "younger children are challenged to see why things work the way they do" [C_Interview1:737]. Mr. Cruise also discussed learning to make science learning more equitable for students, by drawing on "science equity practices" and helping the range of students in his class "in … safe places" through grouping or organizing the classroom [C_Interview4: 380-404].

Mr. Cruise's Description of How His Knowledge and Practice Changed

Mr. Cruise explained that his knowledge and practice for supporting students to construct evidence-based claims changed through (a) decomposing elements of teaching practice during his courses, (b) experiences in the field, and (c) having the opportunity to plan, teach, and reflect on lessons during the program. These three themes appeared throughout all of his interviews.

Mr. Cruise emphasized how analyzing and naming the element of teaching practice aided his learning to support students in science learning. In his first interview, he commented,

> I'll be perfectly honest, studying all of the little minor details about teaching a lesson … really picking them apart is a pain in the butt to me. At the end of the day I'll reflect on what we did and why it's so important to analyze those tiny little parts of what teaching is.… To teach science, being able to now reflect on how these little tiny pieces need to be combined, that's going to be very beneficial to me. [C_Interview1]

In this statement, Mr. Cruise highlights the benefit he saw in considering the details of teaching. He emphasized particular courses in the program in which this decomposition and analyzing of teaching occurred, including the Managing to Teach Class and Children as Sensemakers Courses. In addition, as discussed earlier in this section, Mr. Cruise also commented that the EEE Framework from the Science Methods Course, which decomposed elements of science teaching, was also beneficial. For example, he thought more about not telling students the conclusion and "spoil the end per se" since "it was the part of the [EEE] framework that we were required to use [in Science Methods Course]" [C_Interview3: 404-412].

In terms of learning from being in the field, Mr. Cruise described that "just being in the field" "challenged" him and made him consider the realities of teaching in the classroom [C_Interview1_602-609]. For example, he discussed how "seeing [his] mentor teacher[s] facilitate science lessons gave [him] a set of expectations to uphold" [C_Interview4: 640-645]. His mentor teacher and his field instructor also seemed to help Mr. Cruise learn about planning. In particular, his conversations with his field instructor facilitated learning "the idea of backwards design with assessment and the learning goals," and he had "the big picture conversation with [his] mentor teacher about 'Okay, what direction do you want to have?''' [C_Interview4: 365-377]. His field instructor raised questions about the "teaching equitably piece," commenting on how "the only African American student in [the] class, who also happens to have a learning disability, often" missed the science lessons to go to the resource room. Mr. Cruise commented that after his field instructor pointed this out, "I did my best to get science rearranged … to make sure she could be there" [C_Interview4: 919-936]. This experience seemed to facilitate Mr. Cruise to consider how to include all students in learning science.

Mr. Cruise also emphasized how he learned from the opportunity to carefully plan and enact lessons. In particular, he found the Reflective Teaching Assignment during the Science Methods Course "influential," because he had "an opportunity to use a real set of curriculum materials, … adapt those curriculum materials to [his] interests and to the interest of [his] own students, [and] look at … elements," including "attending to learners and teaching equitably" "systematically" [C_Interview3: 440-460]. Mr. Cruise described the process of planning a science unit during student teaching as similarly influential in his learning. He also discussed how he learned from his teaching and cited how he learned from mistakes he made during peer teaching and his enactments in class. For example, he commented,

> In my lesson planning [for Peer Teaching], I had thought that it would be a good idea to discuss [the main idea of the lesson] first.… Afterwards I was kicking myself thinking, 'Hang on. That's the point of this discussion that we're going to be having.' [C_Interview2].

This particular experience was discussed in several of his interviews, suggesting that this had an impact on Mr. Cruise's thinking.

Summary of Changes

The third row of Figure 7-1 represents Mr. Cruise's support for constructing evidence-based claims during different time points in the teacher education program. The figure does not include the end of the year standardized student enactment because he did not complete one. As seen in Figure 7-1, Mr. Cruise consistently provided high-quality support for analyzing data to reveal patterns and relationships. He improved in supporting students to share and justify their thinking from the Children as Sensemakers Course in Year 1 to his second year in the program. He typically supported students to make a claim about the phenomena and to share evidence or reasoning to support their claim. However, he usually did aspects of the intellectual work involved in justifying the claim with evidence and reasoning. During his student teaching, he showed growth in connecting students' ideas to each other and considering alternative ideas. Mr. Cruise showed strength in his science knowledge for teaching throughout the program. During student teaching this knowledge seemed to grow as he connected the accurate descriptions of the natural phenomena to students' everyday lives and the "big ideas" of science.

In his interviews, Mr. Cruise described growth in his knowledge of supporting science learning and classroom management. He also discussed learning to plan for and support students to find their answers throughout the program. His comments attributed this learning to his field experiences, including conversations with his mentor and field instructor, decomposition of the teaching practices, and his own experiences planning and enacting lessons.

Ms. Schuster's Practice and Knowledge for Supporting Students to Construct Evidence-Based Claims

Ms. Schuster showed an excitement for teaching elementary students and teaching science. She commented that "originally, I wanted to do science in middle school" after college, but "the more experience I'm getting with younger kids, the more I am … more open to teaching the younger kids" [S_Interview1: 89-93]. As a science major, Ms. Schuster had taken over ten science courses. She stated that she appreciated science classes such as organic chemistry, where you "have to apply [the information] in different ways … and physically orient things," more than the biology lecture where she "just [went] though slide after slide after slide" in lectures and to prepare for examinations [S_Interview1: 46-55]. This idea of engagement in learning also came up as Ms. Schuster discussed teaching elementary students, as she said, "Definitely [the student's] engagement" is the most exciting [S_Interview1: 103]. Ms. Schuster saw the challenge in engaging students as well, commenting that "being attuned to all the learners in the classroom" "to be able to engage them all" was the most challenging part of teaching elementary students [S_Interview1: 114-118]. Throughout her interviews, Ms. Schuster underscored her excitement for teaching as "a job that I find a lot of life and joy in doing, by talking with the kids and by them responding and talking with me" [S_Inteview1:104-107].

As seen in the fourth row in Figure 7-1, Ms. Schuster's practice and knowledge seemed to increase over time. In particular, Ms. Schuster's science knowledge for teaching and support for justifying claims with evidence and reasoning seemed to show growth throughout the program. Ms. Schuster attributed her learning to opportunities to teach and analyze her teaching in the field, as well as to her experiences throughout the courses.

Ms. Schuster's Support for Analyzing Data to Reveal Patterns and Relationships

In her enactments, Ms. Schuster consistently provided high-quality support for students to analyze the data to reveal patterns and relationships and share their thinking. As seen in Table 7-7, Ms. Schuster "met expectations" for supporting students to analyze the data to reveal patterns and relationships in each of her enactments during the program. She seemed to show growth in supporting students to share their thinking.

Table 7-7: Ms. Schuster's Use of Teaching Moves and Quality of Support for Analyzing Data to Reveal Patterns and Relationships

	Before Science Methods	Science Methods	End of Year
Creates an additional clear representation to show the pattern	X	X X	X
All of the data are considered	_	X X	_
Makes implicit features of the representation clear	X X	X X	X
Connects representations to each other and the investigation	X X	X X	X
Supports the child(ren) to analyze and interpret the data	X X	X X	X
Probes student thinking	X X	X _	X
Does not do the intellectual work involved in analyzing and interpreting the data	X X	X X	X
Does not ask leading question that provides the reasoning	X X	X X	X
Quality of support	3	3	3

X = teaching move was used; _ = teaching move was not used; 1 = did not meet expectations; 2 = partially met expectations; 3 = met expectations; 4 = exceeded expectations

As seen in Table 7-7, Ms. Schuster's support for analyzing data to reveal patterns and relationships typically included creating a representation to make sense of the data, facilitating students in using and understanding the representation, and supporting students to name patterns. For example, during her Peer Teaching enactment, Ms. Schuster worked with her colleague-students to create a line graph of all of the data collected to answer the investigation question, "What happens when you put a bag of hot water into a container of cold water?" She connected the representation to the data that the students collected, commenting, "After we collected all of the data, we made a graph." She also made implicit elements of this representation clear, helping students to notice "what is the title of our graph" and that there are "two lines in the graph." Using questions such as, "What did we notice?" when looking at the graph with the students, Ms. Schuster supported her students to analyze and interpret the data to identify patterns, such as the lines for the temperatures of the two waters, which "started out really far [apart from each other], and then they come together." She also asked follow-up questions about the students' thinking, such as, "Do we know what the two lines represent?" when a student pointed out that the lines are different colors [S_PeerTeach]. Ms. Schuster used similar moves throughout her enactments to support students in analyzing data to reveal patterns and relationships; however, during her standardized students enactments for the pre-assessment of the Science Methods Course and at the end of the year, she did not use all of the data collected in the representation. She also did not ask follow-up questions during her Reflective Teaching lesson, whereas she did in all the other lessons.

Throughout her interviews, Ms. Schuster emphasized learning to guide students to do the intellectual work of analyzing data to reveal patterns and relationships. For example, in her fourth interview, she commented,

> Before [the program], I'd be "Okay, you stand in front of the class and you present the material to them, you show the data and show them how to make sense of the data," whereas, now, [my teaching is] a lot more based on exploration and, "Okay, you make sense of the data and then we're going to talk about it and see if we're making sense in the same way." It's more … making sure I'm guiding them and supporting them in the right ways, … giving them the materials and [using] guided questions. [S_Interview4]

This quote shows Ms. Schuster's emphasis on pushing students to analyze the data to reveal patterns and relationships and how she saw her role as a facilitator who asks questions and supplies the materials and tools for the work.

Ms. Schuster described the type of prompts that she learned to support her students to "draw connections," such as, "Let's think about why that happened" and "What do you notice now?" [S_Interview1: 556-572]. She also describe how the program "caused [her] to be a lot more aware of the different representation that … I'm using" such as "collecting [information] on the board and talking about it together" [S_Interview4: 416-443]. For Ms. Schuster, these representations seemed to be the tools she planned to use to support students in their learning. Ms. Schuster seemed to feel that she also became "more intentional in everything in the classroom," including what she says, "every question [she] ask[s]," and "the different methods" she uses "to attend to all the learners in the classroom" [S_Interview3:417-430]. These statements suggest that Ms. Schuster felt she learned to purposefully consider the questions, materials, and tools she used to facilitate student learning.

Ms. Schuster's Support for Making Claims Justified by Evidence and Reasoning

The quality of Ms. Schuster's support for making claims justified by evidence and reasoning seemed to improve over the two years in the program. As seen in Table 7-8, she appeared to struggle to facilitate students in constructing evidence-based claims before the Science Methods Course and "did not meet" expectations. In contrast to the quality of support in her pre–Science Methods enactments, Ms. Schuster "exceeded" expectations for quality during the Science Methods Course and end of the year standardized student enactments.

Table 7-8: Ms. Schuster's Use of Teaching Moves and Quality of Support for Making Claims Justified by Evidence and Reasoning throughout the Program

	Before Science Methods	Science Methods	End of Year
Supports the student to make claims	X _	X X	X
Uses a structure to construct evidence-based claims	_ _	X X	X
Uses other scaffolds/tools to support construction of claims (sentence stems, peers, etc.)	_ _	X X	X
Connects students' ideas to each other	_ _	X X	_
Gives feedback on construction of claims	_	X _	_
Follows up on an alternative idea that the child gives	_	X _	X
Does not ignore an alternative idea that the child puts forth	X X	X X	X
Supports students to describe evidence	_	X X	X
Supports students to describe reasoning	_	X X	X
Does not do the intellectual work of naming the evidence for the student	X	X X	X
Does not do the intellectual work of naming the reasoning for the student	_ X	X X	X
Average Quality of Support	1.5	4	4

X = teaching move was used; _ = teaching move was not used; 1 = did not meet expectations; 2 = partially met expectations; 3 = met expectations; 4 = exceeded expectations

In her pre–Science Methods Course enactments, Ms. Schuster did not use many teaching moves to support students to make claims justified by evidence and reasoning (see Table 7-8). For example, during her pre-assessment Standardized Student Enactment, Ms. Schuster did not support the standardized student to make a claim, ending the interaction after calculating a pattern without answering the investigation question.

In contrast to her struggles during the pre–science methods enactments, Ms. Schuster provided several scaffolds and tools to support to make claims justified by evidence and reasoning during the Science Methods Course and end of the year standardized student enactment. For example, during the Reflective Teaching enactment, Ms. Schuster explicitly used a logical structure for constructing evidence-based claims, asking for a "claim supported with evidence," in which students would use "scientific definition[s]" to support their claims [S_RT]. Ms. Schuster also used several other scaffolds and tools for this work, including modeling how to make a claim, providing a sentence stem for students to use when making their claim, designing a checklist for students to use to give feedback about one another's claims, creating an additional worksheet with prompts, and allowing students to work in groups before writing another claim individually (see Table 7-9). The checklist emphasized the importance of a complete, accurate claim by considering whether "all 3 cereals are mentioned" and whether "a claim is made about which cereal is the best source." The checklist also underscored the inclusion of evidence and reasoning by considering whether "there is evidence, 3 numbers supporting each cereal," and whether the students' statements "explain how this helps the body" [S_RT_LessonPlan]. As seen in Table 7-8 and Table 7-9, Ms. Schuster used some of these similar scaffolds, tools, and teaching moves during her Peer Teaching and end of the year standardized student enactments, yet she did not use all of them during these other enactments involving adults acting as students.

Table 7-9: Supports for Constructing Evidence-Based Claims Used by Ms. Schuster during Peer Teaching, Reflective Teaching, and End of the Year Standardized Student Enactments

	Peer Teaching	Reflective Teaching	End of the Year
Introduces/defines claim or evidence	X	X	X
Models how		X	
Provides a worksheet	X	X	
Checklist for strong claim		X	
Sentence stem	X	X	
Works in pairs/groups		X	

As when she discussed learning to allow her students to make sense of the data, Ms. Schuster described learning the importance of her students' doing the work of constructing evidence-based claims. For example, she said she learned to make sure that students "are coming to the conclusions" rather than doing the work for them [S_Interview4: 385-386]. Ms. Schuster also described some of the types of supports that she provided students during the Reflective Teaching Lesson, such as "I gave them time to write claims as a group and then share as whole class" [S_Interview3: 443-446]. She said she did this "explicitly" to provide "different ways … to access the information" [S_Interview3: 432-446]. This quote suggests that Ms. Schuster was purposeful in the types of scaffolds and tools she used.

Ms. Schuster's Science Knowledge for Teaching for Supporting Students to Construct Evidence-Based Claims

Throughout the program, Ms. Schuster's enactments suggested that she had high-quality science knowledge for teaching to support students to construct evidence-based claims. In each of the enactments, she provided an accurate, age-appropriate description of the phenomenon. She also tended to connect the description to a scientific principle or mechanism. For example, as described in the previous section, Ms. Schuster emphasized that students' claims should include information on how having a particular nutrient in the cereal would "help the body" during the Reflective Teaching lesson [S_RT]. This emphasis pushed students to describe the mechanism connected to their claim. Ms. Schuster also applied the description to students' everyday experiences in two of her enactments, Peer Teaching and the end of the year standardized student enactment. For example, during Peer Teaching, she asked the colleague-students, "What would be an example" of energy transferring without being in direct contact [SR_PeerTeach]. The students were able to think of experiences being near a hot car in the summertime.

In her interviews, Ms. Schuster described how her knowledge for science teaching changed over the two years in the program as she developed deeper understanding of science lessons and facilitated student learning. In particular, Ms. Schuster described how she developed an understanding of the investigation-based lessons from the Science Methods Course, saying,

> The engage, experiment, and explain [elements of lessons from the EEE framework] all really do support each other and are really valid…. It's more than just what's the answer here or what's the concept here? [Rather it's] how do we get there, and how can I help my students get there? [S_Inteview3: 360-374]

This quote suggests that Ms. Schuster learned how the different elements of an investigation-based lesson support student learning of science knowledge and practice. Ms. Schuster continued to emphasize how she now understood "an actual structure and process when I go into a science lesson" rather than isolated elements such as "a worksheet" for students to complete or an "experiment" to do [S_Interview3: 379-399]. This new understanding seemed to extend more broadly as Ms. Schuster described how she learned "how to think like a teacher," including how to "approach … the [range of] students in her class" [S_Interview4: 568-678]. This theme of experiencing a change in the way she thought about teaching was woven throughout Ms. Schuster's interviews.

How Ms. Schuster Described Why Her Knowledge Changed

Ms. Schuster seemed to attribute her learning to support students in constructing evidence-based claims to (a) opportunities to teach and reflect on her teaching, (b) learning particular teaching moves or strategies from program courses, and (c) the EEE framework from the Science Methods Course. Each of these three themes appeared in most of her interviews.

Ms. Schuster emphasized the opportunities to teach and reflect on her teaching as most influential to her learning. This emphasis is seen in her statement, "I think that a lot of what you learn from teaching [is] from actually teaching it" [S_Interview3: 514-516]. "Actually teaching it" for Ms. Schuster seemed to include reflecting on her teaching with her mentor teacher or colleagues "at the end of the day, about what went well and what didn't go well" [S_Interview4: 536-539]. Interacting with the students in her placement classrooms seemed to enable her to "see how [children] learn and … what they understand [S_Interview1: 640-647].

Ms. Schuster pointed to the multiple opportunities that she had to teach in the program, including during student teaching (though she did not teach science in student teaching), her field assignments for the Science Methods Course, and Peer Teaching as influential in her learning. In particular, she described how Peer Teaching facilitated her ability to support students in constructing claims because the small group was "attentive to [this teaching practice]," so "you know that the feedback's going to be specific [to] that" [S_Interview3: 503-505]. Ms. Schuster also seemed to appreciate the opportunity to "see different ways [the same lesson] was taught" during Peer Teaching. This opportunity seemed to show the possible ways a lesson could be adapted.

As discussed earlier, Ms. Schuster described how she developed deeper understanding of the connections between science lessons and her experience. She attributed this new understanding to learning about and discussing the EEE framework and lesson plans in the Science Methods Course. Ms. Schuster pointed out how the EEE framework was used "when we wrote the lesson plans," "was so explicitly taught to us," and "was expected of us" during the Science Methods Course [S_Interview3: 410-405]. This exposure to the framework seemed to help her learn to "just consider those things now when you ... teach a science lesson," even though she "only taught a couple of science lessons" [S_Interview3: 405-410]. Ms. Schuster continued to cite the framework as a source of her learning in the fourth interview as well.

In addition to mentioning the Science Methods Course, Ms. Schuster indicated that her work in the range of courses in the program, including the Children as Sensemakers Courses and the Social Students Methods Course, facilitated her ability to use strategies that elicit, probe, and scaffold the range of learners in her class. For example, Ms. Schuster commented,

> My classes for education have made me very metacognitive to where you have to consider of process of doing things…. There has to be a lot of scaffolding and a lot of eliciting that has to go on. [S_Interview1: 586-596].

This new awareness of how to scaffold and elicit thinking seemed connected to a new understanding of "the complexities of science and [the] manage[ment of] all the materials of science" from her courses in the program [S_Interview1: 5532-554]. The courses also seemed to offer a new vision of teaching "centered around … trying to let the students be a part in the learning and not just ... feeding them information" [S_Inteview4: 388-396]. This new vision appeared to facilitate Ms. Schuster's learning the importance of probing student thinking and guiding students to make their own claims. Ms. Schuster also discussed how she learned to use multiple strategies to scaffold learning as she realized "how everyone really, really learns differently at absolutely different levels" [S_Inteview4: 445-453] and the "misconceptions that students can have" [S_Interview2:127-128].

Summary of Changes

The last row in Figure 7-1 represents Ms. Schuster's teaching practice and knowledge for supporting students to construct evidence-based claims over the two years in the program (without a representation for student teaching, because Ms. Schuster did not teach science in student teaching). Ms. Schuster's practice and knowledge seemed to increase over time, with the greatest growth in supporting children to make evidence-based claims in a logical structure. Ms. Schuster's support for analyzing data to reveal patterns and relationships and sharing thinking appeared to improve from the first year to the Science Methods Course. Her science knowledge for teaching improved from the first year to the Science Methods Course as well. This improvement was slight given that Ms. Schuster's science knowledge for teaching "met" expectations during her pre–science methods enactments. Ms. Schuster attributed her learning to opportunities to teach and analyze her teaching in the field in her interviews. Her interviews also emphasized how she developed new understandings of science learning and teaching and learned the importance of eliciting thinking and using scaffolding in supporting all learners during her courses throughout the teacher education program.

Summary of Trajectories

Each of the four focal interns had an individual learning trajectory for supporting children to construct evidence-based claims of phenomena as seen in Figure 7-1. Differences existed among the interns in this trajectory in terms of what components of the teaching practices each intern showed growth in, how much growth occurred, and when the growth occurred. For example, Ms. Atkin showed large improvement in the quality of her support for students in analyzing the data from the first year to the science methods class, whereas Ms. Schuster showed large improvement in the quality of her support for using a logical structure to justify claims during the same time period. Ms. Kelly showed more moderate growth for supporting students to analyze data and using a logical structure for justifying claims during the same time period.

The interns also had varying areas of strength in their teaching. For example, only Ms. Schuster showed continued strength in using a logical structure to justify claims throughout the program. In contrast, Mr. Cruise showed continued strength in supporting students to communicate a claim. The interns also had specific strengths in specific components. For example, Ms. Kelly regularly supported students in making connections to one another's ideas. Mr. Cruise regularly supported students to interpret the data.

The interns also had individual areas of struggle. For example, Ms. Kelly continued to show inconsistency in her support for constructing evidence-based claims throughout the program. Likewise, Mr. Cruise did not support students in using a clear logical structure to justify their claim throughout the program. Ms. Atkin used this logical structure during the Science Methods Course but not afterwards. Finally, Ms. Schuster did not often make connections across science ideas in the curriculum.

In contrast to the differences across their learning trajectories, the interns showed similar areas of strength and growth in supporting children to share their thinking and analyze the data to reveal patterns and relationships. Even early in the program, the interns were able to support students in analyzing the data to reveal relationships and patterns, and to support students in using representations. Ms. Atkin, Ms. Kelly, and Ms. Schuster showed growth in this subpractice over time as well. All four interns showed growth in their science knowledge for teaching over time. However, Ms. Atkin seemed to struggle in this area during the end of the year standardized student enactment.

Two areas of struggle were common for three of the interns throughout the program: supporting students to use a logical structure for justifying claims and doing aspects of the intellectual work for the students. Ms. Atkin, Ms. Kelly, and Mr. Cruise did not use a clear logical structure for justifying claims during student teaching, and Ms. Schuster did not teach science during student teaching. Ms. Atkin, Ms. Kelly, and Mr. Cruise also continued to do aspects of the intellectual work for students throughout the program, although this declined slightly over time.

In addition to the similarities and differences in their trajectories, the way the interns described why their knowledge and practice changed also had similarities and differences. All of the interns named their experiences in the field as influential. Similarly, the interns commonly pointed to approximating practice, reflecting on their practice, and using the EEE framework, as being helpful to their learning. However, each intern also named specific areas of learning that were different from the others. For example, Ms. Atkin discussed the emphasis on leading discussions during the Mathematics Methods Course, whereas Mr. Cruise underscored the role of decomposing elements of teaching practice as important in his learning.

This chapter considered the individual trajectories of four focal interns in learning to support elementary children to construct evidence-based claims of natural phenomena. In the next chapter, Chapter 8, I discuss the findings from this chapter as well as the findings in Chapters 4, 5, and 6 in light of the research base. Then, I provide possible implications from these analyses.

CHAPTER 8

DISCUSSION AND IMPLICATIONS

Science learning through the integration of science practices and content as called for by new reforms allows for deeper understanding of the body of knowledge of science as well as how science knowledge is extended, refined, and developed over time (National Research Council, 2007, 2012; NGSS Lead States, 2013). Facilitating this science learning requires ambitious science teaching, which is uncommon in U.S. classrooms (Banilower et al., 2013; Forbes et al., 2013; National Research Council, 2007). Teachers need to learn new teaching practices and knowledge associated with providing this support (Abell, 2007; Appleton, 2007). To consider how a practice-based approach to teacher education might aid in the learning of these teaching practices and knowledge, this dissertation describes how one cohort of preservice teachers learned to support elementary students in constructing evidence-based claims during a two-year practice-based teacher education program. Findings from this study broadly inform existing research on science teacher learning (Abell, 2007; Thompson et al., 2013). These findings also contribute to the work on how practice-based teacher education can support ambitious teaching practice (Ball & Forzani, 2009; Grossman, Hammerness, et al., 2009; Lampert & Graziani, 2009). This chapter begins with a discussion of findings from the study. I describe the strengths, struggles, and growth of the interns' teaching practice of supporting students to construct evidence-based claims and consider how the practice-based approach may have contributed to this work. I conclude the chapter by describing implications for teacher education and curriculum development.

Learning to Support Elementary Children to Construct Evidence-Based Claims: Strengths, Struggles, and Growth

The cohort of interns showed areas of strength, struggle and growth for the high-leverage teaching practice of supporting children to construct evidence-based claims throughout the two years within the practice-based teacher education program. In this section, I begin by considering the similarities in the entire cohort's change in the subpractices and knowledge for this teaching practice. Then, I consider the similarities and differences among the individual trajectories of the focal interns. I end with a discussion of the trajectory of learning for the entire cohort.

Growth in the Subpractices of Supporting Students to Analyze the Data to Reveal Patterns and Relationships and Supporting Students to Make Claims Justified by Evidence and Reasoning

The interns' lesson plans and enactment suggested that they provided high quality support for the subpractice of supporting students to analyze the data to reveal patterns and relationships and the subpratice of supporting students to make claims justified by evidence and reasoning during the Science Methods Course. This suggested that the interns' abilities in these subpractices grew from the first year to the end of the Science Methods Course. In particular, the majority of interns' plans for their Peer Teaching assignment during the Science Methods Course "met" or "exceeded" expectations for the quality of support. These plans typically included teaching moves that have been connected to facilitating student learning in the research (Berland & McNeill, 2010; McNeill, 2011; McNeill & Krajcik, 2009; Songer & Gotwals, 2012; Wu & Krajcik, 2006), including using a logical structure for evidence-based claims, using representations to analyze the data to reveal patterns and relationships, and providing scaffolds and tools (e.g., sentence stems, prompting questions) for engaging in the science practice.

Similar to the lesson plans, the focal interns' enactments showed the highest quality of support during the Peer Teaching and Reflective Teaching enactments. These enactments used many of the same teaching moves included in the Peer Teaching lesson plans. Moreover, the focal interns regularly probed students' ideas and connected students' statements to each other during these enactments, although this was not typically included in the plans. These probes and connections seemed to facilitate discussion and refinement of ideas similar to others' description of this teaching practice (Berland & Reiser, 2009; Herrenkohl et al., 2011; Zembal-Saul et al., 2013). These plans and enactments suggest that the interns were able to provide high-quality support for constructing evidence-based claims.

These findings are noteworthy in light of other studies that underscore the difficulties that teachers, particularly beginning teachers, have in providing support for constructing evidence-based claims in elementary classrooms (Avraamidou & Zembal-Saul, 2010; Beyer & Davis, 2008; Park Rogers, 2009; Zangori & Forbes, 2013). However, these studies typically considered beginning teachers' ability to enact this teaching practice during student teaching or the induction phase rather than during science methods courses. For example, in a case study of four preservice teachers, the teachers tended to support students in data analysis but did not push students to construct evidence-based claims during student teaching. Only one of the four preservice teachers pushed students to explain what the data showed and how and why the data justified the claims (Zangori &Forbes, 2013). In contrast, all five of the focal preservice teachers in the current study were able to provide support to their student-colleagues to construct evidence-based claims during the Peer Teaching enactments. Four of the focal interns continued many aspects of this work in their Reflective Teaching assignments with an entire classroom of elementary students. In addition, a majority of the cohort of interns planned similar high quality support for their Peer Teaching lessons and Reflective Teaching lessons.

The interns' success in planning for and supporting students to analyze the data to reveal patterns and relationships and make claims justified by evidence and reasoning during the Science Methods Course may be due to the scaffolds and tools they were provided. In completing their assignments for the Science Methods Course, interns used a specialized lesson planning template (See Appendix H). This template included sections to support planning for evidence-based claims such as writing the expected evidence-based claim, attending to students' ideas, and scripting the "Explain" element from the EEE Framework[4]. This template also referred back to the EEE framework itself, reminding the interns to include the decomposed practices of science teaching into the lesson plan. It also related to the considerations for lesson planning that the interns had worked with throughout the program. Similar to the priming tools described by Windschitl and colleagues (2011), these tools and frameworks may have facilitated the interns to think deeply about the interactions they would have with their students in constructing evidence-based claims. Moreover, in their interviews, the focal interns named how they drew on the EEE framework in planning for lessons and how they were expected to use this framework in their teaching during the course.

In addition to the science-specific planning template and EEE Framework, the Peer Teaching planning and enactments included several other scaffolds. During Peer Teaching, the

---

[4] The EEE Framework decomposed pieces of elementary science lessons and provide a vision for how a teacher could support science learning (See Chapter 3 and Appendix C for more information).

interns were provided with the lesson plans and content to teach. This selection of the specific content seemed to decrease the complexity of planning and enacting a science lesson. Sleep and Boerst (2012) had similar findings when they limited the options to scaffold preservice teacher learning of eliciting student thinking. Although less authentic than teaching students in a classroom, the role play involved in Peer Teaching may have also limited the complexity in order to hone the particulars of supporting students to construct evidence-based claims and facilitated the interns' success (cf. Boerst, Sleep, Ball, & Bass, 2011; Grossman, Compton, et al., 2009; Lampert & Graziani, 2009; Nelson, 2011).

Variation in Supporting Students to Analyze the Data to Reveal Patterns and Relationships and Supporting Students to Make Claims Justified by Evidence and Reasoning after the Science Methods Course

The focal interns varied in how they supported students in analyzing the data to reveal patterns and relationships and to make claims justified by evidence and reasoning after the Science Methods Course. During this time period, at least one of the enactments of all five focal interns "met" or "exceeded" expectations for the subpractice of supporting students to analyze the data to reveal patterns and relationships; however, other enactments of each of the interns (except for Ms. Schuster who did not teach science during student teaching) either "did not meet" or "partially met" expectations in this area. In the enactments that "met expectations," the interns used a representation to facilitate students to notice patterns in the data and aided students to analyze and interpret the data. They also supported students to share and justify their thinking about these patterns. These teaching moves have been identified in the literature as conducive to supporting student learning (e.g., Berland & Reiser, 2009; P. Shah, Mayer, & Hegarty, 1999; Wu & Krajcik, 2006). In lessons that "did not meet expectations," the interns typically discussed the findings from the lessons with the class but did not use a representation to support students in analyzing data.

This variation within each intern's support for analyzing data to reveal patterns and relationships seems in contrast to case studies that describe characteristic approaches of particular teachers in engaging their students with science practice (e.g., Berland & Reiser, 2011; McNeill, 2009; Zangori & Forbes, 2013); however, similar degrees of variation in teachers' practice across lessons have also been described (McNeill, 2011). I hypothesize that this variation may be due in part to the disciplinary context of the lessons (cf. Boerst et al., 2011; National Research Council, 2012). For example, Ms. Kelly's first investigation during student teaching on "what is a fruit" and her second investigation on "what is a force" involved two different disciplines, biology and physical science. Although similarities exist in justifying claims across disciplines, these two disciplines regularly draw on different types of representations, evidence, and reasoning (cf. Mayr, 2004; National Research Council, 2012). These differences may make supporting students to engage in constructing evidence-based claims more difficult in one discipline compared to another. Similarly, differences may have existed in the interns' science knowledge for one topic as compared to another or the support provided by the curriculum materials for this work (Abell, 2007; Beyer, Delgado, Davis, & Krajcik, 2009; Enfield, Smith, & Grueber, 2008; Kesidou & Roseman, 2002; McNeill & Krajcik, 2009).

Compared to their support for analyzing data to reveal patterns and relationships, the interns struggled more with the subpractice of supporting students to make claims justified by evidence and reasoning after the Science Methods Course. Only two of the interns, Ms. Schuster and Mr. Cruise, "met" or "exceeded" expectations for the subpractice of making claims justified by evidence and reasoning during this time period. These interns supported the students to provide multiple pieces of evidence or reasoning to support their claims - key elements of engaging in the science practice (Duschl & Osborne, 2002; National Research Council, 2012; NGSS Lead States, 2013). In contrast to the support provided by Ms. Schuster and Mr. Cruise after the Science Methods Course, the other three focal interns either had students name only one piece of evidence or told students the claim and evidence. Commonly, the interns did the intellectual work for the students although both the research base (e.g., Herrenkohl, Palincsar, DeWater, & Kawasaki, 1999; Metz, 1997, 2000) and the students' other interactions in the classroom suggested that the students could do this work.

The interns seemed to struggle more with supporting students to make claims justified by evidence and reasoning compared to supporting students to analyze the data. This finding adds to the research on beginning teachers and elementary teachers' struggles (Avraamidou & Zembal-Saul, 2010; Zangori & Forbes, 2013; Zangori, Forbes, & Biggers, 2013). For example, Zangori and colleagues (2013) found that inservice elementary teachers tended to make adaptations to curriculum materials that would support students to give priority to the evidence such as collecting and analyzing data rather than focusing on the construction of the evidence-based claims. This struggle for elementary teachers may be due to the complexity of this science practice itself. For example, scientific claims need several pieces of evidence and reasoning in order to be sufficiently justified (Duschl & Osborne, 2002; Erduran et al., 2004; McNeill et al., 2006), yet teachers and learners often struggle in identifying sufficient and appropriate evidence for the claims (Haefner & Zembal- Saul, 2004; D. Kuhn, 1989; Land & Zembal-Saul, 2003; Sandoval & Millwood, 2005). Research suggests that teachers may struggle to engage in this science practice themselves (Haefner & Zembal- Saul, 2004; Land & Zembal-Saul, 2003) or to support students in this science practice (Biggers, Forbes, & Zangori, 2013; McNeill, 2009). However, the interns' success in supporting students to make claims justified by evidence during the Science Methods Course suggests that the interns may have had some understanding of the science practice and how to support students in this science practice. Moreover, analyzing data may have also been more common within the interns' placement classrooms than making claims justified by evidence and reasoning, which may have facilitated the interns' success in this subpractice during student teaching.

Compared to teaching one or two lessons during the Science Methods Course, during student teaching, the interns often planned for, taught, and assessed several lessons and subjects in addition to their science lessons during one day. Thus, interns faced greater complexity and authenticity during their student teaching than they had before (Grossman, Compton, et al., 2009). Many have described how the high complexity of teaching can create obstacles to ambitious teaching (Ball & Forzani, 2009; Hiebert & Morris, 2012a; Lampert, 2010b). This complexity may have overwhelmed the interns and created barriers for providing the same high-quality support seen during the Science Methods Course. The interns also did not have or use most of the scaffolds and tools provided for them during the course. For example, although the interns could have used the lesson planning template from the Science Methods Course during student teaching, the interns did not use the template nor did they think this was expected of them. Furthermore, rather than a slow release of the scaffolding towards more authenticity and complexity, the interns often jumped into teaching science after taking over several other subjects. Other studies have suggested how continued used of tools along with a slow increase in complexity over time facilitated preservice teachers in developing high-leverage practices (Boerst et al., 2011; Grossman, Compton, et al., 2009; Thompson et al., 2013; Windschitl et al., 2011). It may be possible that the interns faced too much complexity too quickly to continue providing the type of high-quality support seen in the lesson plans and enactments during the Science Methods Course.

Another possible reason for the interns' struggle to provide high-quality support for evidence-based claims during their student teaching is a conflict with the classroom culture and the expectation that students construct evidence-based claims (Beyer, 2009; Feiman-Nemser & Buchmann, 1985; Forbes & Davis, 2010b; Thompson et al., 2013). Research suggests that emphasis on evidence and sensemaking is uncommon in U.S. elementary classrooms (Banilower et al., 2013; Forbes et al., 2013; Pasley et al., 2004). Similarly, the lack of cognitive demand or expectation that students will do the intellectual work is also a common problem within U.S. classrooms (Stein et al., 1996). Thus, the elementary students in the interns' classrooms may not have engaged in making claims justified by evidence and reasoning; and the interns may not have been supported to engage students in this science subpractice by their mentor teacher. This disconnect between expectations of teacher education programs and field experiences has been discussed in the literature (Dewey, 1965; Feiman-Nemser & Buchmann, 1985; Lampert, 2010a). Ms. Kelly also mentioned her reluctance to introduce constructing evidence-based claims into her classroom since the curriculum materials used by the students and her mentor did not do this work. However, the other interns were able to introduce constructing evidence-based claims successfully during their reflective teaching assignments in the field, suggesting that not all interns had this problem.

Growing Science Knowledge for Teaching Throughout the Program

The interns' science knowledge for teaching seemed to develop over the course of the teacher education program. In particular, the interns' pedagogical content knowledge for teaching elementary science seemed to grow during student teaching. Compared to their earlier enactments of lessons, later in in the program during student teaching, the interns more regularly used an accurate, age-appropriate description of the natural phenomena and connected these descriptions to the "big ideas" of science and to students' lives. This finding adds to other studies that have described similar growth in teachers' pedagogical content knowledge throughout teacher education programs and science methods courses (Avraamidou & Zembal-Saul, 2010; Beyer & Davis, 2009a; Davis & Smithey, 2009; Schneider & Plasman, 2011; Zembal-Saul, 2009; Zembal-Saul et al., 2000).

Several possible explanations exist for this growth in pedagogical content knowledge throughout the program. During student teaching, the interns had regular opportunities to teach and reflect on their teaching each day with their mentor teachers and field instructors, which may have supported their learning. In their review of the literature on teachers' developing pedagogical content knowledge, Schneider and Plasman (2011) suggested that teaching along with supported reflection on one's teaching can facilitate teachers' development of pedagogical content knowledge. The interns were responsible for teaching a unit during student teaching a compared to only one lesson during the Science Methods Course. This work to design a unit may have pushed the interns to see the connections across the concepts within the lessons and links to the big ideas of science. Noticing these connections may have facilitated their ability to support students in seeing these connections similar to the beginning teachers in Windschitl and colleague's study (2011). Finally, the interns may have developed their pedagogical content knowledge through reading and using of the curriculum materials within their classrooms as has been seen in other studies (e.g., Jones & Eick, 2007; Schneider & Krajcik, 2002). All four of the focal interns were using kit-based units during their student teaching, which may have facilitated their ability to provide accurate content similar to the preservice teachers in Nowicki and colleagues' study (2013).

In addition to pedagogical content knowledge, subject matter knowledge is also part of science knowledge for teaching (Ball et al., 2008). As compared to their pedagogical content knowledge, the interns' subject matter knowledge for particular science content did not seem to grow but rather varied depending on context or topic. For example, more interns were able to make accurate claims that aligned with the evidence about a life science topic as compared to an earth science topic. Varying subject knowledge across disciplines has been described in other research on teacher knowledge and science learning (Abell, 2007; National Research Council, 2007). This variation may be due to the interns' varying experiences with different science disciplines and courses (Avraamidou & Zembal-Saul, 2010) or their engagement and interest in learning about particular topics as suggested by the comments in the interns' interviews.

Different trajectories

Similar to other studies of elementary teachers' learning to teach science (Anderson et al., 2000; Zembal-Saul et al., 2000), the focal interns' trajectories in learning to teach students to construct evidence-based claims varied. This variation is not unexpected given the different beliefs, background experiences, and prior knowledge of the focal interns as well as their unique experiences within the program (J. S. Brown et al., 1989; Putnam & Borko, 2000). However, the specifics of the interns' unique trajectories and experiences suggest outside influences and program elements that supported the interns in learning how to teach elementary science. These specifics also highlighted some of the barriers to this learning.

Outside influences that seemed to support the interns in learning to support elementary children to construct evidence-based claims included a desire to teach elementary science, experience with elementary science teaching outside of the program, and experiences with science courses. Each of the five focal interns expressed their desire to teach elementary science; this desire seemed to enable the interns to be motivated and open to learning about science teaching. This similar motivation as a starting point for learning has been described in other studies as well (Avraamidou & Zembal-Saul, 2010; Bryan & Abell, 1999).

Although most of the focal interns had some experience with teaching elementary children outside of the program, Mr. Cruise continued to point to his experiences teaching students elementary science during summer backpacking trips as a source of learning how to engage in this practice. Compared to the other focal interns, he seemed to have had the most experience with teaching elementary science before entering the program. Mr. Cruise provided higher support for students in analyzing data to reveal patterns and relationships than the other interns early in the program. It is possible that his prior experiences may have enabled him to develop some of the discourse and practices of teaching elementary science as he served in an apprenticeship role with other science teachers on these backpacking trips (cf. Lave, 1996; Lave & Wenger, 1991; Putnam & Borko, 2000).

Three of the four interns, Ms. Schuster, Mr. Cruise, and Ms. Atkin, had taken numerous science content courses. These teachers tended to accurately describe the scientific phenomena for their students throughout the program; in contrast, Ms. Kelly, who did not have these extensive experiences, tended to struggle with these descriptions until student teaching. It seems reasonable that the three focal interns' experiences in science content courses supported facilitating their ability to describe the phenomena accurately. However, all of the interns seemed to struggle at times with introducing and encouraging confusing terms or ideas, adding to other studies that suggest that subject matter knowledge is not enough for representing ideas in an accurate and age-appropriate manner (Ball et al., 2008; McDiarmid et al., 1989; Shulman, 1986).

In addition to the outside factors, several opportunities within the program also seemed to influence each intern's learning. For example, Ms. Kelly regularly pointed to how the representations of teaching practice such as videos and readings enabled her to have a vision of science teaching. This description of how the representations supported her in developing this vision is similar to other research on the role of representations in learning to teach (Grossman, Compton, et al., 2009; Little, 2003). Ms. Kelly described how she was able to see through the videos that her students, first graders, were able to engage in this work. Thus, these videos seemed to serve as an existence proof of ambitious science teaching in lower elementary classrooms for Ms. Kelly. The other interns, who mostly taught older grades, may have already believed that their students could do this work or even had seen this teaching in the field and did not need such existence proofs.

Mr. Cruise discussed that opportunities to decompose practice within his lesson planning were especially beneficial to his learning. He described how this decomposition of practice allowed him to notice the important details of teaching that he had not gained through his outside experiences teaching. Thus, Mr. Cruise's experiences watching teaching science as a student in the classroom may have made teaching seem easy (Lortie, 1975), and this decomposition of the practice seemed to facilitate an understanding of the complexity of teaching (Ball & Forzani, 2009). The other interns also described how the EEE framework, a decomposition of a science lesson, influenced their learning.

Other common places of learning across the focal interns were opportunities to approximate practice such as Peer Teaching and student teaching as well as reflecting on their teaching with colleagues, teacher educators, and mentor teachers. In their interviews, several of the focal interns specifically cited how responding to the alternative ideas and discussions about these responses during Peer Teaching pushed their teaching practice forward. Likewise, the ability to pause the enactment, highlight problematic aspects of the teaching, and reflect subsequently with a group seemed to facilitate growth in the interns' practice. The learning described by the focal interns adds to the growing evidence of the effectiveness of the pedagogies of professional practice (e.g., Boerst et al., 2011; Grossman et al., 2009; Nelson, 2011; Shah, 2011; Sleep & Boerst, 2012; Thompson et al., 2013).

The interns' individual trajectories also suggested possible obstacles to learning to support elementary students to construct evidence-based claims. The first obstacle to learning was lack of opportunity to experience science teaching in the field given the common lack of emphasis on science learning in some U.S. classrooms (Banilower et al., 2013; Benedict-Chambers, 2014; Marx & Harris, 2006; Pasley et al., 2004). In particular, Ms. Schuster did not have the opportunity to continue building on her experiences teaching science lessons during student teaching. Thus, she lost out on the opportunities to practice and refine her science teaching within a less complex environment than the role of a first year teacher (Grossman, Compton, et al., 2009; Lampert, 2010a). She may also not have the opportunity to develop her pedagogical knowledge for teaching in the same way the other interns did. In addition, she did not experience the same challenges in doing this work during student teaching that the other interns did and, thus, did not have the opportunity to reflect on and learn from these challenges.

Another challenge that some of the interns faced was aligning the ambitious science teaching espoused by the program with the type of science teaching occurring in their placement classrooms, a common problem for preservice teachers (e.g., Feiman-Nemser & Buchmann, 1985; Thompson et al., 2013). As discussed earlier, Ms. Kelly, in particular, discussed how she did not see the EEE framework being used in her placement classroom and did not feel comfortable introducing a structure for evidence-based claims to her first grade students. This may have contributed to Ms. Kelly's struggles to support students to construct evidence-based claims in her placement classroom. The other interns did not discuss experiencing this conflict. Compared to the other interns in the study who typically supported their students to analyze the data to reveal patterns and relationships and communicate claims, Ms. Kelly struggled with these subpractices when teaching in the field. Thompson and colleagues (2013) also found that some beginning teachers were unable to redirect contextual pressures to teach in conservative ways whereas others were able to redirect these pressures. Other factors may have also contributed to Ms. Kelly's struggles including her beliefs about her first grade students' abilities, her inexperience with investigation-based science, and her self-described concerns about her ability to teach science (Abell, 2007; Appleton, 2007; Davis et al., 2006; Metz, 1997).

Another potential challenge is suggested by a close examination of Ms. Atkin's experience. Ms. Atkin regularly did aspects of the intellectual work of justifying the claim with reasoning and evidence for her students. Yet, she did not seem to realize she was doing the intellectual work for her students, even though she described learning to press for reasoning and her intentions to do in her teaching. I suggest that Ms. Atkin may not have had the opportunity to recognize that she was doing this intellectual work for the students in her class. Unlike Mr. Cruise, Ms. Schuster, and Ms. Kelly who referenced their field instructor and mentor teachers as influential in their learning to support students to construct evidence-based claims, Ms. Atkin did not discuss the roles of her field instructor and mentor teacher in her learning. Rather, Ms. Atkin pointed out how her mentor felt uncomfortable teaching science and how science was not a priority at her placement school. Thus, Ms. Atkin may not have received the same support around for facilitating science learning as the other interns. Ms. Atkin may not have had the knowledgeable other around her to give her the type of feedback she needed to improve her practice (Kazemi et al., 2009; Vygotsky, 1978).

A final challenge to learning to construct evidence-based claims seen in the focal interns' trajectories may be the conflicting visions and goals between the interns and the program as suggested in other studies (Anderson et al., 2000; Thompson et al., 2013). As described above, Mr. Cruise's previous experiences with science teaching seemed to support some aspects of his learning to teach. Through these experiences, Mr. Cruise also developed a strong vision for how elementary science should be taught. This strong vision seemed to focus on different learning experiences rather than the emphases in the teacher education program, which may have resulted in Mr. Cruise not taking-up some aspects of the high-leverage practices emphasized by the courses. For example, Mr. Cruise emphasized the importance of having students investigate and experience the natural world rather than pressing for reasoning and evidence as suggested by the teacher education program. The other interns seemed to take-up the vision of science teaching suggested by the teacher education program more readily as has been seen in other studies (Anderson et al., 2000; Thompson et al., 2013; Zembal-Saul et al., 2000).

Learning by Adding Components of Practice over Time

Although the interns' trajectories showed differences, findings from this study suggest that the interns in the cohort showed several similarities in learning this high-leverage practice, extending the research on how science teaching practice is developed over time (e.g., Avraamidou & Zembal-Saul, 2005; Bianchini & Brenner, 2010; Luft et al., 2011; Roth, McGinn, & Bowen, 1998; Thompson et al., 2013; Zembal-Saul, 2009). In particular, as the interns learned to support elementary students to construct evidence-based claims, they seemed to learn particular components of the teaching practice at different times over the course of the program. For example, early in the program during the Children as Sensemakers Course, the interns supported the students to state a claim without a focus on justification with evidence. Later in the program, during the Science Methods Course, the focal interns typically supported students to justify their claims with evidence and reasoning.

Summary

In sum, the preservice teachers showed growth in learning to support elementary students to construct evidence-based claims during the practice-based teacher education program. They showed the greatest strength in supporting elementary students to analyze the data to reveal patterns and relationships and justify their claims with evidence and reasoning during the Science Methods Course. During this course, the interns had access to additional scaffolds and tools for doing this work. The interns struggled to continue this practice during student teaching, suggesting that the scaffolds and tools from the Science Methods Course may have been removed too quickly. However, the interns showed continued growth in their science knowledge for teaching throughout the program. The focal interns had differing trajectories of learning this high leverage-practice, which points to the differential strengths and obstacles that individual preservice teachers face. Despite individual differences in their trajectory, the interns showed several similarities in their growth for this practice as well.

Implications for Facilitating Teachers to Support Elementary Students to Construct Evidence-Based Claims

In noting the strengths, struggles, and growth of the cohort of interns to support students to construct evidence-based claims, this research has theoretical and practical implications for how we can support teachers to learn to enact this high leverage teaching practice. This dissertation points to factors that may have supported the interns in learning components of this teaching practice, potential obstacles to learning the practice, and what potential tools and scaffolds might be needed to support elementary science teaching.

Theoretical Implications

These findings suggest a possible learning progression for learning to support students to construct evidence-based claims of natural phenomenon. Mirroring how learning progressions for science content and practice allow for a description of the more complex and in-depth understandings that occur over time (Berland & McNeill, 2010; National Research Council, 2007), this progression helps to identify the ways in which teachers may build more in depth and sophisticated abilities to engage in the teaching practice. Similar to the learning progressions for pedagogical content knowledge for science teaching identified by Schneider and Plasman (2011) and the learning progressions for science practices (e.g., Berland & McNeill, 2010; Schwarz et al., 2009; Songer & Gotwals, 2012), this learning progression identifies an entry point and exit point for the learning, with theoretical stepping stones along the way. It acknowledges that there is not necessarily one set path, but instead illustrates one possible path toward learning the practice.

Figure 8-1 displays this theoretical learning progression within an expanded version of the theoretical framework for learning to teach first presented in Chapter 2. Figure 8-1 identifies the learning progression (the top arrow) as an aspect of the learning that occurs as prospective teachers move from outside the profession of teaching to becoming more integrated in the professional practice of teaching within this teacher education program. This learning progression is closely tied to the context in which the learning occurs, similar to others identified in the literature (Schwarz et al., 2009; Songer & Gotwals, 2012). Similar to the Figure 7-1 in

Chapter 7, each box represents the ability and knowledge of the preservice teachers at different times during the teacher education program. This figure also adds a box for what might hypothetically occur during beginning teaching if provided with additional support and tools. The more intense shading corresponds with increased ability to support students in this particular area or increased science knowledge for teaching (referred to as SKT in the figures).

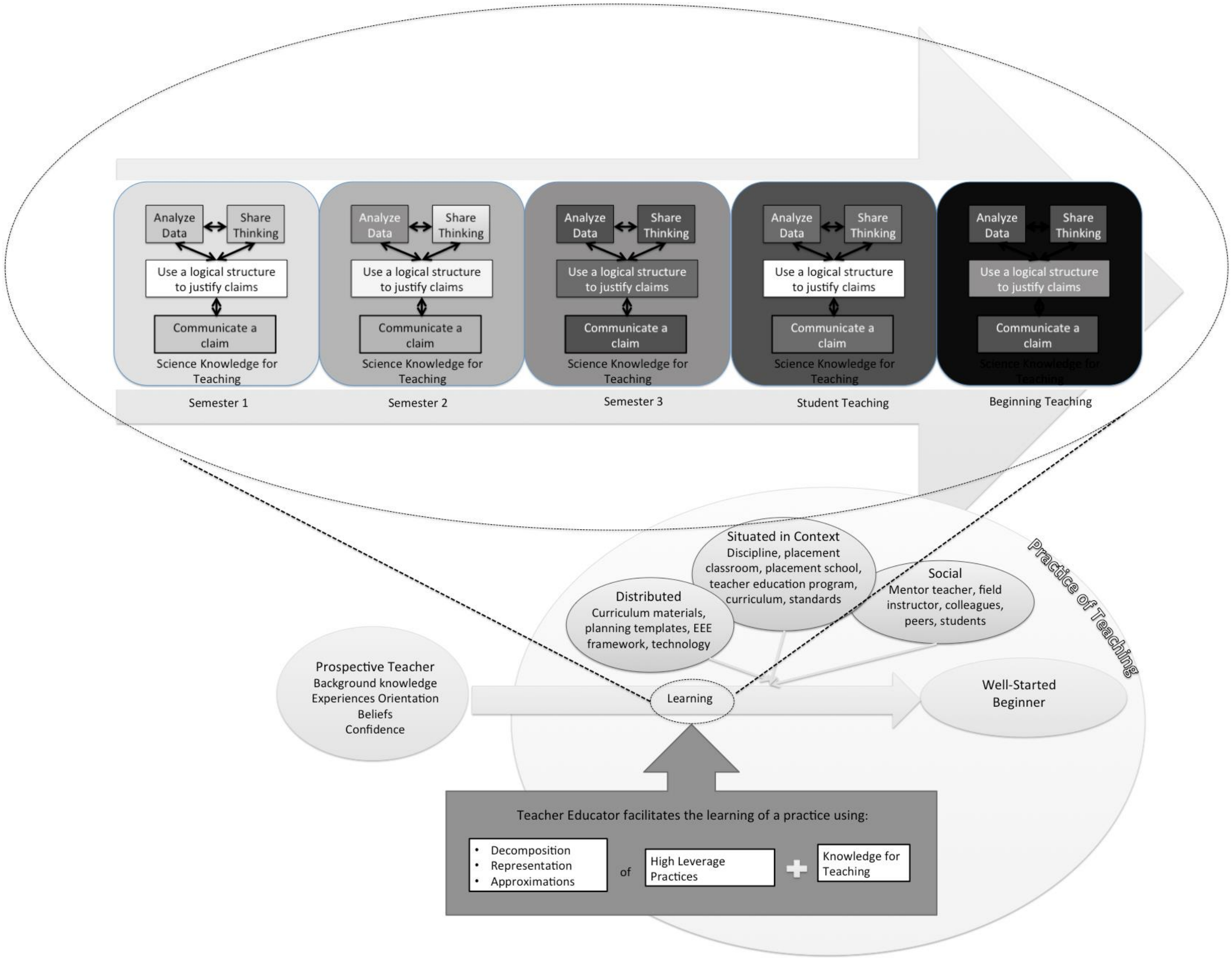


Figure 8-1: Theoretical Framework for the Learning Progression for Learning to Support Students to Construct Evidence-Based Claims within the Teacher Education Program

As seen in Figure 8-1, the learning of the teaching practice of supporting students to construct evidence-based claims of natural phenomena within this program may begin with developing interns' ability to support students to share their claim and to analyze and interpret data to reveal patterns during the first semester in a teacher education program. At this time, the preservice teachers may also begin to have students share their thinking. Second, the preservice teachers may develop proficiency in supporting students to analyze the data to reveal patterns and relationships, particularly using representations of data. Third, preservice teachers may begin to develop their ability to support students to make claims justified by evidence and reasoning. When facing the complexity of student teaching, the interns' support for analyzing the data, sharing their thinking, making a claim, and using a logical structure for the claims to give evidence and reasoning may decline slightly compared to the highly-supported third semester. Next, I posit that a teacher may continue to develop their ability to enact this practice within the next phase of the continuum of learning to be a teacher – as a beginning teacher with their own classroom (Feiman-Nemser, 2001) if provided with additional support and tools. Moreover, the preservice teachers' science knowledge for teaching may develop throughout the program and into beginning teaching as the authenticity of teaching increases.

Learning the teaching practice for the interns involved in this study seemed to match the ways in which the teacher education program supported this learning, similar to how other learning progressions describe a path that matches the support provided in a context (Berland & McNeill, 2010; Lehrer & Schauble, 2010; Songer & Gotwals, 2012). For example, early in the program, the interns focused on eliciting and probing student thinking during their Children as Sensemakers I Course. Likewise, the interns worked on how representations can support student learning during the Children as Sensemakers II Course in the second semester in the program, and the Science Methods Course in the third semester emphasized justification of science claims with evidence and reasoning. These particular foci on aspects of the teaching practice may have helped the interns learn the different elements at different times in the program (Boerst et al., 2011; Grossman, Compton, et al., 2009). Similarly, Boerst and colleagues (2011) described how decomposing a larger practice into nested practices of varying grain size enabled preservice teachers to learn the larger teaching practice over time. The initial focus on eliciting student claims during the Children as Sensemakers I Course may have served as a smaller nested practice for the larger teaching practice of supporting students to construct evidence-based claims. In their interviews, the interns also pointed to learning these different aspects in these courses and were able to describe the connections they made across courses.

Several factors seemed to influence and support this learning progression including the characteristics of the preservice teachers as well as of the teacher education program. As seen in Figure 8-1, the preservice teachers' background knowledge, prior experiences, orientations to teaching, beliefs, and confidence for teaching may influence the learning of the teaching practice. For example, some of the focal interns had more knowledge of science and experience with science teaching, and these characteristics seemed to give the interns a "foot forward" in learning the teaching practice. These characteristics have also been identified by the literature as influential in teachers' learning (e.g., Anderson et al., 2000; Avraamidou & Zembal-Saul, 2005, 2010; Bryan & Abell, 1999; Zangori & Forbes, 2013).

Learning that occurs within this progression is social, distributed, and situated in contexts (Putnam & Borko, 2000) as represented by the three bubbles pointing to the learning in Figure 8-1. In particular, the tools used by the preservice teachers seemed to distribute the work of engaging students in constructing evidence-based claims (Pea, 1993; Putnam & Borko, 2000).

For example, the EEE framework and planning templates reminded the preservice teachers of important elements to consider and include when designing lessons (Windschitl et al., 2011; 2012). Likewise, the interns may have offloaded aspects of their planning and teaching to curriculum materials (M. W. Brown, 2009; Remillard, 2005). The preservice teachers' learning seemed situated in the contexts of the teacher education program as well as the particulars of their placements in schools (J. S. Brown et al., 1989). The grade level, resources, and experiences of the students appeared to influence the interns' ability to support this science practice within their placement classroom, and thus, the preservice teachers' learning to enact the broader teaching practice. In addition, the preservice teachers' learning seemed situated within the scientific discipline in which they enacted this work (e.g., biology vs. earth science). Finally, the interns' learning appeared social as their interactions with colleagues, field instructors, mentor teachers, and teacher educators facilitated their reflection on and development of this high-leverage practice.

This theoretical learning progression also seemed supported by the facilitation of learning through the practice-based approach of the teacher education program as represented by the box on the bottom of Figure 8-1. The use of the pedagogies of practice – representation, decomposition, and approximation - of this high leverage-practice and science knowledge seemed to support the interns' learning (Grossman, Compton, et al., 2009). For example, Ms. Kelly described how seeing the representations of science teaching in a first grade classrooms enabled her to envision how to teach constructing evidence-based claims. Mr. Cruise underscored how decomposing practice facilitated his thinking about planning for science teaching. Ms. Atkin and Ms. Schuster regularly mentioned their experiences in the approximation of practice, Peer Teaching, enabled them to consider how to respond to student ideas. I posit this approach can allow for preservice teachers to develop particular teaching practices in more in-depth and sophisticated ways as suggested by the learning progression.

This learning progression for learning to support students to construct evidence-based claims seemed influenced by multiple courses in the practice-based teacher education program. For example, besides drawing on their Science Methods Course, the focal interns discussed learning how to elicit and probe student thinking from the Children as Sensemakers Courses, learning how to connect students' idea to each other from the Mathematics Methods Course, and the importance of having students justify their claims from the Social Students Methods Course. This suggests that the interns were able to make connections *across* the courses in the program as well as their fieldwork experiences. The interns' ability to make these connections may be due to the purposeful work towards coherence throughout the teacher education program (Davis & Boerst, 2014). Others have discussed how developing coherent opportunities for teacher learning supports teachers' ability to enact the learning within their classrooms (Hammerness, 2006; Penuel, Fishman, Yamaguchi, & Gallagher, 2007), suggesting this coherence may have facilitated the interns' ability to learn this high-leverage science teaching practice.

Methodological Implications

In addition to the theoretical implications about teachers' learning, this study also has implications for the study of teachers' learning over time. These implications arise through considering both the affordances and challenges of the use of longitudinal qualitative case study methodology within this dissertation. Following the interns longitudinally throughout the different contexts of the practice-based teacher education program allowed for a description of how their teaching practice changed over an extended period of time. By considering how interns engage in supporting students to construct evidence-based claims across the different approximations of practice, I was able to describe the incremental changes in their learning over time. Although differing the context may influence the ways which a preservice teacher enacts the teaching practice (e.g., Putnam & Borko, 2000), this study suggests that cross context work can illuminate the potential of preservice teachers' learning within teacher education programs, which has implications for how to study preservice teacher learning over time.

Studying the preservice teachers' practice within the context of approximations of practice also allowed for certain affordances. In particular, the less complex, less authentic approximations of practice, such as teaching in a rehearsal or simulation, illuminated the preservice teachers' potential teaching moves and quality of support, without requiring the preservice teachers to teach elementary students when they are not yet ready and could cause detriment to elementary students' learning. These less authentic contexts for the interns' teaching practice also have limitations in allowing a researcher to make assumptions about whether the interns' practices would look the same within a more authentic location, as has been discussed by others (Boerst et al., 2012). For example, one possible reason why the interns did not connect the claims made during the standardized student enactment to scientific principles is that they did not think it was part of the task. Given this limitation, this study also highlights the importance of developing simulations that align with the experiences that would actually occur in the classroom to allow for an understanding of how the interns might engage in a particular teaching practice

This longitudinal qualitative case study also drew on a range of data in order to triangulate the findings in describing the interns' learning over time (Maxwell, 2005; Miles et al., 2014; Saldana, 2003). The teacher education program's existing, systematic efforts to collect records of the interns' teaching practice across the classes and field experiences (Boerst & Davis, 2014) facilitated my ability to collect this range of data, suggesting that such efforts by teacher education programs can support the study of preservice teacher learning. The records of teachers' practice including lesson plans, class assignments, videorecords of teaching, and reflections on teaching from the entire cohort combined with the interviews with the focal interns allowed me to consider the patterns in the learning for the entire cohort as well as the individual trajectories of the subcases. The focal interns' interviews facilitated description of how and why they learned this teaching practice from their perspectives. In these interviews, the interns seemed able to name aspects of the program that influenced this learning. This research suggests that such interviews can thus facilitate our understanding of how to support interns' learning and help us explain interns' experiences within a practice-based program. This implies that records of practice as well as the teachers' own voices should be included in studies of teachers' learning of practice over time.

Implications for Teacher Education and Curriculum Materials

In addition to the theoretical implications, the findings from this dissertation also have practical implications for the design of teacher education and curriculum materials. Research suggests that a practice-based approach to teacher education facilitated the preservice teachers' development of this high-leverage practice. Using this approach throughout the courses in the program seemed to enable the interns to develop components of the practice over time. However, given the interns' struggles during reflective teaching and student teaching with supporting students to justify claims with evidence and reasoning, preservice teachers might benefit from a slower release of the scaffolds as they move into their student teaching (Beyer, 2009). Despite this struggle, all of the focal interns were able to show areas of success in their placement classrooms, and they regularly pointed to aspects of a practice-based approach as influential in their learning to teach science. In particular, the use of representations, decompositions, and approximations of practice during the Science Methods Course seemed to push the interns' learning forward. This implies that a practice-based approach to teacher education can support the development of teaching practices for supporting science learning.

Early in the program, interns struggled in designing appropriate representations to analyze the data and justifying their claims with evidence and reasoning. In addition, interns described how they did not have opportunities to experience these science practices within their science courses in high school and college. This implies that the preservice teachers may need additional support in their own science learning experiences, including their college science courses, to engage in analyzing data and constructing evidence-based claims. These college science courses might also facilitate potential preservice teachers in understanding the importance of these science practices and how these practices might vary across discipline and topic area.

The tools and frameworks from the teacher education program seemed to facilitate the interns' ability to plan for and enact the high-leverage practice. However, the interns tended to stop using these tools during student teaching. This implies that the preservice teachers need to be encouraged to use these tools throughout their teaching careers. As seen in other studies (e.g., Windschitl et al., 2011), such tools can allow for distribution of the work of teaching, enabling beginning teachers to reach more ambitious teaching. Moreover, additional tools for beginning teachers might facilitate choosing representations for analyzing data to reveal patterns and relationships or using a logical structure for evidence-based claims. These additional tools might include a set of considerations for choosing representations to analyze the data to reveal patterns and relationships, charts for supporting students to use a logical structure at different grade levels, or a unit planning template with science-specific reminders. For example, a set of considerations for representations might include questions such as "What are the implicit features of the representation?" and "How does the representation support analysis of the data to reveal patterns in an age-appropriate and accurate manner?"

In addition to tools for supporting their learning beyond courses, preservice teachers may also need additional feedback to push their learning to teach elementary students to construct evidence-based claims forward. The interns seemed to struggle with facilitating students to do the intellectual work throughout their student teaching. Often, it appeared the interns did not realize that they were doing the intellectual work for their students. Thus, feedback might help the interns notice this struggle and support the preservice teachers in reflecting on and improving their practice in this area. Given the enormous complexity that the interns' field instructors and mentor teachers face supporting the interns' learning across all elementary subject areas, additional support for these roles for identifying difficulties specific to enacting ambitious science teaching might enable providing the just-in-time support needed. Mentor teachers and field instructors may benefit from science-specific tools for analyzing and providing feedback for the preservice teachers. For example, a rubric for considering interns' abilities for supporting construction of evidence-based claims with suggested feedback for common struggles might enable more targeted feedback.

Within this study, the focal interns seemed to draw on the curriculum materials within placement classrooms as tools for deciding how to organize their lessons and to facilitate student learning (Ball & Cohen, 1996; M. W. Brown, 2009; Remillard, 2005). The curriculum materials may have also supported the interns' learning of pedagogical content knowledge as suggested in the research (Collopy, 2003; Jones & Eick, 2007; Schneider & Krajcik, 2002). This potential role in supporting the interns' knowledge implies that curriculum developers might consider addressing more explicitly the struggles of teachers in supporting students in constructing evidence-based claims. In other studies, educative curriculum materials, materials explicitly designed to support teacher and student learning, provided teachers with support to plan and enact science teaching (e.g., Beyer & Davis, 2009a; Bismack et al., 2015; Cervetti, Kulikowich, & Bravo, 2014; Davis & Krajcik, 2005). This study suggests that beginning teachers might benefit from such materials. Designers of curriculum materials might take into account the particular needs of beginning teachers as compared to more experienced teachers. For example, beginning teachers seemed to need support around where students might struggle, the types of representations that might support analysis of the data, and the abilities of their students to do the intellectual work.

The preservice teachers often needed to design additional supports to aid in their students' construction of evidence-based claims because the curriculum materials may not have these supports. The interns pointed out the curriculum materials often did not include an emphasis on supporting all students to construct evidence-based claims, which is a problem described in the research literature (Bismack, Arias, Davis, & Palincsar, 2014; Forbes et al., 2013; Lee & Buxton, 2008). This lack of focus for constructing evidence-based claims within curriculum materials in not unexpected given that the curriculum materials were developed before national calls for integrating science practice with science content (National Research Council, 2007; NGSS Lead States, 2013). More explicit attention in curriculum materials to this science practice may facilitate more ambitious science teaching within elementary classrooms (Davis & Krajcik, 2005; National Research Council, 2007).

Limitations and Future Research

This dissertation characterized preservice teachers' learning to support elementary students in constructing evidence-based claims of natural phenomena during a two-year practice-based teacher education program. This study provided insights into the strengths, weaknesses, and growth in this learning during these two years in the program, having implications for teacher education and curriculum development as well as theoretical understandings of how preservice teachers learn to engage in a high-leverage science teaching practice. This study's consideration of one cohort of 54 interns within one teacher education program limits generalizing to what might happen in a different context or with different teachers. The particulars of the contexts of the placement classrooms, background of the participants, and experiences of those supporting the preservice teachers throughout the program will impact their learning (J. S. Brown et al., 1989). This suggests the need for additional research to consider how preservice teachers might learn this teaching practice in a different context. Despite the inability to generalize to other contexts, this study did provide insights about how learning can happen within this context and the potential that preservice teachers have in learning this practice, allowing it to add to the theory of teacher learning (Eisenhart, 2009).

The focal interns in this study were purposefully selected as interested in science teaching; and, thus, this study cannot point to how teachers with less enthusiasm might engage in this work. In addition, this study did not have information about the content knowledge of the interns beyond the survey information and could not speak to the interns' knowledge across content areas, yet the four focal interns' integrated science majors suggest they might have more content knowledge than other interns. Additional research is needed to highlight the strengths, struggles, and growth of preservice teachers who might not show the same enthusiasm or have the same content knowledge for science teaching. Similarly, Ms. Kelly's lack of experiences with investigation-based science learning seemed to make her less confident and add to her struggles with teaching students in science. New research might look at the unique struggles of different groups of beginning teachers in learning to support students in integrating science practice with science content.

The interns' enthusiasm for science learning as well as their personal connection to the researcher as a science instructor may have caused the participants to overemphasize their use of particular tools or the importance of elements of the teacher education program. In addition, the missing data sources such as missing interviews with Ms. Michaels and no information about Ms. Schuster's teaching practice during student teaching (due the lack of opportunity for her to teach science) limits the ability to further substantiate claims. Although evidence exists that the interns were truthful in their interactions (e.g., Mr. Cruise's emphasis on his learning outside the program rather than inside the program) and the dissertation drew on a range of data, additional questions arise as to whether other preservice teachers or additional data would highlight the same elements and supports within the program as beneficial in their learning. New research might consider what type of tools or supports can facilitate the range of experiences that preservice teachers might bring to teacher education programs.

This research suggests that the preservice teachers struggled in continuing to give the same high-quality support they provided during the Science Methods Course. This finding brings forward questions around the tools and supports that beginning teachers need for supporting their learning: How might we help teachers use these tools and supports across contexts and into their beginning teaching? How might these supports be embedded in curriculum materials or other resources found within daily teaching practice? These questions might continue the work of researching how to facilitate teacher learning throughout their careers (Feiman-Nemser, 2001).

Conclusion

Beginning elementary teachers need support in engaging students in science practice integrated with science content (e.g., constructing evidence-based claims of natural phenomena) as called for by new reforms. A practice-based approach to teacher education has been suggested to facilitate beginning teacher learning, yet little is known about how this approach can aid elementary teachers' learning to teach science. This dissertation contributes to the literature by characterizing preservice elementary teachers' learning to support students in constructing evidence-based claims of natural phenomena during a two-year practice-based teacher education program. The findings add to theoretical understandings of how teachers learn over time and the factors that might influence this learning. The analyses also have implications for the teacher education and science curriculum development, providing evidence for the role of practice-based teacher education in supporting elementary teachers and the types of tools and scaffolding needed to facilitate teacher learning. Thus, this research helps to conceptualize how beginning teachers might learn to support elementary students to engage in science practices integrated with science content and how a practice-based approach to teacher education program can facilitate this learning.

APPENDICES

APPENDIX A: HIGH-LEVERAGE PRACTICES

1. Explaining core content
2. Posing questions about content
3. Choosing and using representations, examples, and models of content
4. Leading whole class discussions of content
5. Working with individual students to elicit, probe, and develop their thinking about content
6. Setting up and managing small-group
7. Engaging students in rehearsing an organizational or managerial routine
8. Establishing norms and routines for classroom discourse and work that are central to the content
9. Recognizing and identifying common patterns of student thinking in a content domain
10. Composing, selecting, adapting quizzes, tests, and other methods of assessing student learning of a chunk of instruction
11. Selecting and using specific methods to assess students' learning on an ongoing basis within and between lessons
12. Identifying and implementing an instructional strategy or intervention in response to common patterns of student thinking
13. Choosing, appraising, and modifying tasks, texts, and materials for a specific learning goal
14. Enacting a task to support a specific learning goal
15. Designing a sequence of lessons on a core topic
16. Enacting a sequence of lessons on a core topic
17. Conducting a meeting about a student with a parent or guardian
18. Writing correct, comprehensible, and professional messages to colleagues, parents, and others
19. Analyzing and improving specific elements of one's own teaching

APPENDIX B: PART OF PROTOCOL FOR CHILDREN AS SENSEMAKERS I INTERVIEW

3 min	**Initial Elicitation about Day and Night** *The purpose of this elicitation is for you to elicit what the child knows about how we have day and night through conversation without the benefit of drawings or a physical model.*	Please tell me how you think we have day and night? *Wait for the child.* *If the child needs support you can use the following questions:* • Where is the sun at night? • How does this happen? • Does the earth move? • Does the sun move? • Where are the stars during the day? *If you are unsure what the child is saying, ask the child to tell you more, or if there are specific ideas that you are unable to understand, say something like,* Can you tell me more about…?		

APPENDIX C: EEE FRAMEWORK

Lesson element (overarching tchg. practices in *italics*)	**Likely dimensions of the lesson element** (scientific practices in *italics*)	**Relevant science teaching practices** ***Teachers may….***
Engage with an investigation question (entails *eliciting stdt. thinking*)	Establish an investigation question or problem (entails *asking questions*)	Pose or co-craft a question or problem for investigation. This question or problem should establish a meaningful purpose for experiencing the scientific phenomenon, and it should generate interest among students.
	Share initial ideas about the question or problem	Elicit students' initial explanations, models, or predictions to answer the problem or question. Encourage students to draw upon their prior knowledge and experiences.
Experience the scientific phenomenon to generate evidence to answer the investigation question (entails *managing small-group work, choosing and using representations and examples*)	Establish data collection for answering the investigation question or problem (entails *planning and carrying out investigations*)	Support students in setting up one or more investigations that allow them to gather data that they can use as evidence to answer the question or problem. With varying degrees of guidance, have students... • Determine what data will be gathered and how and why it will be collected and recorded • Make justified predictions about the outcome of the investigation.
	Carry out the investigation (entails *planning and carrying out investigations*)	Support students in systematically collecting and recording data (e.g., making scientific observations, making systematic measurements) to generate evidence to answer the investigation question or problem. This includes… • Observing and listening to students as they interact • Asking questions to help students begin to make sense of what their data mean, rather than "telling" students the answer. • Redirecting students' investigations to be more systematic, precise, and objective when necessary • Managing the distribution and collection of materials • Facilitating productive small group work
Explain with evidence (entails *explaining core content, choosing and using representations and examples, establishing norms for classroom discourse*)	Identify patterns and trends in the data for answering the investigation question or problem (entails *analyzing and interpreting data, using mathematics thinking*)	Support students in making sense of the data so that they can generate claims with evidence. This includes … • Compiling class data, and if relevant, organize or represent the data in meaningful ways (e.g., in tables or graphs). • Directing students to particular aspects of the data to help them identify and make meaning of patterns or trends in the data. • Helping students select appropriate and sufficient data to use as evidence to support claims.

	Generate scientific claims with evidence and reasoning (entails *constructing explanations*, *engaging in argument from evidence)*	Facilitate a discussion that enables students to answer the investigation question by using the data to generate evidence-based claims. Provide students with scaffolds, such as "I think ____(*claim*) because I observed _____ (*evidence*)" or "What I know: ____ (*claim*). How I know it: _____ (*evidence*)." Provide opportunities for students to share their explanations with others, including peers, parents, etc. Help students… • Revisit their initial ideas about the investigation question, expanding upon or developing new evidence-based claims. • Compare their own explanations with explanations reflecting scientific understanding, via direct instruction, textbooks, models, etc. This includes introducing new terms to students, as appropriate. • Question one another about their explanations
	Apply knowledge to new problems or questions	Support students in applying their knowledge to new learning tasks. For example, • Ask students "what would happen if…" to think through and explain their understanding of science concepts, and/or give a concrete new scenario that requires application of the new knowledge

*At each element, support students in understanding *why* they are learning science this way. For example, help students understand *why* they need to systematically collect and record data during an investigation, or *why* they should share their claims with peers and support them with evidence. This helps connect to all three dimensions of science education.

APPENDIX D: SYLLABUS FOR SCIENCE METHODS COURSE

Teaching Elementary Science

Education 421 Fall 2013

Course Objectives and Organization

In Elementary Science Methods, we will build on current research and best practice to prepare you to foster science learning in elementary school students. Our main goals are for you to:

- describe the three dimensions of the Next Generation Science Standards – Disciplinary Core Ideas, Science Practices, and Crosscutting Concepts.
- incorporate the three dimensions of the Next Generation Science Standards into effective elementary science teaching to support students as they *engage, experience*, and *explain with evidence* through science investigations. Specifically, you will work on science teaching practices such as:
  - appraising and modifying science lesson plans and activities to address a specific learning goal
  - setting up and managing small-group investigative work
  - establishing norms and routines for classroom discourse and work that are central to science (such as asking children for evidence to support their claims)
  - choosing and using representations, examples, and models of science content
  - explaining core content and supporting students in constructing scientific explanations
  - enacting science lessons or portions thereof to support a specific learning goal
- identify and enact instructional practices that make science accessible to *all* students. Some practices that may facilitate equitable instruction include:
  - selecting and enacting the activities with care, including through connecting science to students' lives
  - using scientific language in accessible and accurate ways, and helping children to do so
  - using multiple representations of the ideas and making connections between representations
  - considering a broad conception of scientific expertise
  - being explicit about what might have been invisible to some learners (e.g., providing rationales for instructional decisions, unpacking terminology, having clear rules, being clear about what's invisible or otherwise inaccessible about the scientific phenomenon)
- learn how to prepare, teach, and analytically reflect on elementary school science investigation lessons

The expectations are high this semester. You've already experienced two semesters of coursework in the School of Education and two semesters in the field. This semester, we'll help you make connections between what you've learned already, and what you're learning now.

Throughout the semester, we will work on the goals listed above. We'll read relevant chapters and articles that can help us unpack the ideas related to these, and we'll also use other records of practice (video, student work, etc.) to help bring some of the ideas to life. Each week, we'll be working on some key teaching practices, and you'll be practicing those practices in our ED421 class, in the field, or both. By the end of the course, you should feel better prepared to put the pieces together to teach science effectively as a beginning teacher.

We've structured the class to allow for a focus on elements of science teaching. Many science lessons can be broken down into three basic elements: *engage*, *experience*, and *explain with evidence*. Sometimes, these elements will span across a unit, rather than a lesson. We'll work through different teaching strategies associated with each element, focusing on using investigations to help students learn science content and scientific practices.

What are possible ways to engage, experience, and explain with evidence in science lessons? Watch for these elements when you observe science teaching. For example, you might see a teacher use journal writing to *engage* students by eliciting their ideas at the beginning of a lesson, and/or the teacher might review previous lessons. For the *experience* element, a teacher might provide students multiple opportunities to interact with scientific phenomena and concepts. For example, the teacher could have students conduct a first-hand investigation, supporting them in collecting and recording data systematically. S/he might also have students read a text, watch a video, conduct research using the Web, or use data that had already been connected, and we'll explore in class how these kinds of experiences can complement first-hand experiences with the phenomenon. In the *explain with evidence* element of a lesson, the teacher might have students look for patterns in data, make claims based on evidence, construct a consensus model, or all of the above. Some of these approaches might, in turn, serve as formal or informal assessments.

Course Reading Materials

Required Readings and Other Course Expenditures

Zembal-Saul, C., McNeill, K. L., & Hershberger, K. (2013). *What's Your Evidence?: Engaging K-5 Students in Constructing Explanations in Science*. Pearson Education.

> *What's Your Evidence?: Engaging K-5 Students in Constructing Explanations in Science* provides a framework for you to help your students develop their ability to construct scientific explanations. The book focuses on how you can have students use explanations to enhance conceptual understandings and communicate effectively in the science classroom. The book also includes a DVD with videos of practitioners carrying out many of the strategies discussed by the authors. You can purchase *What's Your Evidence?: Engaging K-5 Students in Constructing Explanations in Science* at Ulrich's.

Michaels, S., Shouse, A., & Schweingruber, H. (2007). *Ready, set, science! Putting research to work in K-8 science classrooms*. Washington, DC: The National Academies Press.

> *Ready, Set, Science!* (abbreviated in the syllabus as RSS!) presents the most up-to-date discussion of reform-oriented science teaching. The book focuses on how you can incorporate scientific practices, such as scientific inquiry, into your elementary science teaching. Written for practitioners, it includes lots of nice descriptions of effective science teaching at the elementary level. You can purchase or access *Ready, Set, Science!* free online at http://www7.nationalacademies.org/bose/TSS_RSS_FAQ.html.

The other required readings are provided on CTools under "Resources" and within the "Weekly Resources" folder, by week.

In addition to the required readings, you should expect to need to spend no more than $25 to cover expenses associated with your science teaching in your elementary classroom.

Additional Resources

You may find some of the following books to be useful, as well. At least portions of these books are available online. Each is linked from the CTools site.

Next Generation Science Standards

> The Next Generation Science Standards is a new set of standards for teaching science (released in 2013) that integrate the core disciplinary ideas in science, science practice, and cross-cutting concepts. The Next Generation Science Standards are available at http://www.nextgenscience.org. While the state of Michigan has not yet adopted the Next Generation Science Standards, Michigan was a lead state in their development.

National Research Council (NRC) (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Committee on a Conceptual Framework for New K-12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

The *Framework*, as this document is called, is the foundation for the Next Generation Science Standards. The Framework is available at http://www7.nationalacademies.org/bose/Standards_Framework_homepage.html.

Michigan Department of Education. *Michigan Grade Level Content Expectations*.

The Michigan Department of Education has a set of standards for teaching science in Michigan. These science standards can be found in the *Michigan Grade Level Content Expectations* (*GLCEs*), available at www.michigan.gov/documents/mde/Item_C_194161_7.pdf .

Common Core State Standards Initiative (2010). *Common Core State Standards for Mathematics*.
Common Core State Standards Initiative (2010). *Common Core State Standards for English Language Arts*.

The Common Core will guide your math and language arts instruction, but you should also use these documents in making connections to science. For example, the ELA Common Core emphasizes content-area literacy and science is a key discipline for being able to make such connections.

American Association for the Advancement of Science (AAAS). (2001). *Atlas of science literacy*. Washington, DC: American Association for the Advancement of Science.

The *Atlas* provides a concept map view of the Benchmarks described above, demonstrating how the different concepts are interconnected. Some of the Atlas' maps are available on-line at http://www.project2061.org/tools/atlas/sample/toc.htm. You may want to purchase this book if you are a science major; the URL is http://www.project2061.org/tools/atlas/default.htm

** Additional resources are available for your use on the CTools course website.

Course Requirements and Grading

The percentages listed here are approximate, but will give you a sense of the relative weight of each assignment. Expectations for these assignments will be discussed in more detail in class, and detailed assignment sheets will be provided. All written work should be uploaded to the corresponding assignment folder in the ED421 CTools site by the specified due date.

Class Attendance, Participation and Additional Written Assignments (20%)

Attendance and participation are expectations in this class as a form of professionalism. We expect you to attend every class, to arrive on time for a prompt start, to stay till the end, and to participate in and contribute to class. It is vital that you attend every class session if at all possible. If you cannot be present for a class session, let your instructor know by e-mail by 8:00AM the day of class. Acceptable absences include absences due to religious holidays; please let your instructor know at the start of the semester if you will miss class for this reason. While it will not be possible to recreate a missed class, please make arrangements with your instructor to complete alternative work that will support the learning you missed. Your instructor will specify the due date for this alternative assignment. More than one absence from the class will make successful learning of the material in the course challenging and put you in danger of not being able to complete the course successfully. The Office of Teacher Education will be notified if there is more than one absence. As always, participation points will be deducted for absences and late arrivals.

"Participation" means that you need to be in the habit of speaking up and being engaged in whole class and small group discussions and activities. Appropriate use of electronic devices is also a part of your professional participation in our class. Using laptops or cell phones as tools for your learning is acceptable, as long as it is not distracting to your colleagues or your instructor. Examples of acceptable use of electronic devices include making records of your practice and consulting resources for work in class. Texting, phone calls, social networking, shopping, and other non-instructional use of these devices are not acceptable in this class at any time, and will result in a reduction in your participation grade. If you are concerned about your ability to meet this professional expectation, please discuss your concern with your instructor. Please let your instructor know if there is an emergency that affects your need for a phone in class.

Additionally, you will have one or more small written assignments such as the science teaching conversation with your mentor teacher or reflections after each segment of the peer teaching assignment.

Peer Teaching in ED421 (three times) (10% each time, or 30% total)

Each peer teacher will have a chance to lead their peer "students" through each of the following three elements of a science lesson: *engage with an investigation question*, *experience the scientific phenomenon* associated with the investigation, and *explain the phenomenon with evidence* to his/her peer teaching team. We refer to these three elements of science teaching as the "*EEE* framework for science teaching".

Experience Element in the Field (one time) (20%)

Teaching the *Experience* element of a lesson will involve co-teaching a science lesson with your mentor teacher in your field placement classroom. The goal is to apply ideas being learned in ED421 to practice small elements of science teaching, sometimes in low-stakes environments, so that when you are teaching entire science lessons (with multiple elements), you will have already developed some expertise. You should plan to teach the "experience" element of an investigation lesson in your field placement classroom.

Reflective Teaching Assignment (30%)

You will teach a full science lesson in your practicum classroom. For the reflective teaching (RT) assignment, you will analyze a science lesson plan using the lesson design considerations framework, develop your version of the science lesson plan using the instructional planning template, teach the lesson to children, reflect on your teaching using your video record, and analyze some student work.

Class Policies and Additional Information

Contacting Us

Email is the best way to reach us. You can also call us, come to our office, or leave something in our mailboxes.

Grading and Late Work

If you cannot complete an assignment on time, please contact your instructor by email in advance of the due date and request an extension. Typically we will give an extension of one week; after that, the work will be counted as late and your grade will be affected.

You may request a re-grade on any assignment. The request must be made via email and you must turn in the revision within one week of the assignment being handed back.

Readings

You are expected to do all the reading in advance of class. Our work in class depends on it.

Written Assignments

For turning in your written assignments, you will use the drop box area in the CTools site. Please turn in your Saturday assignments by 10:00pm on the Saturday evening they are due, and the in-class assignments before class (8:29am) on the day they are due.

Video Assignments

For turning in videos that accompany written assignments, you will use Edthena.

Participating in Program Evaluation and Research

You received information last year about teacher education program evaluation and research. If you have any questions, please ask us or your field instructor. You or your mentor teacher have also received a letter to the parents or guardians of the children in your classroom. Please make sure you follow the instructions you receive about signing, copying, and distributing these letters.

Class start time and procedures

Class will begin promptly at 8:30am, and will release at 11:30am. We will also take a ten-minute break during the three-hour class period. Please sign in, and pick up materials for the class period when you arrive.

Questions, Comments, or Concerns

If you have any questions, comments, or concerns about the class, please do not hesitate to contact us! We're looking forward to working with you this semester!

APPENDIX E: PEER TEACHING ASSIGNMENTS
Peer Teaching *Engage*, *Experience,* and *Explain* Elements of Science Lessons

In the peer teaching assignments, you'll use either the *Stems* or the *Energy* Lesson (both from Science Companion) to teach a series of *Engage, Experience,* and *Explain with evidence* elements of lessons to your EDU 421 peer teaching team over the course of the semester. When you are teaching, your colleagues will act as elementary students (intellectually, not behaviorally). The part of a science lesson that you'll teach (*engage, experience, or explain)* will correspond to the science teaching practices that we will model and discuss in class the previous week. These science teaching experiences will require you to do some thinking and planning in advance, and we will help you with this by modeling aspects of *Engaging*, *Experiencing,* and *Explaining* in class. Immediately after you teach, we will "co-reflect" as a class, to debrief the peer teaching assignment. This re-framing will let us all have a chance to talk about what went well and what could have gone better and work collaboratively on developing your science teaching skills.

When you are not teaching your peers, you will fulfill the role of elementary students for your peer teacher colleague. As the student, you'll get to experience what your own future students will experience. Your impressions and feedback for your peer teacher colleague will be invaluable for developing his/her teaching skills and will also help you think through your own science teaching.

Peer teaching (and learning) offers several advantages to you as beginning teachers:

1) It allows you a "safe environment" in which to test-drive some of the complex methods we talk about in class without the fear of hindering someone's learning. By maintaining an environment of respect for each other's ideas and teaching practices, you'll be able to take chances and try out teaching approaches that may not yet be totally comfortable or natural for you.
2) Given that you are practicing complex science teaching practices, you will inevitably make some mistakes. Many of the mistakes you and your peers will be making during the peer teaching lessons are very common to beginning teachers. We refer to these mistakes as common "problems of practice". The advantage of practicing these science teaching methods in the course as opposed to in a classroom with students is that the teacher educator can stop your lesson to discuss your teaching with the group. If you make a mistake in the classroom, you do not have the luxury of stopping your lesson, thinking through the problem of practice with your instructor and peers, and re-teaching it.
3) Peer teaching provides an opportunity for you to get more experience with science teaching and learning. Unfortunately, science often takes a back seat to other subjects in elementary classrooms, so we hope that this gives you more overall exposure to science teaching.
4) Peer teaching is a way for you to gain confidence in your science teaching abilities. Every opportunity to practice science teaching should help you see that you have developing knowledge, skills, and abilities to teach science.
5) Peer teaching allows you to experience science instruction from the viewpoint of your learners. You can think about what elementary students are likely to do in response to some of these teaching moves and about what sorts of ideas kids are likely to have.

Planning for Peer Teaching

Each week prior to the peer teaching section, we will set aside time for co-planning the upcoming elements of the lesson. We ask that you use the science version of the Instructional Planning Template to facilitate this co-planning of the elements of your lesson. Completing the sections of this template (using the annotated section of the template for guidance) will enable you to consider the many important pieces of a science lesson. While we imagine that you will focus on the portion of the lesson that you will teach the following week during your planning time,

Enacting and Debriefing the Peer Teaching

What do I do for the peer teaching in ED421? How is this organized?

The enactment of the lesson is when you and your colleagues have a chance to try out the teaching practices involved in the EEE framework. Each person will have the opportunity to teach a section of a lesson three times during the semester for 15 to 20 minutes. After the peer teacher has taught, everyone in the group will complete the Peer Teaching Focus Questions based on the peer teacher's enactment. Then, there will be a few minutes of debriefing as a group before the next person teaches.

What are the expectations for teachers and students?

Peer Teacher: During Enactment	Peer "Student": During Enactment
Be responsive to your learners Attend to whether your learning goals are being met Think about how your questions elicit student thinking Think about how your discourse moves orient students to each other and to the phenomenon Relax and don't be afraid to try out an unfamiliar teaching technique	Think like an elementary student and provide appropriate challenges for the teacher (e.g., common student misconceptions) Be skeptical yet convincible Participate thoughtfully! Don't mimic children's behavior issues or otherwise distract from the lesson Consider how your teacher's moves could be interpreted by elementary students

Peer Teacher: During Debriefing	Peer "Student": During Debriefing
Think critically about what was effective and less-than-effective about your teaching Be open to others' input Provide insight into what you were trying to accomplish or what you were struggling with Don't beat yourself up if something didn't work out like you thought it would—learn from it!	Refer to specific examples in offering constructive feedback for the peer teacher Provide the "student's perspective" on the enactment—what would an elementary student have been likely to think or do? Think about how you would have handled this teaching situation if you had been the teacher Consider what a student would want/need changed about the lesson enactment and why

Reflecting on Peer Teaching

Peer Teaching also offers an opportunity for you to discuss the portions of science lessons with your peers and a teacher educator after you enact each element. Then, we ask you to reflect on each Peer Teaching Element yourself afterward to consider how you might build on work you did in class and the discussion you have with your peers and the teacher education. This involves answering this set of questions:

1. What is one move that you made in your teaching or saw another intern do that you want to repeat or try? How would it support student learning?
2. What is one move in your teaching in need of revision? How would you revise it to better support student learning?
3. What is your main take-away point from the peer teaching activity?
4. How does your learning from this peer teaching activity connect to readings or discussions that we have had in class?

APPENDIX F: REFLECTIVE TEACHING ASSIGNMENT

EDU 421 Reflective Teaching Assignment

Due **Friday, December 13, 2013.**

Task & Rationale: You will teach a full science lesson in your practicum classroom this semester. For this reflective teaching (RT) assignment, you will use existing curriculum materials to analyze and adapt a science lesson, video record yourself teaching it to students in your placement classroom, reflect on your teaching, and analyze some student work. This reflective teaching assignment is intended to help you:

- apply your skills in lesson plan analysis and modification to a lesson you will actually teach in your field placement classroom
- build on your peer teaching experiences in ED421 and Experience-in-the-field, moving toward more complex and more authentic experiences with science teaching
- practice teaching science lessons effectively, including envisioning how long different elements will take and what conceptual and logistical issues are likely to arise
- learn how to use written student work to understand and assess students' ideas
- reflect on your lesson and students' work to figure out changes to make for the future
- co-plan with your mentor teacher, field instructor, and/or methods instructor

How should you plan, and what lesson should you teach?

In preparing to teach this lesson, you should find an **existing lesson plan**, rather than developing one from scratch. Your mentor teacher may give you a lesson to teach. If not, ask him or her for resources to help you find an appropriate lesson, or find one yourself (for example, use a lesson we've used in the methods class). Be sure to **talk with your mentor teacher** about your plans well in advance and tentatively schedule your lesson with your mentor teacher during your science teaching conversation. Be sure your mentor teacher understands what you plan to do, and has budgeted the necessary time. Also you need to **go through the investigation or activity in advance** with the actual materials you'll use in the classroom. Use this as a chance to anticipate any management issues that might come up and develop a plan for dealing with them.

Analyze and modify the lesson plan well in advance of the day you will be teaching. This way, you will be able to get input from your methods instructor, field instructor, and/or mentor teacher about any proposed changes.

If you can, you should turn in the Original Lesson Plan Analysis portion of the RT at least one week before you need to teach your lesson; if possible, your instructor will return it to you with feedback that you can incorporate into your lesson planning. Ideally, you'll be able to **co-plan** your lesson with your methods instructor, your field instructor, your mentor teacher, and/or a trusted colleague in the program. You will use the instructional planning template to develop a **lesson plan** for your lesson.

Your lesson should involve having students develop some kind of **written or physical artifact**. This could be a worksheet, a picture, a journal entry, a model, or anything else that you can analyze to get a sense of the students' ideas. You will be required to analyze this written student work, so be sure your lesson includes this feature.

This lesson should involve *engaging* the students with an investigation question or problem as well as the opportunity for students to *experience a natural phenomenon* (e.g., conducting an investigation about light, mixtures, living things, weather, rocks and minerals), and to *explain with evidence* (e.g., supporting students in making claims based on evidence or communicating and justifying findings).

Reflection on Reflective Teaching

After you've taught your lesson, reflect on your lesson enactment and on your students' work.

Answer the following questions in your written reflection:

- What went well? What didn't go so well? Refer to specific portions of your lesson plan.
- How did the timing go, compared to what you had planned? How did the anticipated logistical issues go? Had you planned adequately? What came up that you hadn't anticipated? Were the changes that you made to the lesson productive, with regard to meeting your learning goals?
- Did your students meet your learning goals? Analyze 4 examples of your students' work and make evidence-based assertions about their learning with regard to each of your learning goals (related to content or scientific practices).
- How well did your enactment go with regard to *engaging* students with an investigation question/problem, supporting them in *experiencing* the scientific phenomenon, and *explaining* the phenomenon with evidence? Provide evidence from the video enactment (short clips of 3-5 minutes) to support your discussion (of either strengths or missed opportunities) of the three elements. Please mark these on Edthena. As you have done this semester in your peer teaching experiences, you can use the following dimensions to guide your thinking.
  - Engage:
    - supporting the students to establish an investigation question or problem
    - eliciting students' initial explanations to the problem or question based on their prior knowledge and experiences
  - Experience:
    - supporting the students in establishing data collection
    - supporting the students in carrying out the investigation
  - Explain with evidence:
    - supporting students to make sense of the data
    - enabling students to use data as evidence to answer the original question or problem
    - providing opportunities for students to share their explanations with others
    - supporting students in applying their knowledge to new learning tasks
- To what extent do you feel that you promoted equitable learning opportunities for your students? Describe two instances that demonstrate either strengths or missed opportunities. You might consider how your use of the following equity practices supported you in promoting equitable learning opportunities:
  - selecting and enacting the activities with care
  - using scientific language in accessible and accurate ways, and helping children do so
  - using multiple representations of the ideas and making connections between representations
  - considering a broad conception of scientific expertise
  - being explicit about what might have been invisible to some learners (e.g., providing rationales for instructional decisions, unpacking terminology, having clear rules, being clear about what's invisible or otherwise inaccessible about the scientific phenomenon)
- To what extent do you feel that you represented the science content and practices you were teaching accurately and appropriately? Describe an instance of a place in your lesson where it was very important that you knew the science very well *or* an example of a place where you recognize that you needed to know the science better.
- What did you learn about science teaching from this experience? How did this experience connect with other things you have learned in the course? Did you meet, exceed, or fall short of your own expectations for yourself, including the goal(s) you were focusing on?
- What would you change next time?
- Please feel free to address anything else you think is relevant. Feel free to mark places on your video in Edthena where you have comments or questions.

APPENDIX G: INSTRUCTIONAL PLANNING CONSIDERATIONS

Instructional Planning Considerations

Consideration 1. Quality of Learning Goals

a. Are the learning goals **well-specified**? (Do they specify what students should know, understand, and/or be able to do as a result of engaging in the lesson[5]?)
b. Do the learning goals focus on **worthwhile content**[6]? (Are the learning goals important to learning the discipline; aligned with standards; useful in school, in life, and/or on the test?)
c. Does the lesson **connect** in a sensible **sequence** to other lessons within the unit, to develop a **coherent** storyline?

Consideration 2. Quality of Assessments

a. Are the assessments **aligned** with the main learning goals (including concepts, practices, and skills)?
b. Do the formative assessments enable the students and the teacher to **monitor progress** toward the learning goals?
c. Do the assessments provide **all students** the opportunity to show what they know, understand, and/or are able to do as a result of engaging in the instruction?

Consideration 3. Quality of the Instruction

a. Does the lesson provide high-quality opportunities for students to **participate with, reason about,** and **make sense of the content**?
b. Do the **representations of content** (i.e., explanations, illustrations, and analogies) support students' understandings of the concepts, practices and skills?
c. Are there opportunities for students to **share their ideas** throughout the lesson?
d. Are there opportunities for students to make **connections** among learning goals, activities, tasks, and ideas, within and across lessons?

Consideration 4. Learners in My Classroom

a. Does the lesson provide opportunities to **differentiate** instruction to ensure equitable access to learning for all of my students?
b. Does the lesson demonstrate an awareness of and appreciation for cultural differences and social diversity, draw on diversity as a resource in instruction, and help my students make meaningful **connections** between the content and their own lives?
c. Does the lesson make appropriate **assumptions** about prerequisite knowledge and skills, including knowledge of the concepts and vocabulary? Does the lesson communicate these assumptions and help me prepare my students so that they have equitable access to the learning opportunities?

Consideration 5. Classroom Management and Norms

a. Is the **timing** and pacing appropriate?
b. Is the distribution, use and collection of **materials** well-managed?
c. Are **participation structures** for students (e.g., whole group, small group, partner, individual) appropriate to the learning goals?

---

[5] Although the word "lesson" is used throughout the document, these considerations can also be applied to smaller tasks, larger units as well as other types of resources.

[6] "Content" throughout the document refers to concepts, procedures, ideas, and facts, as well as disciplinary practices (such as making predictions in science or constructing mathematical arguments in mathematics).

APPENDIX H: REFLECTIVE TEACHING AND STUDENT TEACHING LESSONS

Table H-1: Reflective Teaching Lessons for Focal Interns

Lessons	Potential Investigation Question/Focus[7]	Potential Data Analysis[6]	Potential Evidence-Based Claim[6]
Ms. Kelly Reflective Teaching Lesson: Evaporation	*What is happening to the water in our kettle when it disappears?*	Listing of observations from the water on the paper and the boiling water in kettle Noting of similarities and differences in the two experiences	**Claim:** The water on the paper and in the kettle turns to gas. **Evidence:** We saw the water on the paper seem to dry over time. We saw water in the kettle and steam coming from the kettle. **Reasoning:** The water is evaporating. It is turning from a liquid to a gas.
Ms. Atkin Reflective Teaching: Natural Selection	*How does the color of an organism affect its ability to survive?*	Graph or chart comparing the number of beads collected on the different cloths	***Claim:*** *I think the preys that are the same color as the habitat are more likely to survive.* ***Evidence:*** *I think this because at the end of the experiment, there were a greater number of preys that were the same color as the habitat.* **Reasoning:** Being the same color as the environment makes the prey camouflaged or more difficult to be noticed and be caught.
Mr. Cruise Reflective Teaching: Cycling in Ecosystems	*How are the relationships between Prairie organisms similar to those of organisms living on Isle Royale? What are some of the different ways we can represent those relationships?*	Food webs of different ecosystems Comparison of different food webs	*"I think that there are examples of producers, consumers, and recyclers in both of these ecosystems. These organisms interact in complex ways. We can represent these relationships using a food chain or a food web. I think this because my group identified a lot of the relationships that we talked about before the Isle Royale investigation and drew them in our science notebooks."*
Ms. Michaels Reflective Teaching: Sinking leaves	*Why does my leaf sink?*	Comparison of the number of pennies that sank the leaves Comparison of the mass of the pennies and the leaves (this lead to inaccurate claims)	*I think that my leaf will sink if the pennies on top weigh more than the leaf (claim).* *I think this because I tested my leaf with x-amount of pennies and the leaf sank. I then compared the weight of the leaf to the amount of pennies that sank it on my balance scale and found that the pennies weighed more.* **Reasoning: (inaccurate):** The greater weight causes an object to sink.
Ms. Schuster Reflective Teaching: Comparing Cereals	*How can different cereals help our bodies in different ways?*	Completion of data chart of calories, total fat, total carbohydrates, protein, and iron for several cereals Comparison of information across the different cereals	*I claim that life is a better source of iron compared to lucky charms and frosted flakes. I claim this because when comparing food labels life has 8.95mg or iron and frosted flakes has 7.13mg and lucky charms has 4.5mg. Because life is the best source of iron it will help transport iron to the rest of the body*

[7] Italized texted signifies that the interns wrote this within their lessons. Otherwise, this text is provided to give an example of what the potential questions, data analysis, and evidence-based claims might be.

Table H-2: Ms. Kelly's Lessons During Student Teaching

Lessons	Potential Investigation Question/Focus[8]	Potential Data Analysis[7]	Potential Evidence-Based Claim[7]
Ms. Kelly Field Lesson 1: What is a Fruit	What is a fruit?	Students could compare observations of different fruits to name common characteristics.	Claim: A fruit is the part of the plant with seeds. Fruits come in different shapes and sizes. Evidence: All of the fruits had seeds. Some of the fruits were large and some of the fruits were small. Some of the fruits were round and others were tubes. Reasoning: The fruit serves to protect and carry the seed. The seeds can become new plants.
Ms. Kelly Field Lesson 2: Force and Motion	What causes a toy car to move?	Students compile a list of the ways they had their car move. The list can be organized to show the car moved in two ways: a push or a pull	Claim: A push or a pull can move a toy car. Evidence: All of the ways that the toy car moved required a push or a pull. Reasoning.: A force moves objects. A force is a push or a pull.
Ms. Kelly Field Lesson 3: Big Forces and Small Forces	What happens to the speed of the car from a big force? What happens to the speed of the car from a little force?	Students compare the speed of the toy car when given a big force and when given a little force A chart or table could show the difference in force and speed	Claim: A big force causes the car to move fast. A little force causes the car to move slow. Evidence: When I gave the car a big push, the car moved fast. When I gave the car a big pull, the car moved fast. When I gave the car a little push, the car moved slow. When I gave the car a little pull, the car move slow. Reasoning: More force causes more speed (acceleration), so the bigger forces created bigger movements.

[8] This text is provided to give an example of what the potential questions, data analysis, and evidence-based claims might be.

Table H-3: Ms. Atkin's Lesson During Student Teaching

Lessons	Potential Investigation Question/Focus[9]	Potential Data Analysis[8]	Potential Evidence-Based Claim[8]
Ms. Atkin Field Lesson 1 Adding Batteries to Light a Circuit with a Household Lightbulb	What happens when you add more batteries to the simple complete circuit?	Comparing the brightness with more or less batteries Table or chart keeping track of the brightness with the number of batteries	Claim: When you add more batteries to the circuit, the brightness of the bulb increases. Evidence: Each time we added a battery, the bulb became brighter. When we removed a battery, the bulb became dimmer. Reasoning: The increasing batteries increases the voltage, which increases the brightness.
Ms. Atkin Field Lesson 2 Series and Parallel Circuits	What is the difference between types of circuits (batteries in series, batteries in parallel, bulbs in series, and bulbs in parallel) in terms of the brightness of the bulb?	Comparison of the brightness of the bulb in the different circuits to a standardized circuit Organization of data into a table to show the differences in the brightness of the bulb for the different circuit	Claim: Arranging a circuit in parallel does not affect the brightness of the bulb. Arranging a circuit in series does affect the brightness of the bulb. Evidence: The bulb in two batteries in series was brighter than the standardized circuit. The bulb in two bulbs in series was dimmer than the standardized circuit. The bulb in the parallel circuits was the same as the standardized circuit. Reasoning: In a series circuit, the electric current flows in one path and the energy is split among the bulb. In a parallel circuit, the electric current flows in two paths and the same among of electric energy flows through both paths.

[9] This text is provided to give an example of what the potential questions, data analysis, and evidence-based claims might be

Table H-5: Mr. Cruise's Lessons during Student Teaching

Lessons	Potential Investigation Question/Focus[10]	Potential Data Analysis[9]	Potential Evidence-Based Claim[9]
Mr. Cruise Field Lesson 1: Fresh Water and Salt Water	What kinds of water sources are there on the Earth?	Chart listing water sources and the type of water (fresh or salt) Analysis of the model of fresh and salt water (with gallons of water); Comparison of the prediction with the model	Claim: There is a small amount of surface fresh water on the Earth and a large amount of surface salt water. Evidence: I saw from the model that there is one drop of fresh water compared to 10 gallons of salt water. Reasoning: The oceans take-up a large amount of space on the surface of the Earth.
Mr. Cruise Field Lesson 2:	How does water move through the ground and collect under the surface of the Earth	Analysis of a physical model of an aquifer Comparison of predictions with physical model Table that summarizes observations from the model	Claim: Water moves through the soil and accumulates in the rocky layer. Evidence: I saw the water move from the surface down through the layers of the soil. I saw the water in a puddle in the rocky layer in the model. Reasoning: The soil is porous and let the water move through it. The gravity pulls the water down.
Mr. Cruise Field Lesson 3:	What kinds of pollution can you find around the schoolyard?	Table compiling the examples of pollution to reveal patterns and common characteristics	Claim: There are multiple kinds of pollution found in the school yard. The most common type is _____. Evidence: We found ___, ___, and ___ pollution. There was more ___ than any other type. Reasoning: These items are pollutants because they can harm the living things in the environment.
Mr. Cruise Field Lesson 4:	How well does a coffee filter remove pollutants from water?	Comparison of observations from before and after filtering with coffee filter Chart comparing the different pollutants	Claim: The coffee filter could remove some of the pollutants but other pollutants remained in the water. Evidence: The plastic in the water was removed with the coffee filter. The soap bubbles were still in the water after it went through the filter. Reasoning: Different pollutants have different qualities that allow them to dissolve or stay in the water.

[10] This text is provided to give an example of what the potential questions, data analysis, and evidence-based claims might be

Table H-6: Ms. Michael's Lessons During Student Teaching

Lessons	Potential Investigation Question/Focus[11]	Potential Data Analysis[10]	Potential Evidence-Based Claim[10]
Ms. Michaels Field Lesson 1:	How do we use our senses to describe the popcorn?	Chart with observations collected by the different senses	Claim: Our different senses allowed us to notice different things about the popcorn. Evidence: We could see that the popcorn was white. We could hear the popcorn pop. We could feel that the popcorn was rough. We could smell that the popcorn was salty. We could taste the popcorn tasted like popcorn. Reasoning: Our senses allow us to learn about the world around us.
Ms. Michaels Field Lesson 2:	What noises can we hear as we walk through the hallway?	Chart with different noises and organization into categories.	Claim: We could hear many different noises as we walked through the hallway. Evidence: We heard children running. We heard pencils moving. We heard the locker door close. We hear people walking. Reasoning: Our hearing allows us to notice what is going on in the word around us. Without our hearing, we would struggle to tell what is going on.

[11] This text is provided to give an example of what the potential questions, data analysis, and evidence-based claims might be.

APPENDIX I: INSTRUCTIONAL PLANNING TEMPLATE

ED421 Elementary Science Methods

INSTRUCTIONAL PLANNING TEMPLATE

for planning science lessons

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

Learning Goals (1-2 in each)	Connection to Standards (Michigan GLCEs and/or Next Generation Science Standards)	Connection to Activities
SCIENCE CONTENT / CORE DISCIPLINARY IDEAS Students will be able to…		
SCIENTIFIC PRACTICES Students will be able to…		
IF APPLICABLE: CROSSCUTTING CONCEPTS Students will be able to…		
IF PREFERRED: You may integrate your learning goal statement (core disciplinary idea x scientific practice x crosscutting concept)		

EEE Connection	
Investigation question students will answer:	
Claim with evidence you hope students will generate:	I think ___________ (claim). I think this because I've seen or done _______________ (evidence).

Attending to the Learners

Anticipating student ideas, including alternative ideas, misconceptions, and prior knowledge:	
Making the content accessible to all students, including using specific equity practices from class:	

Assessments

Type of Assessment	Learning-Goals Connection

Instructional Sequence

Materials:	

Instructional Sequence: Engage Element

	Steps for Engage Element	
Time	The teacher will:	The students will:

Management Considerations for Engage Element:

Instructional Sequence: Experience Element

	Steps for Experience Element	
Time	The teacher will:	The students will:

Management Considerations for Experience Element:

Instructional Sequence: Explain Element

	Steps for Explain Element	
Time	The teacher will:	The students will:

Management Considerations for Explain Element:

Reflection on Planning

Learning goal for self:	
Preparing to teach this lesson:	

APPENDIX J: SURVEY

Survey Questions

1) Which of the following is a scientific explanation? (Choose one.)

a. I think that if I drop a bowling ball and a donut from the same height at the same time, the bowling ball will hit the ground first because it is heavier.
b. Cold metallic objects placed in warm, humid air form a layer of condensation on their surfaces.
c. Minerals are smaller than rocks because rocks are made of minerals.
d. Plants need water and sun to survive. I think this because the plants we tried to grow without water, sun, or both water and sun did not remain alive.
e. The Huron river was formed by glacial movement.
f. Science is the best elementary subject ever.

2) At the end of an investigation with the question: "How does fertilizer pollution affect the plants and algae in an aquarium?" A student shares his scientific explanation as:
The fertilizer pollution caused my plants to die.
You see that the aquatic plants are turning brown and losing their leaves. What might you say to the student?

a. Did this confirm or deny your prediction from the beginning of the investigation?
b. What happened to the water in your ecosystem?
c. The fertilizer should have caused your plants to grow.
d. What evidence do you see in your aquarium that makes you think this?

3) During an investigation of how living things and nonliving things interact with each other in a terrarium you collect your students' written observations of their constructed terrariums including worms, crickets, and a variety of plants. Here are some examples of students' statements:

1) The plant is dead.
2) The cricket is eating the leaf.
3) The roots got bigger.
4) The worm is cool!

What are categories you might use to provide feedback to students about their written observations?

a) objective
b) answers the investigation question
c) creative
d) correct grammar and spelling
e) specific
f) organized structure

4) How would you explain what a scientific explanation is to an elementary student?

5) How would you describe what a scientific prediction is to an elementary student?

6) What are important features of a question being used for an investigation in science?

7) Why is it important to engage students in collecting and analyzing their own data during an investigation?

8) Why is it important to have students construct evidence-based claims in science?

9) In a fifth grade classroom, some students were studying the life cycle of mosquitoes. They learned that mosquito larvae and pupae spend part of their time at the surface of water.

The students wanted to find out how a larva and pupa behaved when the jars they were in were disturbed. They put one larva and one pupa in identical tall jars of water at 20°C.

The students tapped on the jars when the larva and pupa were at the surface of the water. The larva and pupa dove down into the jars, and then slowly came to the surface.

The students measured the depth each larva and pupa reached and the amount of time each stayed underwater. The students repeated this step five times and calculated the average of each of their measurements.

Their results are summarized in the table below.

DATA TABLE

Number of Trials	Larva		Pupa	
	Average Depth Reached (centimeters)	Average Length of Time Underwater (seconds)	Average Depth Reached (centimeters)	Average Length of Time Underwater (seconds)
5	22	90	38	120

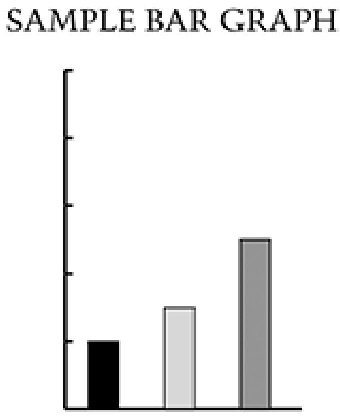
The students have an investigation question of "What are the differences in diving behaviors of between the papa and larvae when disturbed?"

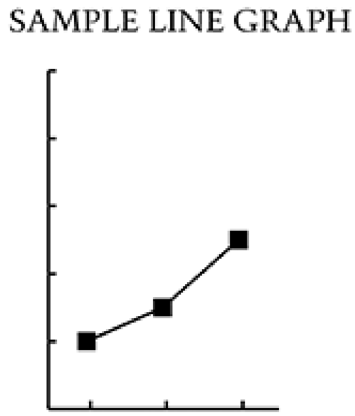
What evidence-based claim do you expect students to write for this question?

10) What criteria would use you to assess the students' evidence-based claim?

11) You will use the data in the table to create two graphs to compare the behaviors of the larva and the pupa.

Which graph format would be best to use for both graphs?





A. Bar graph

B. Line graph

12) Explain why you think this graph format would be best for the information in this table.

13) Name two challenges that upper elementary students may face in constructing a graph and interpreting a graph for this data. How would you help students in these challenges?

14) Name two challenges that upper elementary grade students may face in constructing an evidence-based claim about this data? How would you help students in these challenges?

APPENDIX K: STANDARDIZED STUDENT PROTOCOL

Thank you for meeting with me today.

The goal for the interview today is to find out more about your thinking about how you might teach science to elementary children. We will do this by enacting a simulation where I will act like a student similar to peer teaching. This interview has nothing to do with your grades for the course. While you may not receive a direct benefit from participating in this research, some people find sharing their stories to be a valuable experience. We also hope that this study will contribute to understanding how people learn to teach in order to better support this learning in the future.

You may choose not to answer any interview question and you can stop your participation in the research at any time. We plan to publish the results of this study, but will not include any information that would identify you. If you have questions about this research, you can contact …… at any time.

By giving verbal consent, you are agreeing to be part of the study. Participating in this research is completely voluntary. Even if you decide to participate now, you may change your mind and stop at any time. Do you give verbal consent to be a part of this interview?

I am starting the video camera/audio recorder now... (turn on camera/recorder)

Today you will be working with me acting as a simulated fifth grade student who is learning about the conservation of matter. You will be acting as a fifth grade teacher. You can see the standard on the page.

Prior to this class period session, the students have done a set of investigations about matter, and the class has decided on a set of scientifically accurate claims that are the first page.

You have had a chance to think about how to teach this lesson beforehand. This the pre-assessment you completed for class.

Your task is to plan for supporting a student to make sense the data collected by the three groups during the investigation to answer the investigation questions. You have already completed questions to guide your planning. Here is additional paper and markers for writing or drawing anything that you might use for your plan. Then, you will interact with a simulated Student One from Group A using your plan. Take some time now to review your plan and decide what you would like to do.

Packet One: Directions

You are working with 5th Grade Students on the Big Idea of Conservation of Matter using the Standard:

5-PS1-2. Measure and graph quantities to provide evidence that regardless of the type of change that occurs when heating, cooling, or mixing substances, the total weight of matter is conserved.

Prior to this class period, your class has investigated the properties of matter.
Here are some of the key scientifically-accurate claims that you have agreed on as a class:

- Matter takes up space and has weight (mass).
- Different materials have different properties. Examples of properties include hardness, response to magnetic force, and color.
- Different materials can be mixed together in different ways.
    - A mixture is a combination of two or more materials.
    - A solution is a mixture in which one material, such as a solid, combines with another materials, such as a liquid, so that you can't tell one material from the other.

Your class has the investigation question of:
"How does the weight of a solution compare to the weight of the materials used to make up the solution?"

You did this investigation as a class:

Materials:

- Salt in a plastic cup
- Magnifying lens
- 150 mL water in a plastic cup
- Spoon
- Stirrer
- Scale

Procedures.

1. Make a prediction by answering question 1.
2. Look at the salt with a magnifier. Describe it on your paper.
3. Look at the water in the cup. Describe it on your paper.
4. Record data before mixing the salt and water.
    - Weigh the cup of water on the scale, and record the weight on the data table
    - Weigh the cup of salt on the scale, and record the weight on the data table
5. Make a solution by mixing the salt and the water.
    a. Use the spoon to drop a little salt into the water.
    b. Use a stirring stick to mix the salt in the water.
    c. Continue to add small amounts of salt to the solution. Stir the mixture every time.
    d. Make sure you have mixed all of the salt with the water.
6. Describe the solution of salt and water on your paper.
7. Record data after mixing the salt and water
    - Weigh the cup of salt and water, record the weight
    - Weigh the cup that had salt in it, record the weight

Your Task: You are asked to plan for supporting a student to make sense of the data collected by three groups during investigation to answer the investigation question. The student work is in the packets provided. Then, you will interact with Student One from Group A using your plan. You have 25 minutes to plan using the questions provided.

Student One Prediction Sheet:

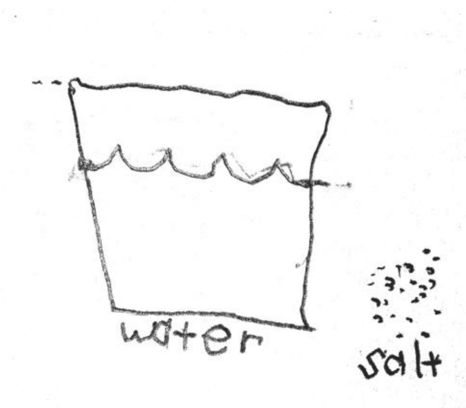
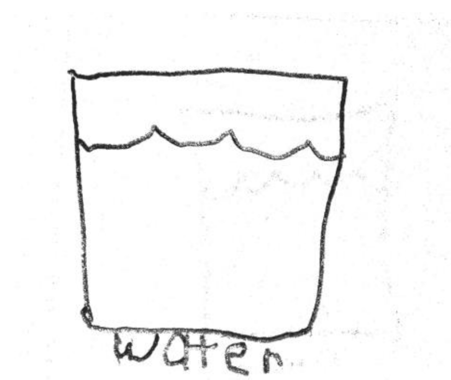
1) Kevin has a packet of salt and a glass of warm water. The glass of water weighs 100 g. The salt weighs 10 g. He mixes the salt and water together. What do you think the mixture of salt and water will weigh?

The mixture will weigh 100g.

Why do you think this?

The salt will disappear in the water. When I mixed salt in water before, I couldn't see it anymore.

Draw your prediction here:

Before mixing	After mixing
	

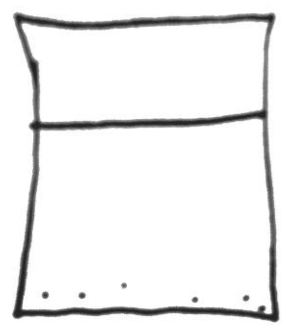
Student Two Prediction Sheet:
Kevin has a packet of salt and a glass of warm water. The glass of water weighs 100 g. The salt weighs 10 g. He mixes the salt and water together. What do you think the mixture of salt and water will weigh?

The mixture will weigh 105g.

Why do you think this?

Some of the salt will dissolve in the water.

Draw your prediction here:

Before mixing	After mixing
	

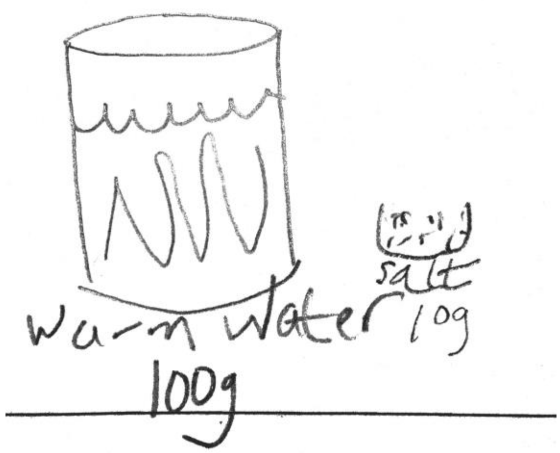
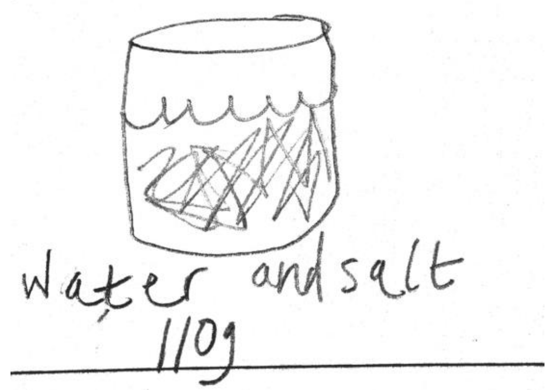
Student Three Prediction Sheet:
Kevin has a packet of salt and a glass of warm water. The glass of water weighs 100 g. The salt weighs 10 g. He mixes the salt and water together. What do you think the mixture of salt and water will weigh?

The mixture will weigh 110g.

Why do you think this?

You’re not adding or taking anything out when you make the solution, so it will be the same.

Draw your prediction here:

<table>
<tr><th>Before mixing</th><th>After mixing</th></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Group A Data Sheet:

2. Observations of the salt with a magnifier glass: small, white, hard

3. Observations of the water: clear, liquid, wet

4. Before mixing salt and water:

Weight of water and its cup	Weight of salt and its cup
400 g	25 g

6. Observations of the salt mixed with the water: see-through, liquid, the salt disappeared in the water

7. After mixing salt and water:

Weight of water and its cup after salt has been added	Weight of cup
415 g	10 g

Group B Data Sheet:

2. Observations of the salt with a magnifier glass: powdery, white, square, light, looks like sugar, would be good on French-fries

3. Observations of the water: see-through, I like to drink it, watery

4. Before mixing salt and water:

Weight of water and its cup	Weight of salt and its cup
400 g	30 g

6. Observations of the salt mixed with the water: water is cloudy, see-through, liquid

7. After mixing salt and water:

Weight of water and its cup after salt has been added	Weight of cup
420 g	10 g

Group C Data Sheet:

2. Observations of the salt with a magnifier glass: solid, white, crystals

3. Observations of the water: transparent, clear, liquid

4. Before mixing salt and water:

Weight of water and its cup	Weight of salt and its cup
405 g	25 g

6. Observations of the salt mixed with the water: transparent, clear, liquid

7. After mixing salt and water:

Weight of water and its cup after salt has been added	Weight of cup
420 g	10 g

Planning: (You will be working with Student One from Group A to help them make sense of all of the groups' data from the investigation.)

1) What is the answer to the investigation question?

2) How did you make sense of the data to answer the investigation question? (You can make a chart, graph, or diagram to help you describe your thinking.)

3) What challenges might students have in answering the investigation question and making sense of this data?

4) What might students be able to do easily in answering the investigation question and making sense of this data??

5) Sketch out a plan for yourself for how you will help Student A make sense of the data and answer the investigation question. You can write down the questions or moves you will use. You may also want to write any tables, graphs or diagrams you might want to use to help the student. (you can use your notes and any resources you create. There is paper, etc to create things).

Introductory Script for One-on-one session

You are going to be working a simulated fifth grade student named Sarah

The purpose of this activity is for you to support Sarah in making sense of the data from the 3 groups to answer the investigation question. Because Sarah is simulated student, you do not have to have a conversation to break the ice with the student, you can just begin by jumping into the work at hand.
Here are copies of the student work, paper and markers that you are welcome to use. You can also use any notes or instructional materials you created during your planning. When you feel that Sarah is able to answer the investigation question appropriately based on the data, you just say something like "I'm finished".

I'm going to video record this session in case we have any questions.

Do you have any questions before we get started?

Ok, you can start when you are ready…..

Protocol for Standardized Student

Line of Thinking: You think that the salt disappeared in the water because you cannot see the salt in the water. You have the alternative idea represented by Student Prediction Sheet One.

When responding to the interns:

1) Do not provide additional information beyond the question asked.
2) You can be convinced if data is provided.
3) Do not write something down unless asked.
4) You can do the math properly.
5) You can ask the intern to restate the question if unclear.

Type of Question	Intern Asks	Response
Initial Questions	"What is the answer to the investigation question?"	It weighs less
	"Where do you see this answer in the data?"	The number at the end is less than the salt and the water
	Why? – why does that happen? Or Why do you think that?	The salt disappeared
	What patterns do you see in the data across groups	my groups is less than the others
	"What do you mean?	My group have less number than other groups – point to the numbers (answer others only if asked)
	what pattern they see between the first and second time?	For mine, the salt and water separately weigh more than them together (answer others only if asked)
	What was your hypothesis	I thought that the salt would disappear in the water. (show paper)
	What did you learn before	respond based on the front info on the paper
	Was your hypothesis right	Yes the salt did disappear
Final Questions	What is the answer (if told so)	It doesn't change
	Why do you think that?	Repeat what was learned

Questions for After the Interaction

1) Do you think that the student appropriately answered the investigation question? Why do you think this?
2) What do think this student thought happened during the investigation? Why do you think this?
3) What challenges did you expect the student to have in making sense of the data? How did you plan for responding to these challenges? Why?
4) What moves that you made do you feel were productive in supporting the students to make sense of the data? Why?
5) What moves that you made do you wish you could change? Why?
6) Why did you make this representation or resource? why did choose this particular resources?
7) What would you do next to support the students' learning? Why?

Other Questions:

1) What have you learned about science teaching from science methods? (Probing questions: Can you give me an example? Why do you think you learned that? How did peer teaching go? What has been helpful? What has not been productive?)
2) Is there anything else that you would like to tell me about science teaching?

APPENDIX L: INTERVIEW PROTOCOL

First read the Consent participate paragraph:
You are invited to be a part of a research study that looks at how teachers support learn to teach elementary science. The purpose of the study is to understand how teachers learn to teach in order to design better teacher education courses. We are asking you to participate because you are an undergraduate student in the Teacher Education Program at the University of Michigan.

If you agree to be part of the research study, you will be asked to participate in one to four face-to-face interviews at the School of Education. Each interview should take about one hour. We would like to audiotape the interview to make sure that our conversation is recorded accurately. The discussion topics include how you see your learning to teacher elementary science and what you see as contributing to this learning. You may also be asked to describe or enact how you would teach part of lesson and why you would make these decisions. In addition to interviews, we would like to videotape some of your lessons during student teaching.

While you may not receive a direct benefit from participating in this research, some people find sharing their stories to be a valuable experience. We hope that this study will contribute to understanding how people learn to teach in order to better support this learning in the future.

You may choose not to answer any interview question and you can stop your participation in the research at any time. We plan to publish the results of this study, but will not include any information that would identify you. If you have questions about this research, including questions about the scheduling of your interview, you can contact Anna Arias.

Define data, evidence
Data—information that has not yet been analyzed or processed; typically gathered through observation or measurement.
Evidence—analyzed or processed data that are used to support a scientific claim or conclusion.
Claims – a statement that answer an investigation question or makes an assertion based on information.

[Hand scenario to intern and have them scenario one]

Interns' knowledge of constructing evidence-based claims and supporting elementary students in this practice based a scenario I: *A teacher plans an elementary science lesson to help second graders learn about how sunlight helps a plant grow. She plans to have the students grow two sets of plants, one near the window and one in the closet. Students will record measurements of the height of these plants and make observations over the course of two weeks. She plans to help the students make sense of the data and make claims based on the data after the two weeks.*

Interview Question
1) Do you think that the second graders can make sense of data to make claims? a. Why or why not? b. If yes, do you it is important to have students make sense of the data and identify claims? Why? 2) How would you help the second graders make sense of the

data and identify claims?

   a. What instructional moves would you use?
   b. What kinds of chart, graphs would you create?
   c. What kinds of questions would you ask?
   d. Why would you do this to support the students?

3) What challenges do you think that second graders would have in making sense of the data and identify claims?
   a. Can you provide a specific example of this challenge?
   b. Why do you think the second graders would have this challenge?
   c. How would you help second graders with this challenge?
   d. Why would help in this way?

[Have intern read scenario two]

Interns' knowledge of constructing evidence-based claims and supporting elementary students in this practice based a scenario 2: *A teacher is planning a science lesson where 5^{th} graders investigate how the length of a shadow changes over course of the day. The teacher plans to have the students measure their shadow at different times during the day. She also plans to have the 5^{th} graders make observations when modeling how the length of a shadow might change for a pin on a spinning ball with a lamp to help them envision the mechanism involved.*

Interview Question

1) Do you think that the 5th can make sense of data they will collect in this lesson?
   a. Why or why not?
   b. If yes, do you it is important to have students make sense of the data and identify claims? Why?
2) What would you do differently to support the 5^{th} grade students as compared to the 2^{nd} graders?
   a. Can you give specific examples?
   b. Why would you do these things differently?
3) What would you do the same to the 5^{th} grade students as compared to the 2^{nd} grade students?
   a. Can you give specific examples?
   b. Why would you do these things the same?
   c.

Interns' description of their learning

Interview Question

1) How has your knowledge about how to support elementary students to make sense of data and construct claims (like you described in the scenarios above) changed since you have started the program? Probes:
    a. Can you give a specific example?
    b. Why do you think this has changed?
    c. Where did you learn this knowledge?
2) How has your practice for support elementary students to make sense of data and construct claims changed since you have started the program? How has what you would do changed over time? (or from one time point to another in the program?) Probes:
    a. Can you give a specific example?
    b. Why do you think this has changed?
    c. Where did you learn to do this?
3) Will you please order these cards from most influential to least influential in learning about how to support elementary students to make sense of data and construct claims? Discussions in science methods class, completing science methods assignments, peer teaching, Children as Sensemakers classes, observing science lessons in the field; being an elementary student, science courses in college/high school, working with students at camp/babysitting; educational psychology course; teaching science lesson during student teaching, other [Give intern the cards]
    a. Questions for probing: Probe – can you tell me a little more about……; can you give me an example, which class discussions, readings? Why was this influential?

Interns' experience observing science teaching in the field

Interview Question

1) Describe how you planned to teach the last science lesson that you taught in the field.
    a. What instructional moves did you plan?
    b. Why did you plan to use these moves?
    c. Did the lesson plan include an explain with evidence element?
    d. If yes, describe this part and moves you planned
2) Describe how you taught this science lesson.
    a. What instructional moves did you use?
    b. Why did you use these moves with your student?
    c. What moves seemed productive? Why?
    d. What moves would you have revised? Why?
    e. Did the lesson include an explain with evidence element?
    f. If yes, describe this part and the moves you planned? (return back to letter a-d)

3) Consider the science lesson where you feel you had the most success. Describe how you planned to teach the last science lesson that you taught in the field.
    a. What instructional moves did you plan?
    b. Why did you plan to use these moves?
    c. Did the lesson plan include an explain with evidence element?
    d. If yes, describe this part and moves you planned
4) Describe how you taught this science lesson.
    a. What instructional moves did you use?
    b. Why did you use these moves with your student?
    c. What moves seemed productive? Why?
    d. What moves would you have revised? Why?
    e. Did the lesson include an explain with evidence element?
    f. If yes, describe this part and the moves you planned? (return back to letter a-d)
5) What did you think you learned about supporting elementary student to construct evidence-based claims from your teaching?
    a. Can you give specific examples?
    b. Why do you these pieces are important?

Any other thoughts or concerns that you want to share with me about science teaching?

REFERENCES

Abell, S. K. (2007). Research on science teacher knowledge. In S. K. Abell & N. Lederman (Eds.), *Handbook of research on science education* (pp. 1105–1149). Mahwah, NJ: Lawrence Erlbaum Associates.

Anderson, L. M., Smith, D. C., & Peasley, K. (2000). Integrating learner and learning concerns: prospective elementary science teachers' paths and progress. *Teaching and Teacher Education*, *16*(5–6), 547–574.

Appleton, K. (2007). Elementary science education. In S. K. Abell & N. Lederman (Eds.), *Handbook of research on science education* (pp. 493–535). Mahwah, NJ: Lawrence Erlbaum Associates.

Arzi, H. J., & White, R. T. (2008). Change in teachers' knowledge of subject matter: A 17-year longitudinal study. *Science Education*, *92*, 221–251.

Avraamidou, L., & Zembal-Saul, C. (2005). Giving priority to evidence in science teaching: A first-year elementary teacher's specialized practices and knowledge. *Journal of Research in Science Teaching*, *42*(9), 965–986.

Avraamidou, L., & Zembal-Saul, C. (2010). In search of well-started beginning science teachers: Insights from two first-year elementary teachers. *Journal of Research in Science Teaching*, *47*(6), 661–686.

Ball, D. L., & Cohen, D. K. (1996). Reform by the book: What is - or might Be - the role of curriculum materials in teacher learning and instructional reforms? *Educational Researcher*, *25*(9), 6–8, 14.

Ball, D. L., & Cohen, D. K. (1999). Developing practice, developing practitioners: Toward a practice-based theory of professional education. In *Teaching as the learning profession* (pp. 3–31). San Francisco: Jossey-BAss.

Ball, D. L., & Forzani, F. (2009). The work of teaching and the challenge for teacher education. *Journal of Teacher Education*, *60*(5), 497–511.

Ball, D. L., Sleep, L., Boerst, T. A., & Bass, H. (2009). Combining the development of practice and the practice of development in teacher education. *The Elementary School Journal*, *109*(5), 458–474.

Ball, D. L., Thames, M., & Phelps, G. (2008). Content knowledge for teaching: What makes it special? *Journal of Teacher Education*, *29*(5), 389–407.

Banilower, E. R., Smith, P. S., Weiss, I. R., Malzahn, K. A., Campbell, K. M., & Weis, A. M. (2013). *Report of the 2012 national survey of science and mathematics education*. Chapell Hill, NC: Horizon Research, Inc.

Bell, P. (2000). Scientific arguments as learning artifacts: designing for learning from the web with KIE. *International Journal of Science Education*, *22*(8), 797–817.

Bell, P., Bricker, L., Tzou, C., Lee, T., & Van Horne, K. (2012). Exploring the science framework: Engaging learner in scientific practices related to obtaining, evaluating, and communicating data. *NSTA Publications*, *November*.

Benedict-Chambers, A. (2014). Developing professional vision for practice: Preservice teachers using students' scientific ideas in simulations of practice. University of Michigan, Ann Arbor.

Berland, L. K., & McNeill, K. L. (2010). A learning progression for scientific argumentation: Understanding student work and designing supportive instructional contexts. *Science Education*, *94*(5), 765–793.

Berland, L. K., & McNeill, K. L. (2012). For whom is argument and explanation a necessary distinction? A response to Osborne and Patterson. *Science Education*, *96*(5), 808–813.

Berland, L. K., & Reiser, B. J. (2009). Making sense of argumentation and explanation. *Science Education*, *93*(1), 26–55.

Berland, L. K., & Reiser, B. J. (2011). Classroom communities' adaptations of the practice of scientific argumentation. *Science Education*, *95*(2), 191–216. http://doi.org/10.1002/sce.20420

Beyer, C. J. (2009). *Using reform-based criteria to support the development of preservice elementary teachers' pedagogical design capacity for analyzing science curriculum materials*. University of Michigan: Unpublished dissertation.

Beyer, C. J., & Davis, E. A. (2006). Characterizing the quality of second-graders' observations and explanations to inform the design of educative curriculum materials (pp. 43–49). Bloomington, Indiana: International Society of the Learning Sciences.

Beyer, C. J., & Davis, E. A. (2008). Fostering second graders' scientific explanations: A beginning elementary teacher's knowledge, beliefs, and practice. *Journal of the Learning Sciences*, *17*(3), 381–414.

Beyer, C. J., & Davis, E. A. (2009a). Supporting preservice elementary teachers' critique and adaptation of science lesson plans using educative curriculum materials. *Journal of Science Teacher Education*, *20*, 517–536.

Beyer, C. J., & Davis, E. A. (2009b). Using educative curriculum materials to support preservice elementary teachers' curricular planning: A comparison between two different forms of support. *Curriculum Inquiry*, *39*(5), 679–703.

Beyer, C. J., Delgado, C., Davis, E. A., & Krajcik, J. S. (2009). Investigating teacher learning supports in high school biology curricular programs to inform the design of educative curriculum materials. *Journal of Research in Science Teaching*, *46*(9), 977–998.

Bianchini, J. A., & Brenner, M. E. (2010). The role of induction in learning to teach toward equity: A study of beginning science and mathematics teachers. *Science Education*, *94*(1), 164–195.

Biggers, M., Forbes, C. T., & Zangori, L. (2013). Elementary teachers' curriculum design and pedagogical reasoning for supporting students' comparison and evaluation of evidence-based explanations. *The Elementary School Journal*, *114*(1), 48–72. http://doi.org/10.1086/670738

Bismack, A. S., Arias, A. M., Davis, E. A., & Palincsar, A. S. (2014). Connecting curriculum materials and teachers: Elementary science teachers' enactment of a reform-based curricular unit. *Journal of Science Teacher Education*, *25*, 489–512.

Bismack, A. S., Arias, A. M., Davis, E. A., & Palincsar, A. S. (2015). Seeking "trickle down": Examining student work for evidence of teacher uptake of educative curriculum materials. *Journal of Research in Science Teaching*.

Black, P., & Wiliam, D. (1998). Assessment and classroom learning. *Assessment in Education: Principles, Policy & Practice*, *5*(1), 7–74.

Blumenfeld, P., Kemplar, T., & Krajcik, J. S. (2006). Motivation and cognitive engagement in learning environments. In *Cambridge handbook of the learning sciences*. New York: Cambridge.

Blumenfeld, P., & Meece, J. L. (1988). Task factors, teacher behavior, and students' involvement and use of learning strategies in science. *The Elementary School Journal*, *88*(3), 235–250.

Boerst, T. A. (2013, April). *Assessments within the Undergraduate Teacher Education Program*. Presented at the TeachingWorks Colloquium, University of Michigan.

Boerst, T. A., Ball, D. L., Shaughnessy, M., Sleep, L., & Lai, Y. (2012). Designing and using simulations to assess preservice teachers' enacted mathematics teaching practice. Presented at the Association of Mathematics Teacher Educators.

Boerst, T. A., Sleep, L., Ball, D. L., & Bass, H. (2011). Preparing teachers to lead mathematics discussions. *Teachers College Record*, *113*(12), 2844–2877.

Borko, H., Jacobs, J., Eiteljorg, E., & Pittman, M. E. (2008). Video as a tool for fostering productive discussions in mathematics professional development. *Teaching and Teacher Education*, *24*(2), 417–436.

Braaten, M., & Windschitl, M. (2011). Working toward a stronger conceptualization of scientific explanation for science education. *Science Education*, *95*(4), 639–669.

Bricker, L. A., & Bell, P. (2008). Conceptualizations of argumentation from science studies and the learning sciences and their implications for the practices of science education. *Science Education*, *92*(3), 473–498.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*(1), 32–42.

Brown, M. W. (2009). The teacher-tool relationship: Theorizing the design and use of curriculum materials. In J. T. Remillard, B. A. Herbel-Eisenmann, & G. M. Lloyd (Eds.), *Mathematics Teachers at Work: Connecting Curriculum Materials and Classroom Instruction*. New York and London: Routledge.

Bryan, L. A., & Abell, S. K. (1999). Development of professional knowledge in learning to teach elementary science. *Journal of Research in Science Teaching*, *36*(2), 121–139.

Cervetti, G. N., Kulikowich, J. M., & Bravo, M. A. (2014). The effects of educative curriculum materials on teachers' use of instructional strategies for English language learners in science and on student learning. *Contemporary Educational Psychology*.

Cochran-Smith, M., & Lytle, S. L. (1999). Relationships of Knowledge and Practice: Teacher Learning in Communities. *Review of Research in Education*, *24*, 249–305.

Cohen, D. K., Gates, K., Glazer, J., Goldin, S., Moffitt, S. L., & Peurach, D. (2010). Policy, Practice, and School Improvement.

Collopy, R. (2003). Curriculum materials as a professional development tool: How a mathematics textbook affected two teachers' learning. *The Elementary School Journal*, *103*(3), 287–311.

Cook, S. D. N., & Brown, J. S. (1999). Bridging Epistemologies: The Generative Dance between Organizational Knowledge and Organizational Knowing. *Organization Science*, *10*(4), pp. 381–400.

Crawford, B. A. (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching*, *37*(9), 916–937.

Davis, E. A. (2006). Characterizing productive reflection among preservice elementary teachers: Seeing what matters. *Teaching and Teacher Education*, *22*(3), 281 – 301.

Davis, E. A., & Boerst, T. A. (2014). *Designing elementary teacher education to prepare well-started beginners* (TeachingWorks Working Papers). University of Michigan: TeachingWorks.

Davis, E. A., & Krajcik, J. S. (2005). Designing educative curriculum materials to promote teacher learning. *Educational Researcher*, *34*(3), 3–14.

Davis, E. A., Palincsar, A. S., Arias, A. M., Schultz, A., Marulis, L., & Iwashyna, S. (2012). Designing educative curriculum materials: Characterizing a process building on complementary sources of influence. Presented at the annual meeting of the American Educational Research Association, Vancouver, Canada.

Davis, E. A., & Petish, D. (2005). Real-world applications and instructional representations among prospective elementary science teachers, *16*, 263–286.

Davis, E. A., Petish, D., & Smithey, J. (2006). Challenges new science teachers face. *Review of Educational Research*, *76*(4), 607–651.

Davis, E. A., & Smithey, J. (2009). Beginning teachers moving toward effective elementary science teaching. *Science Education*, *93*(4), 745–770.

Dewey, J. (1900). *The School and Society*. Chicago: The University of Chicago Press.

Dewey, J. (1965). The relation of theory to practice in teacher education. In *Teacher education in America: A documentary history* (pp. 140–171). New York: Teachers College Press.

Duschl, R. A., & Osborne, J. (2002). Supporting and Promoting Argumentation Discourse in Science Education. *Studies in Science Education*, *38*(1), 39–72.

Eberbach, C., & Crowley, K. (2009). From everyday to scientific observation: How children learn to observe the biologist's world. *Review of Educational Research*, *79*(1), 39–68.

Eisenhart, M. S. (2009). Generalization from qualitative inquiry. In D. Erickan & W.-M. Roth (Eds.), *Generalizing from Educational Research*. New York: Routledge.

Enfield, M., Smith, E. L., & Grueber, D. J. (2008). "A sketch is like a sentence:" Curriculum structures that support teaching epistemic practices of science. *Science Education*, *92*(4), 608–630. http://doi.org/10.1002/sce.20252

Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: Developments in the application of Toulmin's Argument Pattern for studying science discourse. *Science Education*, *88*(6), 915–933.

Feiman-Nemser, S. (2001). From preparation to practice: Designing a continuum to strengthen and sustain teaching. *Teachers College Record*, *103*(6), 1013–1055.

Feiman-Nemser, S., & Buchmann, M. (1985). Pitfalls of experience in teacher education. *Teachers College Record*, *87*(1), 53–65.

Fishman, B. J., & Davis, E. A. (2006). Teacher learning research and the learning sciences. In *The Cambridge Handbook of the Learning Sciences*. Cambridge, NY: Cambridge University Press.

Forbes, C. T., Biggers, M., & Zangori, L. (2013). Investigating essential characteristics of scientific practices in elementary science learning environments: The practices of science observation protocol (P-SOP). *School Science and Mathematics*, *111*(4), 180–190.

Forbes, C. T., & Davis, E. A. (2010a). Beginning elementary teachers' beliefs about the use of anchoring questions in science: A longitudinal study. *Science Education*, *94*(2), 365–387.

Forbes, C. T., & Davis, E. A. (2010b). Curriculum design for inquiry: Preservice elementary teachers' mobilization and adaptation of science curriculum materials. *Journal of Research in Science Teaching*, *47*(7), 820–839.

Garcia-Mila, M., & Andersen, C. (2007). Developmental change in notetaking during scientific inquiry. *International Journal of Science Education*, *29*(8), 1035–1058.

Greeno, J. G., Collins, A. M., & Resnick, L. B. (1996). Cognition and Learning. In D. C. Berliner (Ed.), *Handbook of Educational Psychology* (pp. 15–46). NY: MacMillan.

Grossman, P., Compton, C., Igra, D., Ronfeldt, M., Shahan, E., & Williamson, P. (2009). Teaching practice: A cross-professional perspective. *Teachers College Record*, *111*(9).

Grossman, P., Hammerness, K., & McDonald, M. (2009). Redefining teaching, re-imagining teacher education. *Teachers and Teaching: Theory and Practice*, *15*(2), 273–289.

Grossman, P., & McDonald, M. (2008). Back to the Future: Directions for Research in Teaching and Teacher Education. *American Educational Research Journal*, *45*(1), pp. 184–205.

Grossman, P., & Thompson, C. (2008). Learning from curriculum materials: Scaffolds for teacher learning? *Teaching and Teacher Education*, *24*(3), 2014–2026.

Grossman, P., Wineburg, S., & Woolworth, S. (2001). Toward of theory of teacher community. *Teachers College Record*, *103*(6), 942–1012.

Haefner, A. L., & Zembal-Saul, C. (2004). Learning by doing? Prospective elementary teachers' developing understandings of scientific inquiry and science teaching and learning. *International Journal of Science Education*, *26*(13), 1653–1674. http://doi.org/10.1080/0950069042000230709

Hammerness, K. (2006). From coherence in theory to coherence in practice. *The Teachers College Record*, *108*(7), 1241–1265.

Hammerness, K., Darling-Hammond, L., Bransford, J., Berliner, D. C., Cochran-Smith, M., McDonald, M., & Zeichner, K. (2005). How teachers learn and develop. In L. Darling-Hammond & J. Bransford (Eds.), *Preparing teachers for a changing world: What teachers should learn and be able to do*. San Francisco: John Wiley & Sons, Inc.

Hawkins, D. (1974). I, thou, and it. In *The informed vision: Essays on learning and human nature* (pp. 49–62). New York: Agathon.

Herrenkohl, L. R., & Cornelius, L. (2013). Investigating elementary students' scientific and historical argumentation. *Journal of the Learning Sciences*, *22*, 413–461.

Herrenkohl, L. R., Palincsar, A. S., DeWater, L. S., & Kawasaki, K. (1999). Developing Scientific Communities in Classrooms: A Sociocognitive Approach. *Journal of the Learning Sciences*, *8*(3-4), 451–493.

Herrenkohl, L. R., Tasker, T., & White, B. (2011). Pedagogical practice to support classroom cultures of scientific inquiry. *Cognition and Instruction*, *29*(1), 1–44.

Hiebert, J., & Morris, A. K. (2012a). Extending ideas on improving teaching: Response to Lampert; Lewis, Perry, Friedkin, and Roth; and Zeichner. *Journal of Teacher Education*, *63*(5), 383–385.

Hiebert, J., & Morris, A. K. (2012b). Teaching, Rather Than Teachers, As a Path Toward Improving Classroom Instruction. *Journal of Teacher Education*, *63*(2), 92–102.

Hudson, D. (1986). Rethinking the role and status of observation in science education. *Journal of Curriculum Studies*, *18*(4), 381–396.

Jones, M. T., & Eick, C. J. (2007). Implementing inquiry kit curriculum: Obstacles, adaptations, and practical knowledge development in two middle school science teachers. *Science Education*, *91*(3), 492–513.

Kazemi, E., Franke, M., & Lampert, M. (2009). Developing pedagogies in teacher education to support novice teachers' ability to enact ambitious instruction. In *Crossing divides: Proceeding of the 32nd annual conference of the Mathematics Education Research Group of Australasia.* (Vol. 1).

Kesidou, S., & Roseman, J. E. (2002). How well do middle school science programs measure up? Findings from Project 2061's curriculum review. *Journal of Research in Science Teaching*, *39*(6), 522–549.

Keys, C. W. (1999). Language as an indicator of meaning generation: An analysis of middle school students' written discourse about scientific investigations. *Journal of Research in Science Teaching*, *36*(9), 1044–1061.

Kuhn, D. (1989). Children and adults as intuitive scientists. *Psychological Review*, *96*(4), 674–689.

Kuhn, T. S. (1996). *The Structure of Scientific Revolutions*. Chicago: The University of Chicago Press.

Lampert, M. (2001). *Teaching problems and the problems of teaching*. New Haven: Yale University Press.

Lampert, M. (2010a). Learning teaching in, from, and for practice: What do we mean? *Journal of Teacher Education*, *61*(1-2), 21–34.

Lampert, M. (2010b). Theory, practice and the education of professionals. *The Elementary School Journal*, *98*(5), 511–526.

Lampert, M. (2012). Improving teaching and Teachers: A "Generative Dance"? *Journal of Teacher Education*, *63*(5), 361–367.

Lampert, M., & Graziani, F. (2009). Instructional activities as a tool for teachers' and teacher educators' learning. *The Elementary School Journal*, *109*(5), pp. 491–509.

Land, S. M., & Zembal-Saul, C. (2003). Scaffolding Reflection and Articulation of Scientific Explanations in a Data-Rich, Project-Based Learning Environment: An Investigation of Progress Portfolio. *Educational Technology Research and Development*, *51*(4), 65–84.

Latour, B. (1999). *Pandora's Hope: Essays on the Reality of Science Studies*. Cambridge, MA: Harvard University Press.

Lave, J. (1996). Teaching, as learning in practice. *Mind, Culture, and Activity*, *3*(3), 149–164.

Lave, J., & Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation*. Cambridge: Cambridge University Press.

Lee, O., & Buxton, C. (2008). Science curriculum and student diversity: A framework for equitable learning opportunities. *The Elementary School Journal*, *109*(2), 123–137.

Lehrer, R., & Schauble, L. (2004). Modeling Natural Variation through Distribution. *American Educational Research Journal*, *41*(3), pp. 635–679.

Lehrer, R., & Schauble, L. (2006). Cultivating model-based reasoning in science education. In *The Cambridge Handbook of the Learning Science* (pp. 371–387). Cambridge, NY: Cambridge University Press.

Lehrer, R., & Schauble, L. (2010). What kind of explanation is a model. *Instructional Explanations in the Disciplines*, *1*, 9–22.

Little, J. W. (2003). Inside teacher community: Representations of teacher practice. *Teachers College Record*, *105*(6), 913–945.

Lizotte, D. J., McNeill, K. L., & Krajcik, J. (2004). Teacher practices that support students' construction of scientific explanations in middle school classrooms. In *Proceedings of the 6th international conference on Learning sciences* (pp. 310–317). Santa Monica, California: International Society of the Learning Sciences.

Longino, H. E. (2002). *The Fate of Knowledge*. Princeton and Oxford: Princeton University Press.

Lortie, D. (1975). *Schoolteacher: A sociological study*. Chicago: University of Chicago Press.

Luft, J. A., Bragg, J., & Peters, C. (1999). Learning to teach in a diverse setting: A case study of a multicultural science education enthusiast. *Science Education*, *83*(5), 527–543.

Luft, J. A., Firestone, J. B., Wong, S. S., Ortega, I., Adams, K., & Bang, E. (2011a). Beginning secondary science teacher induction: A two-year mixed methods study. *Journal of Research in Science Teaching*, *48*(10), 1199–1224.

Luft, J. A., Firestone, J. B., Wong, S. S., Ortega, I., Adams, K., & Bang, E. (2011b). Beginning secondary science teacher induction: A two-year mixed methods study. *Journal of Research in Science Teaching*, *48*(10), 1199–1224.

Lunsford, E., Melear, C. T., Roth, W.-M., Perkins, M., & Hickok, L. G. (2007). Proliferation of inscriptions and transformations among preservice science teachers engaged in authentic science. *Journal of Research in Science Teaching*, *44*(4), 538–564.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 95–132). The Netherlands: Kluwer Academic Publishers.

Marx, R. W., & Harris, C. J. (2006). No Child Left Behind and science education: Opportunities, Challenges, and Risks. *Elementary School Journal*, *106*(5), 467–477.

Maxwell, J. A. (2005). *Qualitative Research Design: An Interactive Approach*. Thousand Oaks: Sage Publications, Inc.

Mayr, E. (2004). *What makes biology unique*. Cambridge: Cambridge University Press.

McDiarmid, G. W., Ball, D. L., & Anderson, C. W. (1989). Why staying one chapter ahead doesn't really work: Subject-specific pedagogy. In *Knowledge base for the beginning teacher* (pp. 193–205). New York: Pergamon.

McGinnis, J. R., Parker, C., & Graeber, A. O. (2004). A cultural perspective of the induction of five reform-minded beginning mathematics and science teachers. *Journal of Research in Science Teaching*, *41*(7), 720–747.

McNeill, K. L. (2009). Teachers' use of curriculum to support students in writing scientific arguments to explain phenomena. *Science Education*, *93*(2), 233–268.

McNeill, K. L. (2011). Elementary students' views of explanation, argumentation, and evidence, and their abilities to construct arguments over the school year. *Journal of Research in Science Teaching*, *48*(7), 793–823.

McNeill, K. L., & Krajcik, J. (2009). Synergy between teacher practices and curricular scaffolds to support students in using domain-specific and domain-general knowledge in writing arguments to explain phenomena. *Journal of the Learning Sciences*, *18*(3), 416–460.

McNeill, K. L., & Krajcik, J. S. (2012). *Supporting Grade 5-8 Students in Constructing Explanations in Science: The Claim, Evidence, and Reasoning Framework for Talk and Writing*. Boston: Pearson.

McNeill, K. L., Lizotte, D. J., Krajcik, J., & Marx, R. W. (2006). Supporting students' construction of scientific explanations by fading scaffolds in instructional materials. *Journal of the Learning Sciences*, *15*(2), 153–191.

Merriam, S. B. (2009). *Qualitative Research: A Guide to Design and Implementation*. San Francisco: Jossey-Bass.

Metz, K. E. (1997). On the complex relation between cognitive developmental research and children's science curricula. *Review of Educational Research*, *1*, 151–163.

Metz, K. E. (2000). Young children's inquiry in biology: Building the knowledge bases to empower independent inquiry. In *Inquiry into inquiring learning and teaching in science* (pp. 371–404). Washington, DC: American Association for the Advancement of Science.

Miles, M. B., Huberman, A. M., & Saldana, J. (2014). *Qualitative Data Analysis: A Methods Sources* (3rd ed.). Los Angeles: Sage Publications, Inc.

Morris, A. K., & Hiebert, J. (2009). Introduction: Building Knowledge Bases and Improving Systems of Practice. *The Elementary School Journal*, *109*(5), pp. 429–441.

National Research Council. (1996). *National Science Education Standards*. Washington, D. C.: National Research Council.

National Research Council. (2000). *Inquiry and the National Science Education Standards*. Washington, DC: National Academy Press.

National Research Council. (2007). *Taking science to school: Learning and teaching science in grades K-8*. Washington, D.C.: National Academies Press.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academics.

Nelson, M. M. (2011). *Approximations of practice in the preparation of prospective elementary science teachers*. University of Michigan: Unpublished dissertation.

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. Washington, D.C.: The National Academies Press.

Nowicki, B. L., Sullivan-Watts, B., Shim, M. K., Young, B., & Pockalny, R. (2013). Factors influencing science content accuracy in elementary inquiry science lessons. *Research in Science Education*, *43*(3), 1135–1154. http://doi.org/10.1007/s11165-012-9303-4

Osborne, J. F., & Patterson, A. (2011). Scientific argument and explanation: A necessary distinction? *Science Education*, *95*(4), 627–638.

Park Rogers, M. A. (2009). Elementary preservice teachers' experience with inquiry: Connecting evidence to explanation. *Journal of Elementary Science Education*, *21*(3), 47–61.

Pasley, J. D., Weiss, I. R., Shimkus, E. S., & Smith, P. S. (2004). Looking inside the classroom: Science teaching in the United States. *Science Education*, *13*(1), 1–20.

Pea, R. D. (1993). Practices of distributed intelligence and designs for education. In G. Salomon (Ed.), *Distributed cognitions: Psychological and educational considerations*. New York, NY: Cambridge University Press.

Penuel, W. R., Fishman, B. J., Yamaguchi, R., & Gallagher, L. R. (2007). What makes professional development effective? Strategies that foster curriculum implementation. *American Educational Research Journal*, *44*(4), 921–958.

Pickering, A. (1995). Beyond constraint: The temporality of practice and historicity of knowledge. In J. Z. Buchwald (Ed.), *Scientific Practice: Theories and stories of doing physics*. Chicago: The University of Chicago Press.

Popper, K. (1972). *Conjectures and refutations: The growth of scientific knowledge (4th ed.)*. London: Routledge & Kegan Paul.

Putnam, R., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning? *Educational Researcher*, *29*(1), 4–15.

Reiser, B. J., Berland, L. K., & Kenyon, L. A. (2012). Engaging students in the scientific practices of explanation and argumentation: Understanding A Framework for K-12 Science Education. *NSTA Publications*, (April).

Remillard, J. T. (2005). Examining key concepts in research on teachers' use of mathematics curricula. *Review of Educational Research*, *75*(2), 211–246.

Rivet, A. (2014). Preparing for the Next Generation Science Standards—Analyzing and Interpreting Data. Retrieved April 10, 2015, from http://learningcenter.nsta.org/products/symposia_seminars/NGSS/webseminar8.aspx

Roehrig, G. H., & Luft, J. A. (2006). Does one size fit all? The induction experience of beginning science teachers from different teacher-preparation programs. *Journal of Research in Science Teaching*, *43*(9), 963–985.

Roth, W.-M., McGinn, M. K., & Bowen, G. M. (1998). How Prepared Are Preservice Teachers to Teach Scientific Inquiry? Levels of Performance in Scientific Representation Practices. *Journal of Science Teacher Education*, *9*(1), 25–48.

Rudolph, J. L. (2000). Reconsidering the "nature of science" as a curriculum component. *Journal of Curriculum Studies*, *32*(3), 403–419.

Saldana, J. (2003). *Longitudinal Qualitative Research: Analyzing Change through Time*. Walnut Creek, CA: AtlaMira Press.

Sandoval, W. A., & Millwood, K. A. (2005). The Quality of Students' Use of Evidence in Written Scientific Explanations. *Cognition and Instruction*, *23*(1), 23–55.

Schneider, R. M., & Krajcik, J. (2002). Supporting science teacher learning: The role of educative curriculum materials. *Journal of Science Teacher Education*, *13*(3), 221–245.

Schneider, R. M., & Plasman, K. (2011). Science teacher learning progressions: A review of science teachers' pedagogical content knowledge development. *Review of Educational Research*, *81*(4), 530–565.

Schön, D. (1983). Preface, and Part I: Professional knowledge and knowledge in action. In *The reflective practitioner: How professionals think in action* (pp. vii–x;3–69).

Schwab, J. J. (1962). The teaching of science as enquiry. In *The Teaching of Science* (pp. 3–103). Cambridge, MA: Harvard University Press.

Schwab, J. J. (1964). The structure of disciplines: Meanings and significance. In *The structure of knowledge and the curriculum*. Chicago: Rand McNally.

Schwarz, C. V. (2009). Developing preservice elementary teachers' knowledge and practices through modeling-centered scientific inquiry. *Science Education*, *93*(4), 720–744. http://doi.org/10.1002/sce.20324

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Achér, A., Fortus, D., … Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching*, *46*(6), 632–654.

Shah, A. M. (2011). *Practicing the practice: Learning to guide elementary science discussions in a practice-oriented science methods course*. University of Michigan: Unpublished dissertation.

Shah, P., Mayer, R. E., & Hegarty, M. (1999). Graphs as aids to knowledge construction: Signaling techniques for guiding the process of graph comprehension. *Journal of Educational Psychology*, *91*(4), 690–702.

Shulman, L. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4–14.

Shulman, L. (1998). Theory, practice, and the preparation of professionals. *Elementary School Journal*, *98*(5), 511–526.

Sleep, L., & Boerst, T. A. (2012). Preparing beginning teachers to elicit and interpret students' mathematical thinking. *Teaching and Teacher Education*, *28*(7), 1038–1048.

Songer, N. B., & Gotwals, A. (2012). Guiding explanation construction by children at the entry points of learning progressions. *Journal of Research in Science Teaching*, *49*(2), 141–165.

Stake, R. E. (2000). Case studies. In N. K. Denzen & Y. S. Lincoln (Eds.), *Handbook of Qualitative Research*. Thousand Oaks: Sage Publications, Inc.

Stein, M. K., Grover, B. W., & Henningsen, M. (1996). Building student capacity for mathematical thinking and reasoning: An analysis of mathematical tasks used in reform classrooms. *American Educational Research Journal*, *33*(2), 455–488.

Thompson, J., Windschitl, M., & Braaten, M. (2013). Developing a Theory of Ambitious Early-Career Teacher Practice. *American Educational Research Journal*, *50*(3), 574–615.

Toulmin, S. E. (2007). *The uses of argument, updated edition*. Cambridge: Cambridge University Press.

Van Driel, J. H., Jong, O. D., & Verloop, N. (2002). The development of preservice chemistry teachers' pedagogical content knowledge. *Science Education*, *86*(4), 572–590.

Vygotsky, L. S. (1978). *Mind in society: The development of high psychological processes*. Cambridge, MA: Harvard University Press.

Weiss, R. S. (1994). *Learning from Strangers: The Art and Method of Qualitative Interview Studies*. New York, NY: The Free Press.

White, B., & Frederiksen, J. (2000). Metacognitive facilitation: An approach to making scientific inquiry accessible to all. In *Inquiring into Inquiry Learning and Teaching in Science*. Washington, DC: American Association for the Advancement of Science.

Willson, V. L. (1987). Theory-building and theory-confirming observation in science and science education. *Journal of Research in Science Teaching*, *24*(3), 279–284.

Wilson, S. M., & Berne, J. (1999). Teacher learning and the acquisition of professional knowledge: An examination of research on contemporary professional development. In *Review of Research in Education* (pp. 173–209). Washington, DC: AERA.

Windschitl, M., Thompson, J., & Braaten, M. (2008). How novice science teachers appropriate epistemic discourses around model-based inquiry for use in classrooms. *Cognition and Instruction*, *26*(3).

Windschitl, M., Thompson, J., & Braaten, M. (2011). Ambitious Pedagogy by Novice Teachers: Who Benefits From Tool-Supported Collaborative Inquiry into Practice and Why? *Teachers College Record (1970)*, *113*(7), 1311.

Wu, H.-K., & Krajcik, J. S. (2006). Inscriptional practices in two inquiry-based classrooms: A case study of seventh graders' use of data tables and graphs. *Journal of Research in Science Teaching*, *43*(1), 63–95.

Zangori, L., & Forbes, C. T. (2013). Preservice Elementary Teachers and Explanation Construction: Knowledge-for-Practice and Knowledge-in-Practice. *Science Education*, *97*(2), 310–330.

Zangori, L., Forbes, C. T., & Biggers, M. (2013). Fostering student sense making in elementary science learning environments: Elementary teachers' use of science curriculum materials to promote explanation construction. *Journal of Research in Science Teaching*, *50*(8), 989–1017.

Zeichner, K. (2012). The turn once again toward practice-based teacher education. *Journal of Teacher Education*, *63*(5), 376–382.

Zembal-Saul, C. (2009). Learning to teach elementary school science as argument. *Science Education*, *93*(4), 687–719.

Zembal-Saul, C., Blumenfeld, P., & Krajcik, J. (2000). Influence of guided cycles of planning, teaching, and reflection on prospective elementary teachers' science content representations. *Journal of Research in Science Teaching*, *37*(4), 318–339.

Zembal-Saul, C., McNeill, K. L., & Hershberger, K. (2013). *What's Your Evidence?: Engaging K-5 Children in Constructing Explanations in Science*. Columbus: Pearson.

Zembal-Saul, C., Munford, D., Crawford, B., Friedrichsen, P., & Land, S. (2002). Scaffolding preservice science teachers' evidence-based arguments during an investigation of natural selection. *Research in Science Education*, *32*(4), 437–463.