Supporting Beginning Teacher Planning and Enactment of Investigation-based Science Discussions:
The Design and Use of Tools within Practice-based Teacher Education

By

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DEDICATION

To my family, and in particular Lottie Jane.

You are a smart, brave, and beautiful little girl.

Let this be a reminder you can do anything you put your mind to.

Lokah Samastah Sukhino Bhavantu.

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ABSTRACT

Current reform efforts prioritize science instruction that provides opportunities for students to engage in productive talk about scientific phenomena. Given the challenges teachers face enacting instruction that integrates science practices and science content, beginning teachers need support to develop the knowledge and teaching practices required to teach reform-oriented science lessons. Practice-based teacher education shows potential for supporting beginning teachers while they are learning to teach in this way. However, little is known about how beginning elementary teachers draw upon the types of support and tools associated with practice-based teacher education to learn to successfully enact this type of instruction.

This dissertation addresses this gap by investigating how a practice-based science methods course using a suite of teacher educator-provided tools can support beginning teachers' planning and enactment of investigation-based science lessons. Using qualitative case study methodologies, this study drew on video-records, lesson plans, class assignments, and surveys from one cohort of 22 pre-service teachers (called interns in this study) enrolled in a year-long elementary education master of the arts and teaching certification program. Six focal interns were also interviewed at multiple time-points during the methods course.

Similarities existed across the types of tools and teaching practices interns used most frequently to plan and enact investigation-based discussions. For the focal interns, use of four synergistic teaching practices throughout the lesson enactments (including consideration of students' initial ideas; use of open-ended questions to elicit, extend, and challenge ideas;

connecting across students' ideas and the disciplinary core ideas; and use of a representation to organize and highlight students' ideas) appeared to lead to increased opportunities for students to share their ideas and engage in data analysis, argumentation and explanation construction. Student opportunities to engage in practices that prioritize scientific discourse also occurred when interns were using dialogic voice and the tools designed to foster development of teacher knowledge for facilitating investigation-based science discussions. However, several intern characteristics likely moderated or mediated intern use of tools, dialogic voice, and productive teaching practices to capitalize on student contributions. These characteristics included intern knowledge of the science content and practices and initial beliefs about science teaching. Missed opportunities to use a combination of several teaching practices and tools designed to foster the development of knowledge for science teaching resulted in fewer opportunities for students to engage in data analysis, argumentation based on evidence, and construction of scientific explanations.

These findings highlight the potential of teacher-educator provided tools for supporting beginning teachers in learning to facilitate investigation-based discussions that capitalize on student contributions. These findings also help the field conceptualize how beginning teachers use tools and teaching practices to plan and enact investigation-based science lessons, and how intern characteristics relate to tool use and planned and enacted lessons. By analyzing the investigation-based science lessons holistically, this study begins to unpack the complexities of facilitating investigation-based discussions including the interplay between intern characteristics and tool use, and the ways intern engagement in synergistic teaching practices provide opportunities for students to engage in data analysis, explanation construction, and argumentation. This study also describes methodological implications for this type of whole-lesson analysis and comments on the need for further research investigating beginning teachers' use of tools over time. Finally, I propose the need for iterative design of scaffolds to further support beginning teacher facilitation of investigation-based science lessons.

CHAPTER 1

INTRODUCTION

Current reform efforts prioritize student engagement in productive talk about scientific phenomena. The *Next Generation Science Standards (NGSS)* outline an ambitious vision for science instruction stressing learning scientific content through engagement in science practices (National Research Council, 2012; NGSS Lead States, 2013). Research has described the rich learning opportunities provided to students when teachers are able to plan and enact instruction integrating science content and science practice (Lehrer & Schauble, 2006; McNeill, 2009; Songer & Gotwals, 2012). However, planning and enacting this type of instruction is challenging for teachers (McNeill, 2009; Simon, Erduran, & Osborne, 2006) and rarely occurs in U.S. science classrooms (Banilower et al., 2013; Pasley, Weiss, Shimkus, & Smith, 2004).

Teaching science in this way requires a vision for science instruction that today's teachers may not have (Abell, 2007; Davis, Petish, & Smithey, 2006). The *NGSS* standards require teachers to teach in a way that is different from the science instruction they experienced during their K-12 education (Lortie, 1975). For some, teaching science has become equated with hands-on approaches (Bybee, 2010) or focused on the performance skills needed to successfully complete a "cookbook laboratory exercise" (Osborne, 2014). A false dichotomy of either learning science content or engaging in science practice persists in much of today's science instruction (Pasley et al., 2004), and it is common for teachers to design science instruction that provides opportunities for students to engage in the science practices in a perfunctory or superficial manner (Cartier, Smith, Stein, & Ross, 2013; Fogleman, McNeill, & Krajcik, 2011).

Additionally, teachers struggle to facilitate the kind of classroom discourse needed to support students to make sense of data gathered during investigations (Hogan, Nastasi, & Pressley, 1999; Hogan, 1999; Windschitl, Thompson, Braaten, & Stroupe, 2012). Rather, many discussions that occur after data collection follow the traditional Initiate-Response-Evaluation pattern rather than a more dialogic or responsive pattern, which enables reasoning (Colley & Windschitl, 2016; Mehan, 1979). New teachers tend to regulate such discussions according to their knowledge of the scientific phenomena, maintaining linguistic control and constraining the topics of discussions when their subject matter knowledge is limited (Carlsen, 1987). New teachers tend to lecture more during high-knowledge instructional units (e.g. those for which they have more sophisticated subject matter knowledge). Additionally, teachers with limited subject matter knowledge are more likely to plan activities that prioritize group work, but then struggle to plan sensemaking discussions to support students to make sense of scientific phenomena and engage in productive scientific discourse (Carlsen, 1991). Such instruction limits students' opportunities to engage in several of the science practices outlined by the *NGSS* (e.g., engaging in argument from evidence). To "promote a culture shift to discussions centered around reasoning" (National Research Council, 2014, p.27-28) in classrooms, teachers will need to be provided with considerable support in learning how to plan and enact ambitious science instruction.

A practice-based approach to teacher education (Ball & Cohen, 1999; Grossman, Hammerness, & McDonald, 2009) shows potential for supporting beginning teachers while they are learning to use the tools and teaching practices necessary to engage students in the practices of scientists (Windschitl et al., 2012). Practice-based teacher education may serve as one avenue for providing beginning teachers with the types of support they need to learn to facilitate investigation-based discussions about scientific phenomena. The goal of practice-based teacher education is to prepare beginning teachers to do instruction, not just hear and talk about it, by providing opportunities to use the knowledge and skills necessary for teaching (Ball, Sleep, Boerst, & Bass, 2009). By engaging in the practices of teaching with varying amounts of support from teacher educators, beginning teachers develop the ability to use teaching practices productively with students (Ball & Forzani, 2009; Braaten & Windschitl, 2011; Windschitl et al., 2012). Additionally, within the context of a practice-based teacher education program, researchers hypothesize that the use of teacher-educator provided tools tailored to beginning teacher needs can further foster beginning teachers' learning to plan and enact ambitious science instruction (Thompson, Windschitl, & Braaten, 2013; Windschitl, Thompson, & Braaten, 2011). Similar to educative curriculum materials designed specifically with the intent to support both teacher and student learning (Davis & Krajcik, 2005), tools used within a practice-based teacher education program have the ability to support interns in developing their knowledge for science teaching. However, little is known about how beginning elementary teachers draw upon the types of support and tools learn to successfully enact investigation-based science lessons.

Research Questions and Study Overview

This study aims to advance the field's understanding of how a practice-based teacher education program can support beginning teachers' planning and enactment of investigation-based science discussions. (The preservice teachers in the program studied here are referred to as "interns.") To describe how aspects of the practice-based teacher education program may shape the ways in which interns plan and enact this type of discussions, I focus on interns' use of tools designed specifically to foster their learning to teach science in an ambitious way. Germane to this study is the assumption that a tool operates in the space between an individual and a complex task that might be out of reach for the individual without some form of support or assistance (Cole & Wertsch, 1996; Wertsch, 1991).

Focusing on one cohort of 22 interns, this dissertation aims to further the field's understanding of the types of tools interns find useful in planning and enacting investigation-based science discussions and describe the ways the interns use those tools. Additionally, taking a closer look at six focal interns' characteristics, lesson plans, and lesson enactments, the study also contributes to our understanding of how interns' characteristics and use of supportive tools may shape their planning and enactment of investigation-based science discussions. Use of a qualitative case study approach allows for a close analysis of how a practice-based approach to teacher education combined with the use of supportive tools might support interns to plan and enact investigation-based discussions that capitalize on student contributions. The following research questions guide this study:

1. What tools do interns use to plan and enact investigation-based discussions and how does that use surface in the plans and enactments? How do the interns describe their use of the tools?
2. What are the characteristics of interns' investigation-based discussions, and more specifically:
    a. What types of talk do interns use?
    b. How does intern knowledge and beliefs about science practice and content surface in the discussions?
    c. What are the ways in which interns capitalize on student contributions?

3. How do interns' characteristics (specifically their knowledge and beliefs about science content, science practices, and investigation-based science discussions) and use of tools relate to one another and to characteristics of interns' plans and enactments of investigation-based discussions?

Using Ball and colleagues' (2008) model of knowledge for teaching, I developed, and in some cases modified a suite of tools to support interns' learning to facilitate investigation-based discussions. I analyze the entire cohort's use of these tools to plan two investigation-based science lessons. For a subset of focal interns who were selected to represent a range of knowledge, teaching practice, and previous experiences, I analyze the use of the tools during lesson enactments.

Additionally, I decompose the practice of facilitating investigation-based discussions into several subpractices research has shown to be important for planning and enacting productive investigation-based discussions that capitalize on student contributions (Boerst, Sleep, Ball & Bass, 2011; Cartier et al., 2013; Ross, 2014; Windschitl et al., 2012). I analyze the entire cohort's planned use of the productive practices and look closely at the use of these practices in focal interns' lesson enactments. Close analysis of focal interns' characteristics, specifically their knowledge and beliefs about science content, science practice, and investigation-based discussions, and their lesson plans and enactments enabled a description of the possible relationships that occur between intern characteristics and tool use, and also lesson plans and enactments. Rather than analyzing only the sensemaking discussions occurring at the end of the lesson enactments like much of the prior research investigating teacher facilitation of discussions in science (e.g., Hogan et al., 1999; Sassi, Bopardikar, Kimball, & Michaels, 2013), this study looks at the investigation-based lessons holistically to being to unpack the complexity of the interplay between use of tools and intern characteristics. Additionally, by looking at the investigation-based lessons as a whole I describe ways in which interns use specific tools and teaching practices synergistically rather than in isolation providing opportunities for students to engage in science practices that prioritize scientific discourse. Data sources for the study include course assignments (including 44 lesson plans), surveys and assessments, videorecords of lesson enactments (approximately 14 hours of video), and interviews.

The analyses suggest that interns used a range of tools and productive teaching practices to capitalize on student contributions when planning and enacting their investigation-based discussions, and similarities existed across the types of tools and teaching practices interns used most frequently. Interns also justified their use of tools in similar ways describing that the tools helped them to keep the goals of science teaching in mind. Additionally, interns described that the tools were coherent with the larger teacher education program and helped them attend to their students' ideas and needs. For the focal interns, combined use of teaching practices throughout the lesson enactments--specifically consideration of students' initial ideas; use of open-ended questions to elicit, extend, and challenge ideas; making connections across students' ideas and the disciplinary core ideas; and use of a representation to organize and highlight students' ideas—may have led to increased opportunities for students to share their ideas and engage in data analysis, argumentation and explanation construction. Student opportunities to engage in practices that prioritize engagement in scientific discourse also occurred when interns were using dialogic voice and the tools designed to foster development of teacher knowledge for facilitating investigation-based science discussions. However, several intern characteristics likely mediated or moderated intern use of tools, use of dialogic voice, and use of productive teaching practices to capitalize on student contributions. These characteristics included intern knowledge of the science content and practices and initial beliefs about science teaching. Missed opportunities to use a combination of several teaching practices and tools designed to foster the development of knowledge for science teaching resulted in fewer opportunities for students to engage in data analysis, argumentation based on evidence, and construction of scientific explanations.

Findings from this study extend the field's understanding of how practice-based teacher education combined with the use of tools can support beginning teachers to facilitate investigation-based discussions that prioritize student ideas (Boerst, Sleep, Ball & Bass, 2011; Cartier et al., 2013; Ross, 2014; Windschitl et al., 2012). The study also provides evidence for the types of tools and experiences that may foster development of knowledge for science teaching (e.g., Arias, 2015; Windschitl, et al., 2012). This dissertation builds on and extends Remillard's (2005) theoretical construct of a participatory relationship to teacher education programs, providing empirical evidence of the relationships that exist between novice teacher characteristics, use of resources or tools, and teachers' planned and enacted lessons. Finally, this study extends literature describing the combinations of productive teaching moves that provide students additional opportunities to reason dialogically (e.g., Colley & Windschitl, 2016).

In Chapter 2, I review the literature on supporting beginning teacher learning to facilitate investigation-based discussions including details of a practice-based approach to teacher education, and the successes and challenges associated with supporting beginning teacher learning. I also provide details of a model for teacher knowledge (Ball et al., 2008), and define and decompose the practice of facilitating investigation-based discussions. In Chapter 3, I describe the suite of tools designed and/or modified to support development and knowledge and practice of science teaching specific to facilitating investigation-based discussions. Chapter 4 outlines the study design and methods, including descriptions of the context, participants, and analysis used for this dissertation. Chapters 5, 6, 7, and 8 describe the findings from the analysis. Chapter 5 describes interns' use of tools to plan and enact investigation-based discussions. Chapter 6 focuses on interns' planned use of productive practices for capitalizing on student contributions. Chapter 7 provides detailed descriptions of focal interns' engagement in the productive teaching practices, use of dialogic and authoritative voice, and student engagement in science practices during lesson enactments. Chapter 8 looks closely at the relationships that existed between focal interns' characteristics and their planned and enacted lessons. Chapter 9 discusses these findings in light of the literature and describes implications of the study.

CHAPTER 2

CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

This chapter provides the theoretical frames and evidence from empirical research that inform this dissertation. I begin by defining multiple uses of the term *practice* and different types of knowledge teachers need to enact science instruction that integrates science content and practice. Then, I outline the challenges science teachers face in learning to teach in this way. Next, drawing on sociocultural and situated learning perspectives, I consider the research on practice-based teacher education, its potential to support beginning teacher learning, and the challenges associated with this type of approach to teacher education. Then, I look closely at the practice of facilitating investigation-based discussions. I analyze interventions and practice-based science methods courses that have aimed to support teachers' learning to facilitate investigation-based discussions. Finally, I discuss potential relationships that exist between intern characteristics, specifically knowledge and beliefs about science content and science practices and knowledge and beliefs about science teaching, and intern tool use and planned and enacted investigation-based science lessons.

Defining Practice

Because of the importance of the term *practice* in connection to both science practices and teaching practices discussed within this study, defining its multiple meanings is essential. Using three of Lampert's (2010) definitions of practice, and Arias' (2015) analysis of the connection of these three definitions of practice involved in learning to teach and to the practices involved in learning science, I refer to the term *practice* in the following ways:

1. *A collection of practices*: In learning to teach - a set of high leverage or ambitious teaching practices (Grossman, Hammerness et al., 2009; Windschitl et al., 2012). This could include practices for both the planning (such as using an instructional planning template to develop a lesson plan) and enactment (such as using talk moves to lead a whole class discussion) of lessons. In learning science – using a set of practices scientists use to learn about and describe scientific phenomena (e.g., engaging in argument from evidence) (National Research Council, 2012; NGSS Lead States, 2013).
2. *To practice: to rehearse to do something repeatedly to study it*: In learning to teach – an intern may rehearse an investigation-based discussion asking students to make claims about the impact of pollution on ecosystems in front of her peers before teaching students. In learning science – to communicate to other students how pollution affects ecosystems, an elementary student may practice a presentation in front of a small group before presenting in front of her whole class.
3. *Practice as in a profession*: In learning to teach, the profession of teaching. In learning science, a discipline of science (e.g., physics or biology).

A Model for Teacher Knowledge

Defining the types of knowledge science teachers need to plan and enact ambitious science instruction that integrates science content and science practice is a complex, but necessary, task. Without a clear conception of what is meant by types of knowledge needed for science teaching, it will be difficult to improve science education and train future science teachers to be able to engage in ambitious science teaching. Within this text, I define the knowledge needed for science teaching by drawing on prior research and models of expert teaching. I address and define different domains of teacher knowledge, and I provide concrete examples of each domain. Additionally, I make connections between these different domains of teacher knowledge and the practice of teaching or the "tasks and activities involved in the work" of teaching (Ball & Forzani, 2009, p. 503).

When creating my own conceptual model of knowledge needed for science teaching, I draw heavily on the work of Ball and colleagues (2008), and their thinking about the types of knowledge essential for mathematics teaching. Ball and colleagues' (2008) model builds on the concepts of subject matter knowledge (SMK) and pedagogical content knowledge (PCK) identified by Shulman (1986) and expanded in the context of science teaching by Magnusson and colleagues (1999). My current model of knowledge needed for science teaching is shown in Figure 2-1. Knowledge for science teaching encompasses knowledge of scientific content and knowledge of science practices, as well as the integrated nature of the two.

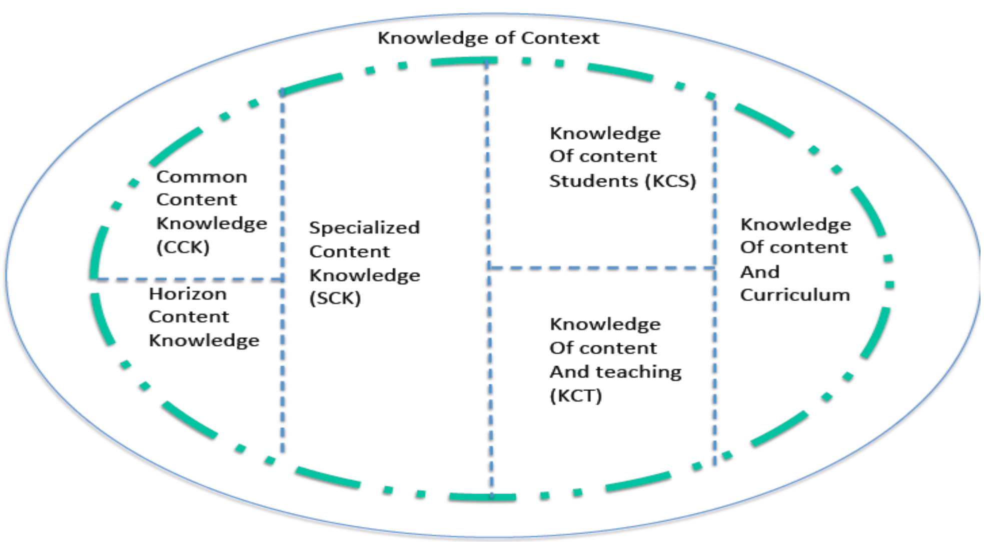

Figure 2-1: Conceptual framework for knowledge needed for science teaching (adapted from Ball et al., 2008)

Defining Subject Matter Knowledge

Similar to the work of Ball and colleagues (2008), within my conceptual framework, I include common content knowledge, horizon content knowledge, and specialized content knowledge for teaching as the three domains of subject matter knowledge essential for science teaching. As seen in Figure 2-1, the borders that define these different aspects of subject matter knowledge are porous showing that the three domains of subject matter knowledge interact with one another and are not isolated. For example, a teacher may need to draw upon his or her common content knowledge in order to utilize his or her specialized content knowledge. Defining these three types of subject matter knowledge provides increased specificity to what is included in Shulman's (1986) concept of SMK.

Common content knowledge. Common content knowledge is knowledge a teacher builds through experiences in science content courses or through work as a scientist in a disciplinary field. This includes knowledge of scientific facts, concepts, the ever-changing nature of science, and substantive and syntactic science knowledge (Abell, 2007; Schwab, 1978; Shulman, 1986). This domain of teacher knowledge encompasses the mechanistic explanations of natural phenomena and knowledge of the common practices of scientists. In teaching practice, this domain of teacher knowledge may be shown when a teacher is able to provide a mechanistic explanation of natural phenomena to others. This may or may not be at an appropriate level for students – which demonstrates the importance of teacher PCK in science.

In respect to the science practices, this knowledge may be used to create authentic experiences for students to draw upon and use the scientific practices stressed by the *NGSS* (National Research Council, 2012; NGSS Lead States, 2013). For example, when asking students to construct explanations, a teacher may draw on his or her common content knowledge that scientific explanations require multiple pieces of evidence for justification. Drawing upon this domain of knowledge is essential for creating a classroom in which students could experience and "understand the nature of scientific inquiry" (Crawford, 2000, p. 934).

Horizon content knowledge. Horizon content knowledge is an understanding of how common content knowledge fits into a larger picture within the science disciplines (Ball et al., 2008). This includes both knowledge of how a specific content idea fits into the curriculum across grade levels, as well as how a concept fits within the different disciplines in science. In teaching practice, this domain of teacher knowledge may be apparent when a teacher considers and supports students to construct the "big picture" idea within a science lesson (Windschitl et al., 2012). To do so, a teacher needs to draw upon his or her knowledge of how the smaller concept being addressed in the lesson fits into "the more comprehensive scientific ideas that could help students make sense" of the activities designed to target that concept (Windschitl et al., 2012, p. 888). Teachers need to draw on their horizon content knowledge to enact lessons in ways that these connections become clear to students, helping students to understand how scientific knowledge builds from grade to grade, and how concepts are used across the scientific disciplines.

Specialized content knowledge. Specialized content knowledge is both the unique knowledge needed for teaching that is not drawn upon frequently in other professions (Ball et al., 2008), and also the knowledge required to synthesize all other aspects of the model to make in the moment decisions to benefit student learning. As Ball and colleagues (2008) state, specialized content knowledge requires an "uncanny kind of unpacking [of concepts]…that is not needed– or even desirable – in settings other than teaching" (p. 400). Specialized content knowledge includes teachers' knowledge of how to make and evaluate connections between everyday language and scientific language based (Brown & Spang, 2008) on the language students use in the moment to describe phenomena they may be observing. Additionally, it includes teachers' knowledge of how to connect student ideas with representations of phenomena that can be used to explicate and/or test student thinking. When students are engaged in science practice, specialized content knowledge describes teachers' ability to name and provide rationales for the science practice. Lastly, it includes looking for patterns within student responses to questions, and evaluating which teaching strategy may be most appropriate to use in response to those patterns to help further student understanding (Ball et al., 2008).

Defining Pedagogical Content Knowledge

Shulman (1986) defines pedagogical content knowledge as going beyond just subject matter knowledge to the knowledge of the subject matter essential for teaching. This domain includes teachers' understandings of what makes concepts difficult or easy for students, students' likely prior knowledge of content, and common alternative ideas about concepts (Shulman, 1986). Additionally, it includes teachers' knowledge of curriculum (Grossman, 1990; Magnusson et al., 1999). Ball and colleagues (2008) provide a more nuanced definition of PCK that I use for my own conceptual model of knowledge for science teaching. Rather than describing all three aspects of PCK illustrated in my model, *knowledge of content and teaching* and *knowledge of content and students* will be the two PCK focuses in this study[1].

Knowledge of content and teaching. This domain of teacher knowledge draws upon teachers' knowledge of content and knowledge of ways to teach that content (Ball et al., 2008).

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[1] This study does not look deeply into interns' knowledge of content and curriculum. For two assignments, the interns were provided with curriculum materials rather than having to search out their own. Interns were asked to analyze this curriculum using five considerations (see Appendix G), but because they are not choosing the materials on their own, the lessons may not depict their knowledge of content and curriculum.

This includes knowledge of instructional strategies and knowledge of appropriate representations shown to help students understand scientific phenomena (Magnusson et al., 1999; McDiarmid, Ball, & Anderson, 1989). In practice, a teacher may show evidence of this domain of knowledge by purposefully choosing one type of scientific model or analogy over another after determining the advantages and disadvantages of such a choice (cf. Ball et al., 2008).

Knowledge of content and students. This domain of PCK for science teaching is the knowledge teachers have of content interacting with knowledge of students (cf. Ball et al., 2008). Magnusson and colleagues (1999) and McDiarmid and colleagues (1989) discuss a similar type of teacher knowledge termed knowledge of students' understandings of science and knowledge of learners respectively. This includes knowledge of common alternative ideas students have about particular science topics, and teachers' ability to anticipate common prior knowledge, and knowledge of what will make the content interesting for students (Ball et al., 2008).

In practice, evidence of this knowledge includes the teacher probing students' understanding during the initial activities within a lesson, listing common alternative ideas relating to the content being covered by the lesson within a lesson plan, and anticipating possible student responses to planned questions (Grossman, Hammerness et al., 2009). This also includes choosing appropriate activities for students to engage in science practices in an authentic way that is accessible for all students (Crawford, 2000).

Considering the interactions. Like with subject matter knowledge, the boundaries between the three aspects of PCK are porous. Again, it is the interaction between the aspects of PCK that contribute to knowledge for science teaching (cf. Ball et al., 2008). Additionally, the six domains of PCK and SMK interact. For example, within the domains of PCK mentioned previously, knowledge of content is a focus. Without common content knowledge, a teacher may be unable to leverage his or her knowledge of the students and vice versa. A similar argument can be made for the specialized content knowledge for teaching. Without knowledge of students, a teacher may be unable to make in the moment decisions to evaluate student thinking to choose activities (drawing upon knowledge of content and teaching) to further student understanding (Ball et al., 2008). All domains work in tandem with one another to contribute to science knowledge for teaching.

Challenges Relating to Teacher SMK and PCK

Both subject matter knowledge and pedagogical content knowledge needed for science teaching are multi-faceted, vast, and complex. In this section, I provide evidence from research investigating the level of understanding of each domain of knowledge that is typical for beginning science teachers and challenges science teachers face when that knowledge is underdeveloped.

Inadequate understanding of the content and nature of the science disciplines is a challenge science teachers face (Davis et al., 2006) in learning to teach in a way that integrates science content and practice. Most elementary teachers learn common content knowledge and horizon content knowledge through high school or undergraduate science courses. In many elementary education programs, beginning teachers are required to complete a minimal number of undergraduate science courses, some of which may be designed specifically for elementary education majors. These courses often cover the substantive knowledge at a surface level, and rarely do beginning elementary teachers complete coursework in all the science disciplines they are expected to be able to teach (Anderson & Mitchener, 1994).

Additionally, studies have shown, despite coursework, teachers' understandings of science are unsophisticated (Davis et al., 2006). Often prospective elementary teachers enter into teacher education programs with the same alternative ideas as their students (Abell, 2007; Davis et al., 2006). For example, in a study of prospective elementary teacher understanding of astronomy topics, the majority of teachers' responses (64%) were inaccurate conceptions of science (Trumper, 2003). Illuminating underdeveloped horizon content knowledge, studies found beginning teachers lacked the understanding of how science concepts within and among the disciplines were connected (Gess-Newsome & Lederman, 1993; Lederman, Gess-Newsome, & Latz, 1994).

Additionally, unsophisticated understandings of the practices of scientists and the nature of science (NOS) present a challenge for teachers learning to teach in a way that supports the vision of the *NGSS*. Many prospective elementary teachers have experienced education that does little to develop knowledge of the practices listed in the *Framework* (American Association for the Advancement of Science, 2011; Osborne, 2014), and they retain alternative ideas about the NOS despite participation in history of science courses (Abd-El-Khalick & Lederman, 2000). Additionally, many beginning teachers lack confidence in their understandings of science, in both scientific content and science practices. They report having negative experiences in science courses and a low sense of self-efficacy for understanding science (Appleton & Kindt, 2002; Gess-Newsome & Lederman, 1993; Lederman, et al., 1994).

Perhaps due to this underdeveloped understanding of the NOS and how new science knowledge is created, beginning elementary science teachers may not identify students' sensemaking as a priority of their instruction. Instead, beginning elementary teachers focus on hands-on activities and data collection as a way to reinforce topics covered earlier (Appleton, 2002; Davis, et al., 2006; Haefner & Zembal-Saul, 2004; Minogue, Madden, Bedward, Wiebe, & Carter, 2010; Zangori, Forbes, & Biggers, 2012; Zangori & Forbes, 2013). Additionally, in some cases, beginning teachers may lack the subject matter knowledge that allows them to identify instructional representations that would be productive for student learning (Davis & Petish, 2005; Yerrick, Doster, Nugent, Parke, & Crawley, 2003). These examples highlight how development of knowledge of content and teaching could be limited by underdeveloped common content knowledge.

Teachers also may have underdeveloped understandings of how to engage students in the scientific practices, such as explanation construction or argumentation. Several studies have found that teachers struggle to engage their students in aspects of argumentation and explanation construction (e.g., Berland & Reiser, 2009; McNeill, 2009; Simon et al., 2006). Researchers hypothesize that teachers struggle to support students' engagement in the science practices because of underdeveloped understanding of the science practices or the inability to draw on their knowledge of the practice in order to design productive learning experiences for students to engage in the practices (Biggers, Forbes, & Zangori, 2013; Davis, Beyer, Forbes, & Stevens, 2011; Forbes & Davis, 2010; Zangori & Forbes, 2013).

Several studies also highlight challenges teachers face due to underdeveloped knowledge of content and students. Beginning teachers tend not to think about students' ideas about science phenomena very carefully (Abell, 2007; Davis et al., 2006) and have limited ideas of what to do with students' ideas after eliciting them (Gotwals & Birmingham, 2015; Zembal-Saul, Blumenfeld, & Krajcik, 2000). Beginning teachers tend to focus on whether or not students "get it" rather than pressing students to explain their reasoning further (Furtak, Thompson, Braaten, & Windschitl, 2012). Gotwals and Birmingham (2015) found beginning teachers dichotomously characterize student thinking as "right" or "wrong" and fail to notice important nuances in student thinking. Failure to notice these nuances in combination with limited knowledge of how to adapt instruction based on those ideas may lead to limited opportunities for student learning (Gotwals & Birmingham, 2015).

In sum, all domains of teacher knowledge are important and underdeveloped knowledge in one domain may shape or limit knowledge development in other domains. Thus, it is important to consider all domains of teacher knowledge when supporting beginning teachers to facilitate investigation-based discussions.

Considering Knowledge and Beliefs

Crawford (2007) explains that "knowledge and beliefs about teaching are entangled, since what one believes about teaching necessarily hinges to a large extent, on one's knowledge of his or her discipline as well as one's beliefs about how children learn" (p. 616). Knowledge is often defined as being empirically based, developed over time, and well-structured. In contrast, beliefs are defined as highly subjective with significant emotional components, and they are based on previous experiences (Gess-Newsome, 1999). The research questions driving this study consider both teacher knowledge *and* teacher beliefs. Because of the entangled nature of knowledge and beliefs, during this study it is not my intent to characterize teachers based on one construct or the other; rather I intend to consider the interplay between the two. Furthermore, as I describe next, I consider the importance of their interplay with practice, as well.

Engaging in the Practice of Teaching: Knowledge Alone is Not Enough

The domains of knowledge described previously, and the challenges teachers face due to underdeveloped knowledge in one or more of the domains illustrate that simply having this knowledge is not enough. There is a difference between having knowledge, and knowing how to enact that knowledge in practice (Hammerness et al., 2005; Lampert, 2010). Elementary teachers must possess both *knowledge for practice* and *knowledge in practice. Knowledge for* *practice* is referred to as "formal knowledge and theory" often gained through content courses and teaching methods courses, whereas *knowledge in practice* is referred to as "practical knowledge" often gained through the experience of teaching (Cochran-Smith & Lytle, 1999, p.250).

For example, a fourth-grade teacher might engage students in investigation-based discussions about heat energy transfer. During the discussion, students engage in the scientific practices of argumentation, explanation construction, and communication of information. This teaching practice requires the teacher to utilize all five domains of knowledge for science teaching and requires the teacher to translate that knowledge into pedagogy that will provide students opportunities to learn. Drawing on her *common content knowledge*, a teacher must have a deep understanding of how heat energy transfer is the exchange of kinetic energy from one particle of matter to another particle of matter, and that thermal equilibrium (or two systems reaching the same temperature) is reached when all particles in the system have equal amounts of kinetic energy. Drawing on her *common content knowledge* and *knowledge of content and teaching,* the teacher must know the types of evidence needed to support the explanation of how heat energy is transferred, and she must also be able to provide experiences for students to gather similar types of data to serve as evidence by engaging in investigation.

Drawing on her *knowledge of content and students* and *knowledge of content and teaching,* the teacher must also know how to engage students in practices of argumentation, explanation construction, and communication in a way that will foster sensemaking. This includes knowing and enacting instructional strategies to support students' engagement in the science practices (e.g., using a framework to scaffold explanation construction) and to facilitate whole-class discussions (e.g., using specific talk moves to help students share their thinking and listen to the ideas of others).

She will also need to consider what her learners need while she is enacting the lesson and adapt her instruction accordingly while utilizing her *specialized content knowledge* and *knowledge of content and students*. For example, if one small group of students is not taking temperature measurements at consistent time intervals, the teacher may decide to compare that group's data with data from a group that did take temperature measurements at constant intervals. The teacher encourages the groups to discuss the differences in the data and come to a collective conclusion about why being consistent with time interval is important. The teacher's decision to juxtapose the two groups' data and discuss it as a whole class would need to be made after she noticed her students struggle with data collection.

The knowledge and practices needed to facilitate a productive investigation-based discussion extend beyond those described; however, the example highlights the interaction between both *knowledge for practice* and *knowledge in practice* needed to create learning opportunities for students to make sense of scientific phenomena. In the past, science methods courses have fallen short of supporting beginning teachers to move from their more formal knowledge base, *knowledge of practice*, to the more practical knowledge based, *knowledge in practice* (Anderson & Mitchener, 1994; Ball & Cohen, 1999).

Finding ways in which teacher education can foster development of both *knowledge for practice* and *knowledge in practice* is challenging. Shifting methods courses to be more practice-oriented offers one avenue of supporting teachers to move between these two types of knowledge (Ball & Cohen, 1999; Ball & Forzani, 2009). However, a single methods course in the context of a formal elementary teacher certification program is not intended to be a panacea for equipping beginning teachers with all the knowledge needed for science teaching. Rather, the goal of a practice-oriented science methods course is to prepare "well-started beginners" who continue to learn from experiences over time (Avraamidou & Zembal-Saul, 2010; Davis & Boerst, 2014).

Research on Practice-Based Approaches to Teacher Education

By utilizing a situated learning perspective practice-based teacher education can provide beginning teachers opportunities to engage in learning that is situated, social, and distributed (Brown, Collins, & Duguid, 1989; Putnam & Borko, 2000). Putnam and Borko (2000) argue that for learning to happen, it is important to provide opportunities to learn both in a formal learning setting (i.e., a university course) and within the context the knowledge and skills will be used (i.e., an elementary classroom, teaching elementary students). For example, the science methods course in the more formal setting may be an appropriate place for beginning teachers to learn about talk moves a teacher could use to help facilitate an investigation-based discussion. However, that learning should be supplemented with opportunities to see actual teachers using those talk moves with students to connect and respond to student ideas. Furthermore, beginning teachers should be provided opportunities to practice utilizing the talk moves to facilitate investigation-based discussions.

A practice-based teacher education program provides all types of opportunities to learn by situating learning in authentic activities of teachers – for example lesson planning, enactment, and reflection. Not all of the learning opportunities within a methods course need to occur within an elementary classroom; rather the opportunities can be situated in some aspect of the work of teaching itself (Ball & Forzani, 2009). For example, within a methods course, the course instructor (or teacher educator) can utilize videos of teaching and artifacts, such as student work or curriculum materials, to situate the learning in teaching practice. Additionally, the teacher educator can design learning opportunities to prepare beginning teachers to actually do instruction, not just hear and talk about it (Ball et al., 2009) by having them practice enacting investigation-based discussions with peers, and then enacting investigation-based discussions with elementary students in a mentor teacher's classroom.

Pedagogies of Teaching Practice

To provide these opportunities, teacher educators can utilize Grossman and colleagues' (2009) three pedagogies of practice: approximation of practice, representation of practice, and decomposition of practice. Figure 2-2 outlines a definition of each pedagogy of practice, and also highlights examples of each pedagogy of practice that occurs within the science methods course that is the context of this study. While I am separating the three pedagogies for the purpose of clarifying each type, there is overlap between them. For example, when one beginning teacher is engaging in an approximation of practice involving other interns, another beginning teacher is experiencing a representation of practice (Grossman, Compton, et al., 2009)

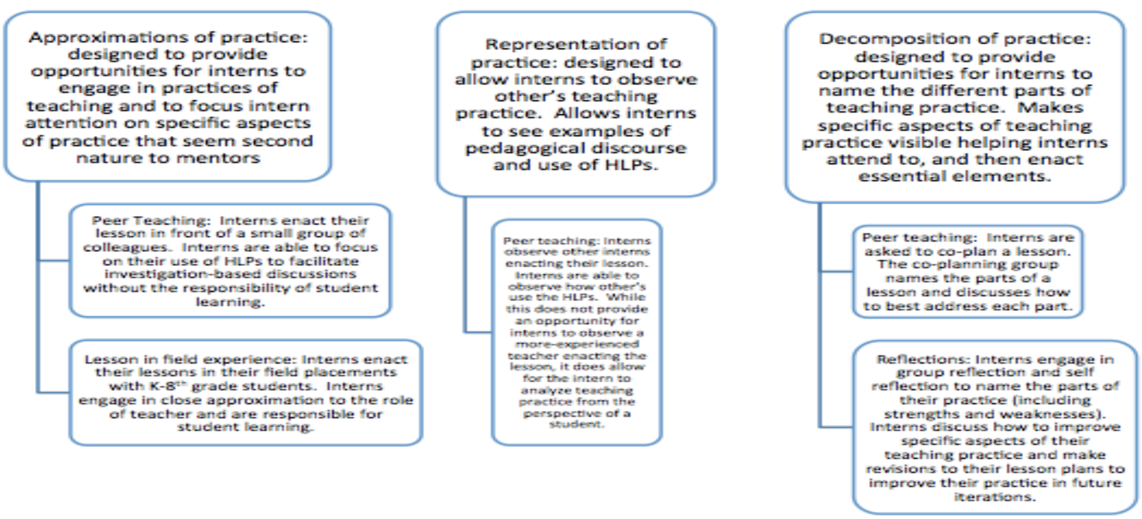

Figure 2-2: Grossman and colleagues' (2009) pedagogies of practice and use in the methods course

These pedagogies of practice can vary in form (Grossman, Compton, et al., 2009). Representations of practice allow beginning teachers to observe others' teaching practice.

Representations of practice can include, but are not limited to, observing another teacher directly (e.g., observing the mentor teacher teaching a science lesson in the field placement classroom) and observing a video record of another teacher. Representations of practice provide exemplars for prospective teachers and allow them to access information that may be otherwise invisible. For example, after watching a lesson enacted by her mentor teacher, the beginning teacher has an opportunity to ask the mentor teacher about her thinking and clarify her understanding of why the mentor made specific choices (Grossman, Compton, et al., 2009).

Given that beginning teachers have difficulty noticing the intricacies and complexities in teaching practices, several of the practices of teaching may still be invisible (Grossman, Compton et al., 2009; Grossman, Hammerness, et al., 2009). Decomposing a complex practice, like planning and enacting investigation-based discussions, involves breaking down the practice and naming the parts. Decomposition of practice provides opportunities for beginning teachers to think deeply and critically about what they see in representations of practice and what they do in their own approximations of practice. In doing so, prospective teachers gain experience participating in the discourses of teaching using the specialized language of the profession. Once they are able to name and discuss the practices, beginning teachers can learn to attend to particularly important components of practice and enact those practices with students (Grossman, Compton, et al., 2009).

In approximations of practice, the emphasis is on enactment. Approximations of practice vary in the degree of complexity and authenticity along a continuum. Less authentic approximations of practice, like analyzing a written case, highlight a few of the facets of the teaching practice, allow for more narrow participation by the beginning teacher, and allow increased opportunities for rehearsal. During the approximation of practice, the beginning teacher has opportunities to stop and start the practice, asking questions along the way. More authentic approximations of practice, like planning and enacting a science lesson, more closely resemble actual teaching and more fully integrate the beginning teacher in the practice of teaching. During more authentic approximations of practice, the beginning teacher also has fewer opportunities to stop and start her action to ask clarifying questions. Approximations allow for beginning teachers to experience instructive successes and instructive failures, both of which can be seen as learning opportunities (Grossman, Compton, et al., 2009). Grossman and colleagues (2009) also argue it is important to provide beginning teachers experiences that fall in multiple places along the continuum to gain a better understanding of the complexities of the practice.

By utilizing all three pedagogies of practice throughout a teacher education program, and more specifically within a science methods course, beginning teachers are afforded opportunities to construct knowledge for science teaching (cf. Putnam & Borko, 2000) while participating legitimately and peripherally in the discourse and practices of the teaching community (Lave & Wenger, 1991). Further, the three pedagogies align with Brown and colleagues' (1989) and Putnam and Borko's (2000) call for learning opportunities to be situated, distributed, and social. The learning is situated in that it occurs in connection with an authentic practice of teaching. The learning is distributed in that knowledge is shared among groups of people including the beginning teachers, the mentor teachers, the field instructors, and the teacher educators. These groups work together to co-construct meaning by decomposing and recomposing teaching practice. The learning is social in that it requires beginning teachers to gradually become more legitimate members of a community of practice, to perform practices utilized by the community, and to discuss those practices with other community members (Lave & Wenger, 1991; Putnam & Borko, 2000).

Challenges Associated with Practice-Based Teacher Education

Organizing a teacher education program around this practice-based approach does not come without challenges. Often there is a disconnect in what is required by the methods coursework and what occurs in the beginning teacher's field placement classroom. For example the mentor teacher may not be aware of what occurs in the science methods course or may have a different definition of a specific teaching practice or science practice (Crawford, 2007). Further still, the mentor teacher may have experienced a teacher education program that focused more on utilizing observations of teaching and analyzing those observations as the primary way of learning to teach rather than a combination of observation and opportunities to practice enactment. When prior experiences of the mentor teacher and the mentor teacher's beliefs about teaching and those that are required by the practice-based teacher education program are different, learning opportunities for the beginning teacher may be limited (Feiman-Nemser & Buchmann, 1985; Rozelle & Wilson, 2012; Zeichner, 2010).

Providing Cohesion

Past research has shown providing consistent and cohesive experiences for beginning teachers may support development a more accurate, reform-oriented vision of teaching. Anderson and colleagues (2000) and Zembal-Saul and colleagues (2000) used several conceptual themes to create cohesiveness when designing teacher education courses for an elementary teacher education program. These themes included learning as active construction of knowledge, and instruction as engagement. In addition, Anderson and colleagues (2000) emphasized tools such as technology for planning and teaching throughout the beginning elementary teachers' experiences during the teacher education program.

Through the use of these types of consistent and cohesive conceptual themes and tools during an elementary teacher education program, beginning teachers developed a vision for teaching in a way that aligned with the goals of the program (Anderson et al., 2000; Davis & Smithey, 2009; Zembal-Saul et al., 2000). Over time, beginning teachers increased the emphasis on science content within their plans and also were able to plan for the use of multiple types of representations during science units. Additional attention was also paid in the plans to thinking about students' ideas and attempting to assess students' knowledge about the science content and practices (Anderson et al., 2000; Davis & Smithey, 2009; Zembal-Saul et al., 2000). Although it is difficult to determine which aspects of a coherent teacher program contribute most to development of teacher knowledge and practice, it is likely that a suite of tools such as a lesson-planning template along with several other experiences integrated throughout the program could serve as support to develop knowledge aligned with the goals of the program. Use of a suite of tools is by no means meant to be a panacea for all beginning teacher knowledge and practice development, but rather one of many resources on which beginning teachers can draw. A suite of tools designed to support development of teacher knowledge serves as one part of a cohesive whole, and supports pre-service teachers by asking them to draw upon knowledge gained in their course work and apply that knowledge to work with students in the field.

Determining a Focus for Practice-Based Teacher Education

Additionally, the field has just begun to describe the practices on which these teacher education programs should focus. Because time to learn to teach science is limited within an elementary teacher education program due to beginning teachers needing to take methods courses in additional disciplines (e.g., mathematics, English/language arts, social studies), science teacher educators must carefully select and focus on a smaller set of teaching practices.

Researchers focused on developing practice-based teacher education programs have suggested criteria for selecting these core or high-leverage practices (HLPs). Grossman and colleagues (2009) suggest these practices be those which: (1) occur frequently in teaching, (2) novices can enact using different curricula or instructional approaches, (3) novices can begin to master, (4) allow novices opportunities to learn more about students and teaching, and (5) are research-based and have the potential to improve student achievement. Ball and colleagues (2009) and Davis and Boerst (2014) echo these criteria, explaining that HLPs should include those teaching practices which can be used across grade levels and subject areas, are likely practices to be learned by a beginner, and are those which can be seen as useful building blocks in learning how to do the work of teaching. Windschitl and colleagues (2012) add to these criteria stating the practices should also "build on one another instructionally and play recognizable roles together in a coherent system of teaching" (2012, p. 883).

For a practice-based approach to teacher education to be supportive of teacher learning, teacher educators must recognize areas and aspects of the practice with which beginning and experienced teachers struggle to be able to logically decompose and recompose teaching practices and facilitate discussions around those teaching practices (Kazemi, Franke, & Lampert, 2009; Lampert et al., 2013). For example, when supporting beginning teachers' learning to plan and enact investigation-based discussions, teacher educators need to: (1) define and decompose the practice of planning and enacting investigation-based discussions, (2) recognize the areas or aspects of leading classroom discussions that are difficult for teachers and consider the previous research or interventions aimed to support teachers in facilitating these types of discussions, (3) design instructional activities that allow beginning teachers to experience representations of the practice and engage in approximations of the practice either through rehearsal with colleagues or with actual elementary students, and (4) design opportunities for beginning teachers to decompose their own and others' practice and reflect on areas of success and missed opportunities (cf. McDonald, Kazemi, & Kavanagh, 2013). This example illustrates the complexity of the practice of teacher educators, which then has the potential to limit or provide learning opportunities for beginning teachers. Thus, because the practice of facilitating investigation-based discussions is central to this study, it is important to consider the research that has been done investigating each of these areas.

Facilitating Investigation-based Discussions

In this section, first I describe how researchers define and decompose the practice of facilitating whole class discussions more generally, looking across multiple subject areas. Then I consider the ways in which science education researchers define and decompose the practice in connection to the practices of the discipline. Second I consider the research on the challenges teachers face (both in respect to teaching knowledge and teaching practice) when planning and enacting investigation-based discussions. Third I discuss research detailing interventions and practice-based science methods courses that have aimed to support teachers' learning to facilitate investigation-based discussions.

Defining and Decomposing the Practice

The practice of leading classroom discussions is often included in researchers' lists of teaching practices that align with previously described criteria (Ball et al., 2009; Cartier et al., 2013; Grossman, Hammerness, et al., 2009; Windschitl et al., 2012). However the grain size at which that practice is defined differs. Grossman and colleagues (2009) define the practice as *leading classroom discussions,* which is made up of smaller instructional routines or teaching moves like revoicing student answers or modeling academic discourse. In mathematics education, Boerst and Sleep (2007) define *whole class discussions* as a domain made up of practices of a smaller grain size. Boerst and Sleep (2007) explain the practices of *eliciting students' ideas*, *managing group work*, and *establishing norms for classroom discussions* and the accompanying *teaching moves,* such as revoicing and use of wait time, are essential for productive classroom discussions. Similarly, Kloser (2014) defines the practice of "facilitating discourse" in science classrooms as creating opportunities for student to engage in science-related talk with the teacher and peers. Fluency with this practice is demonstrated by providing multiple types of opportunities for discussions, facilitating sharing of ideas and evidence, and justification of those ideas.

In the field of science teacher education, Windschitl and colleagues (2012) describe four individual practices and a coherent framework to guide ambitious science teaching. Windschitl and colleagues (2012) define the practice as *involving students in disciplinary talk,* situating small group and whole class discussions within several disciplinary practices of science (e.g., asking questions, analyzing data, developing and using models, and constructing explanations).

Windschitl and colleagues (2012) outline four teaching practices that allow students to "reason dialogically" and "develop durable forms of understanding" while constructing and revising mechanistic explanations (p.885). Through teachers' use of these practices, students are apprenticed into the epistemic language and scientific ways of thinking while considering students' everyday language, experiences, and knowledge. These practices include one planning practice, *Constructing the Big Idea*, and three enactment practices referred to as *Discourses*: (1) *Eliciting students' ideas to adapt instruction,* (2) *Helping students make sense of the material activity, and* (3) *Pressing students for evidence-based explanations*. Windschitl and colleagues (2015) comment that each of these practices can be broken down into *sub-goals*. For example, *Discourse 1: Eliciting students' ideas to adapt instruction*, may, in fact, be made up of three *sub-goals: eliciting students' ideas, representing publically selected elements of students' thinking, and adapting subsequent instruction based on partial understandings students appear to have*.

Considering the potential parallels between mathematics education and science education, Cartier and colleagues (2013) describe five teaching practices that are productive for *task-based*[2] *discussions.* The five practices included are:

1. *Anticipating* how students are likely to respond to a task
2. *Monitoring* what students are doing while working on the task
3. *Selecting* particular students to present their work during the whole-class discussion
4. *Sequencing* student work to be displayed in a particular order
5. *Connecting* different students' responses to each other and to key scientific ideas

(Cartier et al., 2013, p. 28)

Cartier and colleagues (2013) explain these practices are designed to help teachers support students to share ideas, focus on meaning making, and develop new or richer understandings of scientific phenomena. Instead of focusing on in-the-moment responses to student contributions to the discussion, the five practices emphasize the importance of planning.

Calling for teachers to engage students in discussions while using formative assessment practices, Gotwals and Birmingham (2015) prioritize *eliciting, identifying, interpreting,* and *responding* to students' science ideas. When done well, these formative assessment practices can be thought of as *responsive teaching* (Colley & Windschitl, 2016; Gotwals & Birmingham, 2015; Pierson, 2008) and may engage students in dialogic talk about big ideas (Duschl, Schweingruber, & Shouse, 2007), identify prior knowledge and alternative ideas (diSessa &

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[2] Cartier and colleagues (2013) list three categories of *tasks:* (1) experimentation, (2) data representation, analysis, and interpretation, and (3) explanation.

Minstrell, 1998), and provide feedback for students and about teaching (Kohler, Henning, & Usma-Wilches, 2008).

Despite the different terms used to describe the practice (and sub-practices) of facilitating investigation-based discussions, all of the descriptions have several things in common. All consider the teacher as an agent for creating a supportive classroom culture for science discussions. The teacher must also support students to do the cognitive work utilizing open questions that invite multiple responses, foreground and capitalize on students' ideas and questions, and steer the discussion toward intended learning goals (Kucan & Palincsar, 2013).

The teacher serves as a facilitator, rather than a conveyor of knowledge. This is not to say the teacher does not play a major role in the discussion. On the contrary, the role of facilitator requires the teacher to maintain a "consistent prominence" during the discussion (Kucan & Palincsar, 2013, p. 133). Stepping into this role requires the teacher to be less concerned about evaluating whether or not students are right or wrong, but rather to focus on listening to students' reasoning, notice nuances in students' ideas, and adjust instruction accordingly (Colley & Windschitl, 2016; Gotwals & Birmingham, 2015).

Additionally, science education researchers agree that investigation-based discussions can provide a space for students to engage in multiple science practices (Berland & Reiser, 2009; McNeill, 2009; McNeill & Pimentel, 2010; Sampson, Grooms, & Walker, 2011; Windschitl et al., 2012). To begin these discussions, students are supported in publically analyzing data. Then, a teacher may ask students to develop claims to answer an investigation question posed at the start of the investigation. To push students to support their claims with scientific reasoning, teachers may ask students to represent their thinking by drawing a model showing a set of inter-related ideas about a scientific phenomenon (Windschitl et al., 2012). Students use their models to support their claims and engage in argumentation using evidence. Through whole-class investigation-based discussions, students can come to collective agreements regarding the best explanation for the scientific phenomenon, and compare that explanation to the scientifically accepted explanation (Duschl et al., 2007; National Research Council, 2012; Sampson et al., 2011; Windschitl et al., 2012).

Illuminating Challenges in Facilitating Investigation-based Discussions

Researchers have noted both teaching knowledge and the ways in which teachers enact (or fail to enact) teaching practice as areas that shape facilitation of investigation-based discussions. Illustrating one example of how subject matter knowledge of scientific content shapes discussions, Carlsen (1987) found that when secondary science beginning teachers did not have a strong understanding of the science topic they were teaching, student participation in discussions was minimal. Additionally, beginning teachers frequently used low cognitive-level questions to control the classroom discourse (Carlsen, 1987).

Similarly, Windschitl and colleagues (2012) found secondary science beginning teachers had difficulty identifying the *big idea* (e.g., transformation of energy) their lessons were asking students to grapple with, and teacher identification of the big idea was a "critical precondition to trying out sophisticated forms of instruction" (p. 888). Windschitl and colleagues (2012) argue that without identification of a big idea, ambitious science teaching, which includes all three enactment practices, could not be initiated. These studies highlight the importance of subject matter knowledge of scientific content in shaping enactments of investigation-based discussions.

Similar patterns have been found when investigating how subject matter knowledge of the science practices shapes investigation-based discussions. Beginning teachers rarely ask students to use models the way scientists do, to support claims and argue for explanations (cf.

Kuhn, 1963; Latour & Woolgar, 1986). Rather, many teachers believe models are useful only as a visual to explain scientific phenomena to others (Cullen & Crawford, 2004). With respect to explanation construction and argumentation, beginning teachers may not understand the purpose of argumentation. This is likely because they have had little previous experience engaging in argumentation themselves, or they define the practice in a way that is not aligned with the vision of the *Framework* (McNeill, 2009; National Research Council, 2012; Osborne, Erduran, & Simon, 2004; Osborne, 2014; Simon et al., 2006). Beginning teachers may also struggle to understand the constructs and defining features of knowledge building in science and the role of these constructs in justifying knowledge produced by science (e.g., how scientific claims are supported by data and evidence) (Osborne, 2014).

Due to this underdeveloped understanding of how and why the science practices are used to construct and justify scientific knowledge, beginning teachers may not understand why they should facilitate these types of discussions or why students should engage in the practices in the first place (Osborne, 2014; Windschitl et al., 2015). Recent research in the areas of student learning and expert teaching has agreed that careful orchestration of classroom talk (involving both students and teacher) aids productive reasoning by students (Colley & Windschitl, 2016; Engle, 2006; Leinhardt & Steele, 2005; Mortimer & Scott, 2003; Windschitl et al., 2015), and in this way "sensemaking through scaffolded discussions is the primary mechanism for promoting deep understanding of complex concepts and robust reasoning" (Michaels, O'Connor, & Resnick, 2008, p. 284). Despite this research showing the learning opportunities these types of discussions can provide, beginning teachers may still feel like they are engaging students in investigation-based discussions only to reproduce textbook accounts of the history of science (Windschitl, et al., 2015).

Even if beginning teachers have well developed subject matter knowledge, this does not equate to well-developed pedagogical content knowledge or productive teaching practice for facilitating investigation-based discussions. This is in part because facilitating investigation-based discussions productive for student learning requires the teacher step into the role of facilitator, one who listens, encourages, and helps direct the discussion toward the intended learning goals (Crawford, 2000; 2007; Shah, 2011). Teachers must anticipate, monitor, and connect student thinking (Cartier, et al., 2013), and then be responsive to the substance of student thinking (Coffey et al., 2011). To do so teachers could use a set of talk moves such as open ended questions to elicit and respond to students' ideas and help students connect ideas throughout the discussion (Colley & Windschitl, 2016; National Research Council, 2014; Nystrand, Wu, Gamoran, Zeiser, & Long, 2003).

Research has shown, rather than following a more dialogic pattern in which students converse with one another, whole-class discussions often follow the Initiation – Response – Evaluation (IRE) tridactic discourse pattern (Lemke, 1990; Mehan, 1979). Teachers often dominate the conversation in terms of duration of talk and direction. In doing so, teachers limit the opportunities they have to learn about their students' thinking (Herrenkohl, Palincsar, DeWater, & Kawasaki, 1999; Hogan et al., 1999; Lemke, 1990). This discussion format also sacrifices student opportunities to reason publically – one of the key aspects of scientific talk (Ford & Forman, 2006; Ford, 2008; Lemke, 1990).

Even if teachers are able to break the cycle of IRE dialogue and allow student talk to dominate the conversation, teachers struggle to know what to do with student ideas once elicited (Harris, Phillips, & Penuel, 2012; Penuel, Moorthy, DeBarger, Beauvineau, & Allison, 2012). Rather than being an opportunity to collectively construct knowledge and use student ideas as resources, teacher requests and accompanying student contributions seem to reinforce the norm of being respectful to others (Harris et al., 2012; Penuel et al., 2012; Windschitl et al., 2015).

Teachers also struggle to support student engagement in the practices of explanation construction and argumentation, which frequently occur during investigation-based discussions. For example, Simon and colleagues (2006) found despite participation in a yearlong series of workshops designed to support teachers' learning to engage students in scientific argumentation, several teachers had difficulty facilitating the construction of arguments. These teachers also failed to have students engage in counter-arguing and reflection. Additionally, the quality of the students' arguments did not improve over the course of the intervention (Simon et al., 2006). Similarly, researchers have found teachers struggle to help students select appropriate observations to use as evidence for their claims (McNeill & Krajcik, 2007; McNeill, 2009). Even when students do use evidence to make sense of scientific phenomena, teachers rarely ask students to attempt to persuade others of their findings (Berland & Reiser, 2009).

In sum, teachers struggle facilitating investigation-based discussions when they have underdeveloped subject matter knowledge of the scientific content or science practices, underdeveloped pedagogical content knowledge for science teaching, or underdeveloped teaching practice (or a combination of all three). Thus, there is a need to support teachers in developing their knowledge for science teaching (both SMK and PCK) and teaching practice for facilitating purposeful investigation-based discussions.

Supporting Teachers to Learn What "Works" to Facilitate Discussions

In the next section, I describe aspects of teaching practice that support students to reason dialogically including types of talk and engagement in teaching practices that capitalize on student contributions. Additionally, I summarize prior research describing teacher education programs utilizing tools designed to support beginning teachers' learning to teach in ways that are responsive to student ideas. Finally, using Remillard's (2005) participatory framework, I consider how beginning teachers' resources (e.g., beginning teacher subject matter knowledge, beliefs about science teaching, etc.) may influence their use of practices and tools to plan and enact investigation-based discussions.

Types of talk. Orchestrating productive investigation-based discussions calls for a diverse set of talk moves and teaching strategies that teachers can use to shape whole-class discussions. Research provides evidence of several different strategies that can provide additional opportunities for students to make sense of scientific phenomena. For example, Cervetti and colleagues (2014) found that discussions during which students began to engage in student-to-student sensemaking talk, "were shaped by specific conceptual framing questions, which were often provided to the student in print and referred to by the teacher in the course of the discussion" (p. 563). In the same study, researchers found that sensemaking talk occurred only when students had first hand experiences with the scientific phenomena – meaning students were provided opportunities to investigate the phenomena by engaging in several science practices (Cervetti et al., 2014).

The type of questioning is also an important factor in facilitating student-to-student talk during discussions (Cervetti et al., 2014; Hogan, 1999; Hogan, Nastasi, & Pressley, 1999b; McNeill & Pimental, 2010; Nystrand et al., 2003). McNeill and Pimentel (2010) and Nystrand and colleagues (2003) found teachers' use of open-ended questions encouraged students to clarify their thinking to others and connect their ideas to previous ideas shared by other students. Teachers' use of open-ended questions was often paired with increased student talk and increased used of evidence and reasoning to justify ideas (McNeill & Pimental, 2010).

Research also provides evidence for benefits of modeling elements of productive talk for students (Brown & Spang, 2008; Brown & Ryoo, 2008; McNeill & Pimentel, 2010; Stroupe, 2014; Thompson et al., 2016). McNeill and Pimentel (2010) found when a teacher made explicit connections between students' ideas, students reflected on their own and others' thinking and considered multiple viewpoints. Additionally, when teachers model scientific discourse and reasoning for students, for example by using multiple pieces of evidence to justify one's claim and connect that claim to others' ideas, students are more likely to follow teachers' discursive patterns, using multiple pieces of evidence and making connections themselves (Brown & Spang, 2008).

In the *Literacy for Science* workshop (National Research Council, 2014), Michaels argued that providing teachers with broad suggestions of how to guide classroom discussions (e.g., using higher order questions) fails to provide useful guidance. Teachers benefit more from learning specific *talk moves* (National Research Council, 2014) to help students navigate through the practices of explanation construction and argumentation. The use of talk moves allows teachers to shift between *authoritative* and *dialogic* discourses, both of which are needed to support students' learning (Sassi et al., 2013).

In *authoritative discourse*, the teacher introduces and focuses on the canonical explanation of scientific phenomena through question and answer sequences to help students understand the established knowledge. In *dialogic discourse*, the teacher encourages students to grapple with diverse ideas and identify how those ideas relate to one another and to the established scientific knowledge (Mortimer & Scott, 2003; Scott, Mortimer, & Aguiar, 2006). These two types of discourse exist in tension in the science classroom. Teachers need to make purposeful shifts between the two during investigation-based discussions to help guide student understanding of scientific phenomena (Scott et al., 2006). For example, engaging in *dialogic discourse*, a teacher might pose an open-ended question to her students to elicit their initial ideas, and then follow up the open-ended question with a prompt to facilitate student connection of ideas, allowing students to share ideas with each other without teacher evaluation. After the students have had time to discuss their ideas with each other, the teacher might switch to *authoritative discourse*, using a teacher monologue to summarize the students' ideas and reiterate the important content that was discussed. With the goals of the lesson in mind, teachers can shift into authoritative discourse productively, keeping the lesson on track progressing toward the learning goals, while still allowing space for students to do the intellectual work and discuss their ideas dialogically.

Talk moves can serve as one tool to bring about both authoritative and dialogic discourse (Michaels, O'Connor, Hall, & Resnick, 2002; Sassi et al., 2013). Because researchers have advocated for the use of talk moves to shift between authoritative and dialogic discourse, in this study I describe teachers' use of those types of talk moves while engaging in the two types of discourse.

Productive teaching practice and use of tools. While the focus on types of talk is important, Windschitl and colleagues (2015) suggest research on how to support teachers to engage in other aspects of teaching practice is equally as important. Colley and Windschitl (2016) argue that while having a "tool kit of discourse moves is necessary", talk moves alone are not enough to break the common I-R-E discussion patterns pervasive in U.S. science classrooms (p. 1034). Responsive pathways that foster sensemaking discussion (i.e., instances in which the teacher initiates the discussion, students respond, and then through revoicing or questioning the teacher prompts students to elaborate upon, clarify, restate, justify or compare ideas in play) occurred more frequently when teachers used several talked moves. For example, the teacher poses an open-ended question and prompts students to elaborate in combination with drawing student attention to a referent (Mercer, 2008) such as a representation[3] of data or public record of student ideas (Colley & Windschitl, 2016).

Additionally, members of the science education community have advocated for the development of a metalanguage to help teachers discuss several of the science practices (e.g., explanation and argumentation), in which students engage during investigation-based discussions (National Research Council, 2014). Studies have explored how teachers learn to use metalanguage and frameworks (e.g., Toulmin's (1958) framework for argumentation) to help students engage in science practices (Arias, 2015; Berland, 2008; Berland & Reiser, 2011; Berland & Reiser, 2009; McNeill, 2009; McNeill & Pimentel, 2010; McNeill, 2011; Windschitl et al., 2012). For example, Arias (2015) found beginning teachers within a practice-based teacher education program were able to learn to support students to construct explanations over time while drawing on an Engage-Experience-Explain framework for science teaching (Benedict- Chambers, 2014; cf. Bybee et al., 2006; Davis, in press) and other tools such as a claim-evidence-reasoning framework (McNeill& Krajcik, 2011; cf. Toulmin, 1958).

Similarly, Ross (2014) found the use of the five-practice framework (Cartier et al., 2013) was supportive for teachers' learning to use productive teaching practices to facilitate task-based discussions. Use of the five practice framework also supported development of secondary science teachers' pedagogical design capacity (Brown, 2009) to plan lessons that provided

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[3] Like Colley & Windschitl (2016), within this dissertation, I use "representation" to describe ways teachers can help students to organize their data or use of a graphic organizer to publicly record students' ideas during the lesson. I do not intend to use "representation" in reference to "scientific models" or "instructional representations" intended to depict different ways to represent science content (e.g., electric current flowing electric circuits shown as water flowing through pipes).

students opportunities to engage in sensemaking talk (Ross, 2014). The beginning teachers also described the learning cycle (Bybee et al., 2006) as a helpful resource for planning task-based discussions. Teachers who demonstrated high pedagogical design capacity for planning task-based discussions developed a monitoring tool to be used while students were engaging in the task. The monitoring tool listed anticipated students' ideas (both scientifically accurate ideas and common alternative ideas), and planned questions to further elicit students' thinking (Ross, 2014).

Windschitl and colleagues (2012) found the use of their four-practice framework and accompanying tools for ambitious science teaching helped beginning teachers in a practice-based teacher education program engage students in productive discussions about scientific phenomena. Windschitl and colleagues (2012) advocate for the use of three types of tools: *Core tools*, *Priming tools*, and *Face-to-face tools*. *Core tools*, such as the four-practice framework in model-based inquiry, are used to organize the lessons' overall purposes, and provide direction for instruction. These tools also become a reference for shared language about the science practices in the community of learners. *Priming tools* are used for planning. These tools are intended to prepare the teacher for purposeful interactions with learners around important science ideas, and they become a basis for shared language about features of teaching practice, such as talk moves. Lastly, *Face-to-face tools*, such as *back-pocket questions* that teachers can use to probe students' thinking about patterns in data or about scientific phenomena more generally, directly mediate interactions during the discussions and scaffold students' participation in complex reasoning and science talk and practice (Windschitl et al., 2012).

The present study looks closely at how beginning teachers utilize the types of tools both Windschitl and colleagues (2012) and Ross (2014) describe. Windschitl and colleagues (2012) and Ross (2014) explored the types of tools that supported *secondary* science beginning teachers. Therefore, some of these tools were adapted for use by elementary beginning teachers within elementary science classrooms. The design and modification of the suite of tools is described in detail in Chapter 3 of this dissertation.

Relationships between teacher characteristics, tool use, and teaching practice. Less is known about how teachers learn to recognize and capitalize on students' ideas as "resources" to help guide discussions about scientific phenomena. Windschitl and colleagues (2015) argue there is "strong anecdotal evidence that some teachers are pre-disposed to attend to student reasoning and to use students' ideas productively in instruction, while other teachers appear unable to recognize or cultivate student reasoning" (p. 15). This begs the question, is this type of teaching "teachable"? If so, what teacher characteristics may shape how teachers enact this type of instruction, and what other types of tools can be used to help to support teachers, particularly beginning elementary teachers, in facilitating this type of teaching? Thus, the purpose of this study is to begin to investigate these lingering questions.

To depict relationships that exist between intern characteristics and tool use, I draw on Remillard's (2005) participatory framework (See Figure 2-3). This framework is grounded in the theoretical perspective that teachers and curriculum materials participate together in an ever-changing, collaborative relationship (Brown, 2009; Remillard, 1999; 2000; 2005).

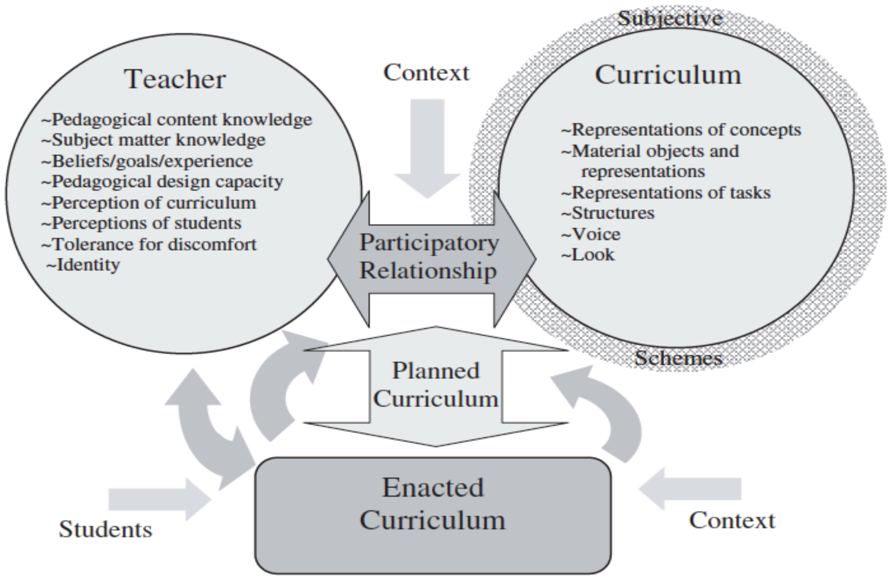

Figure 2-3: Remillard's (2005) teacher-curriculum participatory relationship framework

In this study, I adapt the participatory framework to highlight relationships between intern characteristics and use of tools provided by a science methods course (the context of this study). Within this participatory relationship, tools provided during the methods course serve a dual purpose (Beyer & Davis, 2012). First, the tools serve as resources to guide intern planning and lesson enactment, containing content, representations, and instructional approaches for guiding student learning. Second, drawing on the conception of "tool" from a sociocultural perspective, the tools are products of social activity (Cole & Werstch, 1996; Vygotsky, 1978; Werstch, 1991). Subjective meanings shape ideas within the tools and intern conceptions about science teaching mediate intern interaction with the tools (cf. Beyer & Davis, 2012).

The participatory relationship between intern characteristic and tools is reminiscent of past studies describing teacher use of curriculum materials as mutual adaptation (McLaughlin, 1976; Remillard, 2005). Mutual adaptation is the idea that both the curriculum and its users change through an iterative process over time. Just as intern interaction with the tools may shape the tools, intern interaction with the tools may also, in turn, shape intern knowledge for science teaching and thus impact teaching practice (cf. Vygotsky, 1978; Werstch, 1991). Thus, the tools can play an active role in shaping how beginning teachers think about and learn to teach elementary science.

In addition to the ways the tools shape the participatory relationship, the interns play an active role in the participatory relationship. As interns read and experience use of the tools during the methods course, they draw upon their own knowledge and beliefs, both about science content and practice and science teaching more generally. The resources interns bring with them to the methods course ultimately shape how they interact and use the tools (cf. Remillard, 2005). Therefore, both the interns and the tools are simultaneously interacting with one another and shaping both the planned and enacted investigation-based science lessons. Several hypotheses of how interns' characteristics mediate tool use and vice versa are presented in Chapter 4 of this dissertation.

In sum, interns' characteristics, specifically their knowledge and beliefs about science content and science practices and knowledge and beliefs about science teaching mediate how interns interact with, interpret, and adapt tools designed specifically to foster development of knowledge for science teaching. In turn, use of the tools can shape how interns think about, plan, and enact investigation-based science lessons.

Conclusion

This chapter outlined the empirical findings and theoretical perspectives about supporting beginning elementary science teachers to facilitate investigation-based discussions by providing students opportunities to learn science content through engagement in science practices. I also decomposed the teaching practice of facilitating investigation-based discussion describing both challenges beginning teachers face and productive teaching practices that provide opportunities for students to engage in explanation construction and argumentation with evidence. Finally, I discussed the use of Remillard's (2005) participatory relationship framework to describe potential relationships that exist between intern characteristics, specifically knowledge and beliefs about science content and science practices and knowledge and beliefs about science teaching interacts with intern tool use and planned and enacted investigation-based science lessons. The next chapter describes how I draw on both empirical evidence and theoretical perspectives to design and modify a suite of tools to support interns to facilitate investigation-based discussions.

CHAPTER 3

DESIGNING A SUITE OF TOOLS

Building on existing literature, I developed and/or modified tools to support beginning teachers to learn to facilitate investigation-based discussions in science. Within the science methods course that was the context of this study, interns were provided with a set of eight tools designed with the purpose of supporting interns to engage in the productive practices that capitalize on student contributions (Cartier et al., 2013; Ross, 2014; Windschitl et al, 2012). As a reminder, I assume that a tool operates in the space between an individual and a complex task that might be out of reach for the intern without some form of support or assistance (Cole & Wertsch, 1996; Wertsch, 1991). For example interns were given a *talk moves tool* that provided science-teaching specific talk moves that can be used to support productive teacher-to-student and student-to-student dialogue during each element of the *Engage-Experience-Explain (EEE) framework*. These talk moves could then be used to support interns to script segments of their investigation-based discussions providing opportunities for students to engage in argumentation. Each tool was designed to support development of specific domains of teacher subject matter knowledge and/or pedagogical content knowledge for science teaching. Table 3-1 provides a summary of the tools and the domains of knowledge they target. This chapter describes each of the tools, provides detail on how the tool was used within the elementary science methods course, and explains which domain(s) of knowledge the tool was designed to support.

Table 3-1: Suite of Tools Designed to Support Teacher Knowledge for Science Teaching

Tool Name:	Description:
EEE Framework	Science lesson framework designed to support teachers in engaging students in the practices of scientists while learning about scientific content. The EEE framework outlines what teachers do during each element of the framework as well as what students do during each element of the framework. Additionally, the tool provides connections to the NGSS science practices and the high leverage practices that are cornerstones of the teacher education program. (See Appendix A.) Fosters pedagogical content knowledge: knowledge of content and teaching.
Instructional Planning Template	A lesson-planning template designed to support teachers' planning of investigation-based science lessons. Prompts teachers to think about and plan for important elements of the lesson including anticipating students' ideas about scientific phenomena, considering how the lesson fits in with the big ideas in science, management considerations for handling small group work and investigation materials, etc. (See Appendix B.) Fosters all knowledge domains.
Skeleton lesson plan tool	A modified and basic version of the instructional planning template which helps to remind teachers of the overall lesson trajectory including: NGSS standard the lesson is considering, investigation question, important data that can be used as evidence to support scientifically accurate claim, and the C-E-R statement that is included as a learning goal for the lesson. (See Appendix C.) Fosters all knowledge domains.
Card sorting activity	Designed to help support teachers develop and consider the subject matter knowledge important for the focal lessons. Teachers can use their completed card sorting activity to help plan lessons and larger units. There is potential for teachers to use this activity with their students to support students' learning of important science concepts. (See Appendix D.) Fosters subject matter knowledge: common content knowledge, horizon content knowledge.
Talk moves tool	Designed to provide talk moves that can be used to support productive teacher-to-student and student-to-student dialogue during each element of the EEE framework. The tool outlines possible talk moves that can be used to elicit students' ideas, monitor data collection and help students understand the nature of the investigation, press students to provide explanations with justifications, and connect students' ideas. (See Appendix E.) Fosters pedagogical content knowledge: knowledge of content and students.
Alternative Ideas Tool	Provides interns a set of research-based common alternative ideas students are likely to have about a scientific phenomenon. Tool can be used to anticipate student thinking. (See Appendix F.) Fosters pedagogical content knowledge: knowledge of content and students.
Monitoring tool	Designed to help teachers monitor student activities while students engage in planning and carrying out investigations. When using this tool, teachers are asked to consider likely student ideas (both scientifically accurate as well as common alternative ideas) and student struggles that are common when engaging in scientific practices. (See Appendix G.) Fosters pedagogical content knowledge: knowledge of content and students, knowledge of content and teaching.
Claim-Evidence-Reasoning (C-E-R) Template	Primarily for use with students. Provides elementary students a sentence starter and framework for writing evidence-based claims. Helps to remind students of the investigation questions, and the three parts of an evidence-based claim (including the use of multiple pieces of evidence). Particularly useful for groups of students who are new to the C-E-R framework. (See Appendix H.) Fosters pedagogical content knowledge: knowledge of content and students, knowledge of content and teaching.

Engage-Experience-Explain Framework

The elementary education science methods course utilizes the *Engage-Experience-Explain (EEE)* (See Benedict-Chambers, 2014; Davis, in press) *framework* (See Appendix A) for investigation-based elementary science lessons. This core tool decomposes science teaching into three distinct elements: *Engage*, *Experience*, and *Explain with Evidence*, similar to the 5E instructional framework (Bybee et al., 2006). During the *Engage Element*, interns are asked to support students in identifying an investigation question or problem and elicit students' ideas about that question. In the *Experience Element*, interns are asked to support students in establishing data collection and carrying out the investigation. The *Explain with Evidence Element* asks interns to support students to analyze data gathered in the Experience element and find patterns within that data. Interns are also asked to help students construct evidence-based claims and apply their knowledge to new situations. Whole-class investigation-based discussions typically occur during the Explain element of this teaching framework; however, the teaching moves made by the intern during the Engage and Experience element shape the enactment of the Explain element.

The *EEE framework* was designed to support teachers in engaging students in the practices of scientists while learning about scientific content. The *EEE framework* outlines what teachers can do during each element of the framework, providing decompositions of the larger teaching practices involved in enacting an investigation-based discussion, as well as what students do during each element of the framework. Additionally, the tool provides connections to the *NGSS* science practices and the high leverage practices that are cornerstones of the teacher education program. Much like the 5E instructional framework, the *EEE framework* provides the interns with information needed to make decisions about how an investigation-based science could be sequenced and provides suggestions for instructional strategies and techniques that are likely to be effective (Bybee, et al., 2006).

By providing these suggestions, the *EEE framework* works to foster development of interns' pedagogical content knowledge, specifically their knowledge of content and teaching. For example, by using the *EEE framework* to plan their lessons, interns are prompted to use instructional strategies that consider students' prior knowledge about scientific phenomena, and allow students to develop scientific claims based on data from the in-class investigation.

Instructional Planning Template

The elementary education science methods course utilizes an *instructional planning template*, a priming tool aligned with the *EEE framework*. Interns were asked to use the *instructional planning template* to plan all of their lessons associated with assignments in the science methods course. Interns use a similar template throughout their teacher education program; however, the template for the science methods course (See Appendix B) was modified specifically to foster planning of investigation-based science lessons. For example, the template prompts the interns to consider common alternative ideas students may have about a particular science topic, requires interns to describe how the individual lesson aligns with the goals of the larger science unit, and provides space for interns to develop a claim based on evidence and reasoning students should be able to construct after the lesson is complete. Additionally, the *instructional planning template* prompts interns to think about and plan for classroom-management considerations for handling small group work and investigation materials so students are able to engage in the practices of scientists (e.g., carrying out investigations). The version of the template included in this dissertation was developed iteratively over time, providing additional support for interns in areas previous research determined were areas of teacher struggles (e.g., missed opportunities to press students to provide multiple pieces of evidence) (Arias, 2015; Arias, et al., 2016; Beyer & Davis, 2009; Davis, 2006).

The instructional planning template serves as a tool for planning in a similar way to the lesson-planning considerations presented by Zembal-Saul and colleagues (2000) – guiding interns' thinking about subject matter knowledge, and pedagogical content knowledge. For example, by prompting interns to consider multiple pieces of evidence that could be used to support the scientifically accurate claim for the lesson, interns have the opportunity to develop both common content knowledge of the scientific phenomena of focus, and also knowledge of content and teaching by determining which pieces of data from the investigation students can use as evidence to support their claims.

The template also incorporates the greater overall vision of the teacher education program (Davis & Boerst, 2014). The instructional planning template not only provides interns with cohesiveness and a clear trajectory within each lesson they plan (Leinhardt, Zigmond, & Cooley, 1981; Leinhardt & Greeno, 1986), but also across their experiences within the teacher education program.

Skeleton Lesson Planning Tool

The *skeleton lesson planning tool*, a priming tool, is a modified and simplified version of the *instructional planning template* used in the science methods course, designed for interns to use while teaching their lessons to elementary students. Interns could choose to use this tool, but use was not required in the methods course. The tool was developed after interns enrolled in prior iterations of the science methods course requested a shorter version of the *instructional planning template* that they could refer to while working with students. Several students in both the undergraduate and masters version of the science methods course expressed that, while helpful in the planning stages, the *instructional planning template* was difficult to teach from.

The *skeleton lesson planning tool* prompts interns to consider the overall lesson trajectory of their investigation-based lessons, as well several aspects of the lesson deemed important by the methods course instructors including: the *Next Generation Science Standards* performance expectation targeted by the lesson, the lesson's investigation question, important data that could be used as evidence to support a scientifically accurate claim, and the scientific claim based on evidence and reasoning that was included as a learning goal for the lesson. Like the *instructional planning template*, the *skeleton lesson planning tool* was designed to guide interns' thinking about subject matter knowledge and pedagogical content knowledge, emphasizing salient aspects of the lesson in an abridged way.

Card Sorting Activity

Interns completed the *card sorting activity* (Appendix D), a priming tool, in association with the two lessons they planned during the science methods course. These lessons are described in further detail in the next chapter, but focused either on the function of plant stems or thermal equilibrium (described as the peer teaching lesson) and a content area being covered in the intern's field placement classroom (described as the Lesson in Field Experience lesson or LiFE lesson). Rather than using the *card sorting activity* to begin to design their own curriculum like the teachers in Windschitl and colleagues' (2012) study, interns completed the *card sorting activity* to familiarize themselves with the lessons and corresponding pre-existing curriculum units (e.g., the Science Companion Energy Unit; Chicago Science Group, 2012).

For the first *card sorting activity*, associated with the peer teaching lesson focused on either functions of stems or thermal equilibrium, interns were given a set of big ideas from the unit curriculum materials and the *Atlas for Science Literacy* (American Association for the Advancement of Science & National Science Teachers Association, 2007), for example – "energy has many forms". Then, individually, each intern was asked to organize the big ideas in a two dimensional space, representing how the ideas are related to one another. Interns were asked to describe how the ideas related to one another on the lines connecting the big ideas, provide a short summary of how the peer teaching lesson fits into the "bigger picture" being covered by the unit, and list three questions that arose for them about the science content by completing this activity.

During their co-planning sessions for the peer teaching assignment, the interns were instructed to utilize and revise their initial *card sorting activity* as they planned for peer teaching. Interns worked collaboratively to revise their initial *card sorting activity*, but each intern was asked to submit a revised version of his or her *card sorting activity* after the final peer teaching.

The second *card sorting activity* was completed in a similar way. However, the interns developed their own set of "big ideas" using the unit curriculum materials associated with the lesson they planned to teach for the Lesson in Field Experience (LiFE) lesson assignment. Again, each intern was asked to organize the big ideas in a two dimensional space, representing how the ideas are related to one another. Interns were asked describe how the ideas relate to one another on the lines connecting the big ideas, provide a short summary of how the LiFE lesson fits into the "bigger picture" being covered by the unit, and list three questions that came up for them about the science content by completing this activity. Interns were able to choose to do this assignment individually or collaboratively with others teaching lessons within the same unit.

Informed by Windschitl and colleagues (2015), I adapted the *card sorting activity* to help support interns to develop and consider the subject matter knowledge that was important for the focal lessons. Because prior research has found teacher identification of the big ideas as a critical precursor to enacting ambitious science teaching (Windschitl, et al., 2012), it was important to provide interns with an opportunity to grapple with or refresh their own ideas about the science content.

Completion of the *card sorting activity* provided interns an opportunity to develop common content knowledge including details about the mechanistic explanation of the phenomenon students would be investigating in the interns' focal lessons. Completion of the *card sort activity* also provided an opportunity for interns to develop horizon content knowledge (Ball, Thames, & Phelps, 2008). By considering how the big ideas within the science unit were connected, interns may have a developed an understanding of the comprehensive science ideas required to help students make sense of the multiple investigations students would complete during the larger unit (Windschitl, 2012).

Talk Moves Tool

The *talk moves tool* (Appendix E), a priming tool for planning and face-to-face tool to be used directly with students, was provided to interns at the beginning of the science methods course. The tool is aligned with the *EEE framework* and outlines possible talk moves that can be used to elicit students' ideas, monitor data collection, press students to provide explanations with justifications, and connect students' ideas.

The use of talk moves allows teachers to shift between authoritative and dialogic discourses, both of which are needed to support students' learning (Sassi, Bopardikar, Kimball, & Michaels, 2013). In line with current research stating teachers benefit more from learning specific talk moves (Michaels, O'Connor, & Resnick, 2008; National Research Council, 2014) to help students navigate through the practices of explanation construction and argumentation, this tool was designed to suggest talk moves that could be used to support productive teacher-to-student and student-to-student dialog during each element of the *EEE framework*. Some of the talk moves provided were subject-neutral, for example, use of the phrase "tell me more about that." Others were science-teaching specific, for example, use of the phrase "Given your thinking so far, what do you predict will happen during our investigation and why?". The science-teaching specific talk moves were informed by suggested talk moves for facilitating science discussions (e.g. Kucan & Palincsar, 2013; Schweingruber, Shouse, Michaels, 2007; Zembal-Saul, McNeill, & Hershberger, 2013). The *talk moves tool* was also designed to support interns to engage students in the science practices of explanation construction and engagement in argumentation with evidence.

The set of science-teaching specific talk moves aligned with the *EEE framework* were designed to foster intern development of pedagogical content knowledge, particularly knowledge of content and teaching. For example, through using science-teaching specific talk moves, interns had the opportunity to support students to construct scientific explanations and engage in argumentation. Similar general talk moves were introduced in other subject-specific methods courses in the teacher education program; however, this was the first time the interns had received science-teaching specific talk moves. By making the talk moves subject-specific, it may have made the features of investigation-based science teaching more salient.

Alternative Ideas Tool

The *alternative ideas tool* (Appendix F), a priming tool, provided interns with a set of research-based common alternative ideas students are likely to have about scientific phenomena. The set included common alternative ideas (diSessa & Minstrell, 1998) students may have about scientific phenomena of focus for the peer teaching lessons, but the set did not include common alternative ideas for all of the concepts interns would be teaching for the lesson in the field assignment (LiFE). Within the *instructional planning template*, interns were prompted to consider possible alternative ideas students may have, but interns were not prompted to find likely student ideas in reputable sources.

Students have a wealth of ideas about natural phenomena based on the world in which they live (diSessa & Minstrell, 1998). While experienced teachers may be able to anticipate these ideas, novice teachers are unlikely to be in a position to do so (Abell, 2007; Davis et al., 2006; Furtak, Thompson, Braaten, & Windschitl, 2012). Thus, providing interns with a list of research-based common alternative ideas provides an opportunity for development of pedagogical content knowledge, particularly knowledge of content and students (Davis & Smithey, 2009). For example, if an intern knows children are likely to think that condensation forms on the outside of a glass of ice water because the water leaks through the class, the intern might plan in advance how to address the idea if it were to arise during an investigation-based discussion. Rather than simply labeling the student's idea as incorrect, the intern may develop a series of questions to ask the student to probe his or her thinking, or point the student toward evidence that might contradict that line of thinking.

Monitoring Tool

Interns were provided with an exemplar *monitoring tool* (Cartier, et al., 2013) (Appendix G) at the beginning of the methods course. The *monitoring tool* serves as both a priming tool, to be used during lesson planning, as well as a face-to-face tool to be used directly with students during the lesson enactment. The exemplar *monitoring tool* was created for a lesson focused on supporting students to follow the flow of electric current in a simple circuit. All interns experienced this lesson from the "student perspective" on the first day of the methods course.

The instructor used the monitoring tool as part of her instruction, and then debriefed with interns discussing the use of the tool to monitor ideas as interns were experiencing the lesson. The exemplar lists common researched-based alternative ideas as well as scientifically accurate understandings. Interns were then encouraged to use the exemplar to develop similar *monitoring tools* for both their peer teaching lesson and lesson in the field lesson assignments. Development of *monitoring tools* was not required for either assignment.

When creating the *monitoring tool* for each of their lessons, interns identified the features required for the scientific explanation of focus. One of those features might include listing multiple pieces of evidence for each claim being made. By identifying these features, the intern then might use the *monitoring tool* to formatively assess students' understandings during the enactment.

Additionally, when creating the *monitoring tool*, interns must anticipate common alternative ideas students may have about the science content and likely struggles students may have when engaging in carrying out investigations. For example, an intern may anticipate students might think a "short circuit" means there must be some sort of "break" in the path of electrical current flow. Additionally, interns may anticipate students may struggle with making clear, complete, and objective observations. In doing so, the intern recognizes that his or her students will come to the investigation with some understandings about the scientific phenomena, and may be better positioned to develop a plan to support students who are struggling with either the scientific content and/or the science practices "without taking over the thinking for them" (Cartier et al., 2013, p.52).

Finally, creation of the *monitoring tool* may prompt interns to determine how to respond to the work students produce that may not be accurate or complete (Cartier, et al., 2013). Interns tend not to think about students' ideas about science phenomena very carefully (Abell, 2007; Davis et al., 2006) and have limited ideas of what to do with students' ideas after eliciting them (Gotwals & Birmingham, 2015; Zembal-Saul, Blumenfeld, & Krajcik, 2000). By anticipating various ideas students may have about the scientific phenomena, an intern might be better able to plan what to do to guide students toward a more accurate understanding of the phenomena while still allowing students to do the cognitive work (Cartier, et al., 2013). For example, if an intern determines students struggle to make clear, complete, and accurate scientific observations, the intern may then use the *monitoring tool* in conjunction with the *talk moves tool* to develop questions that prompt students to think about the quality of their scientific drawings.

By using the *monitoring tool* to keep track of students' ideas during investigations, interns are provided an opportunity to foster development of teacher knowledge of content and students. Rather than circulating only to focus on whether students are on-task and using materials correctly, use of the *monitoring tool* prompts interns to carefully attend to what students say while they work together in groups. By having the anticipated student ideas, probing questions, and talk moves with her as the intern circulates, she can focus on asking questions to make students' thinking visible and help to clarify students' thinking for other group members (Cartier, et al., 2013).

Additionally, through use of the *monitoring tool*, the intern can begin to plan for the investigation-based discussion. By having a record of the ideas that arose during small-group discussions, the intern can begin to select which students or groups of students she wants to contribute at specific times during the investigation-based discussion. For example, if while monitoring students' ideas, one group of students was discussing why their data were not matching their predictions due to measurement errors, the intern could then plan to have that group of student contribute to the discussion when the class was contemplating probable causes of anomalous data. By noting which groups of students have particularly useful ideas[4] to contribute for specific aspects of the discussion, the intern will be better able to facilitate an investigation-based discussion that provides students with opportunities to both grapple with struggles and learn and discuss the disciplinary core ideas driving the lesson.

Providing opportunities to foster intern knowledge of content and students and knowledge of content and teaching, the *monitoring tool* was designed with the intent of helping interns anticipate and monitor student ideas about science content and science practices while students engage in planning and carrying out investigations. When creating and using the tool with students, interns are asked to consider the key features that must be present for a scientifically accurate claim based on evidence, the challenges students are likely to encounter or the alternative ideas that are likely to arise, and potentially how the intern might respond to the features and/or ideas that are not scientifically accurate (Cartier, et al., 2013).

Claim-Evidence-Reasoning Template

Interns were provided with the *claim-evidence-reasoning template* (Appendix H) at the start of the methods course. The template, a face-to-face tool, was designed to be used directly with students. The course instructor modeled how this template could be adapted for a lesson focused on supporting students to follow the flow of electric current in a simple circuit. Again, all interns experienced this lesson from the "student perspective" on the first day of the methods course completing the template as they experienced the investigation. The template provides interns with an example of a claim-evidence-reasoning handout a teacher might use with students

[4] Useful ideas may not always be the scientifically accurate ideas, but rather a common alternative idea many students had prior to the start of the investigation. The intern could then follow that idea by prompting students to consider if there is enough evidence to support that idea.

during an investigation-based science lesson. Interns were encouraged, but not required, to make similar handouts for their peer teaching lesson and lesson in the field assignments. Interns were also provided with suggestions of how to modify the claim-evidence-reasoning template to make it appropriate for each grade-level. For example, interns teaching students in grades K-2 were encouraged to have students draw their predictions rather than write them.

Given current reform efforts focused on engaging students in the science practice of constructing explanations (National Research Council, 2012; NGSS Lead States, 2013) and the difficulties teachers face with engaging their students in explanation construction (e.g., Berland & Reiser, 2009; McNeill, 2009), beginning teachers likely require additional support in doing so. The *claim-evidence-reasoning template* serves as a scaffold for students new to using the claim-evidence-reasoning framework for explanations (e.g., McNeill & Krajcik, 2011; Zembal-Saul, et al., 2013). The handout reminds children of the investigation question for the lesson, and the three parts of an evidence-based claim, including multiple pieces of evidence.

With the template, interns were also reminded of important components of an explanation, potentially fostering development of teacher knowledge of content and teaching. Additionally, by using the handout with students, interns may have been reminded of several important aspects of investigation-based lessons including asking a scientific question, making predictions with justification, recording and using data collected during the investigation, and finally crafting evidence-based claims that answer the investigation question.

Through use of the *claim-evidence-reasoning template*, interns may have been provided an additional opportunity to develop knowledge of content and students. Similar to the *monitoring tool*, by using the *claim-evidence-reasoning template* the intern may recognize that his or her students will come to the investigation with some understandings about the scientific phenomena, and may encourage his or her students to share those ideas by drawing or writing predictions. Interns can then use the handout to formatively assess students' initial understandings and determine patterns in student thinking. By noticing these patterns, the intern may be able to tailor students' experiences to help students progress toward a more accurate understanding of the science content. Interns can also provide an appropriate representation within the handout that will help students to begin to recognize important patterns in the data, and press students to provide multiple pieces of evidence for their claims. Finally, the intern can use the *claim-evidence-reasoning template* to formatively assess students understanding of the science content after the investigation is complete, and use this data to modify future instruction.

Use of the Tools Together

I designed or modified each of the tools so interns could use the tools in a complementary way during the methods course. For example, by aligning the *talk moves tool* and *lesson planning template* with the *EEE framework*, it was my hope that interns would be able to easily integrate the talk moves and overall goals of each element of the framework into their lesson plans. Creating tools that can be used together also allowed for emphasis of the most salient features science teaching (e.g., the integration of science content and science practices) and overarching goals of the teacher education program to be emphasized (e.g., recognition of student ideas as resources). For example, by consistently pressing interns to be aware of and utilize students' ideas (for example though the use of the *alternative ideas tool*, *monitoring tool*, and *claim-evidence-reasoning template*) interns may have been more likely to recognize that students often have ideas about scientific phenomenon prior to beginning the investigation-based science lesson.

Conclusion

This chapter outlined the tools that were designed and/or modified for the interns enrolled in the science methods course. I began by summarizing each tool and providing detail on how the tool was used within the methods course. Finally, I explained the domains of knowledge for science teaching each tool was designed to foster. The next chapter describes how I draw on my theoretical framework and research base in developing the design of the study, the collection of data, and the analysis of that data.

CHAPTER 4

METHODS

This descriptive study used qualitative data collection and analyses that were intended to better reveal how interns' knowledge and beliefs about science teaching and use of tools relate to one another and relate to characteristics of interns' plans and enactments of investigation-based discussions. In exploring these relationships, this study sought to (a) describe and examine interns' use of tools to plan and enact investigation-based discussions, (b) investigate the types of talk interns use, (c) describe how intern knowledge and beliefs about science practice and science content surfaced in the plans and enactments, and (d) discuss the ways in which interns capitalized on student contributions. Data for this study included interns' lesson plans, videos of interns' lesson enactments, interviews, and additional course assignments from the interns' science methods course. This chapter describes the research design, setting, and methods for this study. I begin this chapter by describing the study context and participants. Next, I describe how my role as the researcher and methods course instructor may have affected this study. Then, I provide detail about the study participants, data sources, and data collections and coding. Finally, I describe the data analysis methods with respect to each research question.

Study Setting

The Teacher Education Program

This study focused on participants who were part of one cohort of interns within a master of the arts with certification for elementary teaching program at a large Midwestern university in the United States. The program is twelve months in length, and participants (ranging in age from 22 to 45 years) entered the program having previously obtained a bachelor degree.

During the program, interns complete course work, including a month-long science methods course. Simultaneously interns complete part of a yearlong classroom internship with a cooperating mentor teacher in a local elementary classroom. At the completion of the program the interns receive a master of the arts degree in elementary education along with a teacher certification in one of the following areas: language arts, mathematics, integrated science, or social studies.

The program is accredited by the Teachers Education Accreditation Council (TEAC), which certifies that the program adheres to TEAC's quality principles. The program has outlined a set of high-leverage practices that are used throughout the courses (Appendix I) and are emphasized throughout the program. Teaching interns enter the program having met state requirements for coursework in a range of subject areas, including science. During the program, interns complete the courses outlined in Table 4-1. The two courses in bold in Table 4-1 are the focus of this study. The *Workshop on the Teaching of Science* (the science methods course) is the only course in which science in the content area of focus. The *Reflective Teaching Experience* is the fieldwork and seminar course in which interns enroll concurrently with science methods course. This course serves as an opportunity for the interns to apply what they have learned in the science methods course and put it into practice in the field.

Table 4-1: Course Schedule for Interns

Summer	Developmental Reading and Writing Instruction in the Elementary School Teaching with Digital Technologies Mathematics for Elementary School Teachers Teaching and Learning Reflective Teaching Experience
Fall	Individualizing Reading and Writing Instruction in Elementary Classrooms Teaching of Social Studies in the Elementary School Teaching Students with Exceptionalities Workshop on Teaching Mathematics Reflective Teaching experience
Winter	Teaching Language, Literacy, and Academic Content **Workshop on the Teaching of Science** Foundational Perspectives on Educational Reform **Reflective Teaching Experience**
Spring	Second Language Learning ESL Practicum Education in a Multilingual Society Second Language Assessment Research and Educational Practice

Reflective teaching experience. At the start of the winter semester (specifically during the months of January and February), the interns work six to nine hours per week within elementary classrooms learning to plan and enact elementary lessons using the high-leverage practices outlined in Appendix I. During this time in the field they receive guidance from both mentor teachers and field instructors. Starting in mid-February the interns transition into student teaching where they are in their mentor teacher's classrooms full time, again receiving guidance from their mentor teacher and a field instructor. By April, interns are expected to act as lead teacher within the mentor teacher's classroom and take on full responsibilities to plan, enact, and assess instruction in all subject matter areas.

Workshop on the teaching of science. The workshop on the teaching of science is the only formal science methods course offered within the program curriculum, and all interns are required to take the course. The course consists of twelve three-hour class meetings over the months of January and February. The first and fourth high-leverage practices listed in Appendix I, "explaining core content" and "leading whole-class discussions of content" are emphasized during the interns' workshop on the teaching of science.

In addition to focusing on explaining core content and leading whole-class discussions of content, the goals of the science methods course include: (a) describing the vision of science learning outlined in the *NGSS*, (b) incorporating this vision into developing science teaching practices (e.g., appraising and modifying curriculum materials; explaining core content and supporting students in construction of explanations, argumentation, and communication about scientific phenomena), (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. By focusing on supporting interns' learning to facilitate investigation-based discussions, interns also develop understanding of the four main course goals outlined above. For example, by facilitating investigation-based discussions, interns provide students opportunities to engage in the science practices of argumentation, and explanation construction. Through the use of talk moves, interns will provide opportunities for all students to engage in these practices making science more accessible to all types of students.

The course works toward the goals by engaging interns in several assignments, instructional activities, and readings. Instructional activities include peer teaching during which interns teach portions of a science lesson to a small group of their peers and a teacher educator (all of which are acting as elementary students). Peer teaching occurs three times throughout the course, giving interns an opportunity to plan and enact each element within the EEE framework. Prior to teaching, interns plan their enactment with other members of the cohort. Following each enactment, the peer-teaching group participates in a reflective discussion led by the teacher educator. Peer teaching is designed to provide the interns with representations of practice (Grossman, Compton et al., 2009), opportunities to engage in practicing science teaching (Lampert, 2010), and opportunities to engage in reflection and decomposition of those practices.

Assignments for the course include (a) a lesson plan sketch for an investigation-based discussion on the topic of conservation of matter, (b) a write up of a conversation with an elementary student about his or her thinking about a science topic, (c) three peer teachings, and (d) lesson in field experience (LiFE). As a reminder, both the peer teaching and the lesson in the field assignments require interns to complete the *card sorting activity* to support interns in assessing and developing their own understanding of the science content. Additionally, both the peer teachings and the lesson in field experience require the interns to develop lesson plans for all three elements of the *EEE framework* and reflect on their enactments.

All of the assignments provide interns opportunities to engage in approximations of teaching practice needed to enact investigation-based discussions and support students in learning scientific content through engagement in science practice. For example, co-planning with other interns for their peer teaching lessons simulates the collaboration they may do with coworkers during their first year of teaching. These approximations of practice gradually increase in complexity and authenticity (Davis, 2016).

In addition to these assignments, the science methods course provides additional opportunities to learn about and develop practices for planning and enacting investigation-based discussions. Table 4-2 summarizes these learning opportunities and assignments associated with the methods course. These additional learning opportunities include observing a variety of representations of practice including the course instructor modeling a lesson, video records of elementary teachers enacting investigation-based discussions, and vignettes of teachers' practice in assigned readings (see Figure 2-2 for examples of how the course assignments align with Grossman and colleagues' (2009) pedagogies of practice).

Interns are also asked to read selections of texts and important science education documents (e.g., the appendices of the *NGSS*) and have opportunities to discuss aspects of these readings during course meetings. The course utilized Zembal-Saul and colleagues (2013) text *What's your evidence?: Engaging K-5 children in constructing explanations in science* to support interns' understanding of the purpose of investigation-based discussions (to support student sensemaking) and the associated science practices students should engage in during these types of discussions. In the text and associated videos of science teaching, Zembal-Saul and colleagues (2013) suggest teachers use the claim-evidence-reasoning framework to scaffold student explanation construction. Throughout the text, the claim is defined as the answer to the investigation question. The claim must be supported by multiple pieces of evidence from the investigation and reasoning. Reasoning is defined as the larger scientific principle or big idea the lesson intends to support students to understand.

Table 4-2: Summary of learning opportunities

Learning opportunity	Description	Location
Lesson plan sketch	Interns create a plan to engage a group of fourth grade students in an investigation-based discussion about the conservation of matter	Methods course
Modeled lesson	Course instructor modeling of a science lesson involving an investigation-based discussion.	Methods course
Student ideas conversation	Interns interview an elementary student in their mentor teacher's class to investigate the student's ideas about what causes the seasons and either the structure/function of plant stems or how heat energy is transferred.	Field Placement
Video records and vignettes	Interns watch or read about teachers enacting elements of the EEE framework and have opportunities to discuss and decompose the pedagogical moves seen in the representations.	Methods course
Readings	Interns read about elements of the EEE framework, and scientific content and science practices emphasized by the NGSS and discuss these readings during course meetings	Methods course
Peer teachings	Interns plan for, enact, and reflect on teaching the three elements of the EEE framework to a small group of their peers and a teacher educator. Prior to planning, interns completed a card sorting activity to assess and develop understanding about scientific phenomena. Lesson plans and the card sorting activity were revised over the course of the three peer teachings.	Methods course
Lesson in field experience	Interns plan for, enact and reflect on a lesson taught to students in their field placement. Within this lesson there is an expectation that the interns conduct a whole-class investigation-based discussion about scientific phenomena. Prior to planning, interns completed a card sorting activity to assess and develop understanding about scientific phenomena.	Field Placement

As a reminder, interns are also provided with the suite of tools (described in Chapter 3) to support them to facilitate investigation-based discussions. All of the tools provided during the methods course were designed to support development of specific domains of teacher knowledge and practice.

Role of the Researcher

I first became interested in how interns enact investigation-based discussions when I apprenticed Elementary Science Methods – the corresponding science methods course for the undergraduate teacher education program – in fall of 2012. In the fall of 2013 and fall of 2014, I had opportunities to serve as instructor of the undergraduate elementary science methods course. In the winter of 2015, I served as the instructor of Workshop in Science Teaching. During these opportunities, I noticed the variation in interns' abilities to enact investigation-based discussions about scientific phenomena. I also noticed interns' struggles when attempting to engage students in discourses of science through explanation construction, argumentation, and communication about scientific phenomena. Noticing these struggles provoked me to ask questions about interns' knowledge and practices for planning and enacting investigation-based science discussions, and their beliefs about the purpose of these types of discussions. Additionally, my work with the Elementary Educative Curriculum for Teachers of Science (ELECTS) research project funded by the National Science Foundation inspired me to think about the types of tools that would further support interns' learning to plan and enact investigation-based discussions.

At the time this study took place, I was instructor of the science methods course as well as primary researcher of this study. Because I served in multiple roles during this study, I defined each role prior to beginning my research. For example, while serving as course instructor, I concentrated on aspects of planning and supporting interns to plan and enact investigation-based science lessons. Because much of the data collection (with the exception of the interviews) involved assignments and coursework that occur regularly in the course, I was able to foreground my role as instructor during the course. Because I was the instructor of record for the science methods course, I had direct access to the course assignments (e.g., peer teaching lesson plans and enactments), many of which served as data sources for this study. I obtained consent from interns to be involved in the research study, and I informed all participants that their involvement in the study was not in any way related to their final grades for the course. For the subset of 6 interns who volunteered as focal participants in the study, I explained their interview responses were confidential and provided them an additional opportunity to reflect on their planning and enactments of investigation-based discussions.

In order to best serve the learning of my students while the course was in session, I refrained from analyzing any data gathered until the course and any associated grading was complete. A second researcher conducted interviews that occurred when the course was in session to avoid conflicts of interest, and I was unaware of which interns had volunteered as focal participants until after the course was complete. I assumed the role of interviewer and researcher once the course and associated grading were complete.

Because I had established rapport with interns during the course, conducting interviews with my own students after the conclusion of the course allowed me to facilitate personal and honest conversations after the course was over. This may not have been possible if a third party conducted the interviews (Fontana & Frey, 1994). However, it is possible that my role as course instructor limited interns' trust and openness during interviews, or caused them to feel compelled to say what they thought I wanted them to say. Consistency between what interns said during interviews and what was learned from the analysis of their lesson plans, lesson enactments, and end-of-course reflections provides evidence of honesty of their comments.

Participant Selection

This study involved 22 teaching interns (6 male, 16 female) who gave me consent to analyze their course work and records of practice. The interns had these teaching majors: 68% language arts, 22% mathematics, 5% social science, and 5% integrated science. Interns were made aware that confidentiality would be maintained to the best of my ability, and pseudonyms would be used in all research documents produced from the study.

Participants were selected, in part, for their typicality (Stake, 2000). The participants were white females, typical of teachers in the U.S. population (National Center for Education Statistics, 2008). Although the majority of participants in this cohort were female, this cohort had a higher percentage of males compared to previous cohorts (27% male participants in the cohort of study versus 3% male participants in the previous cohort). As in every instance, however, the participants had varying backgrounds and experiences. For example, several interns had completed college-level course work in multiple science disciplines, and others had experienced no science instruction during their undergraduate course work.

A group of six interns (called focal interns throughout this dissertation) from this cohort participated in additional interviews during and after the science methods course. Table 4-3 outlines the self-identified characteristics of these interns. The experiences and teaching practice of the six focal interns represent sub-cases from the larger case of experiences and teaching practice of interns in the cohort. Focusing on the sub-cases allows for an in-depth analysis of each intern's use of tools and characteristics of investigation-based discussions (Miles, Huberman, & Saldana, 2014).

To select the focal participants, I used purposive sampling criteria (Miles et al., 2014) looking at prior experience with science content and science teaching, grade-level for student teaching placement, and content area for certification. This purposeful selection provided an opportunity to obtain information about the importance of prior experience with science and how that experience may shape interns' knowledge and beliefs about investigation-based discussions. The interns selected represent a range of previous experiences with their own science instruction and personal interest in teaching science, and they had limited previous experiences teaching science. Using this sampling technique allowed me to consider how variation in intern characteristics (e.g., prior undergraduate coursework in science) may shape how they use tools to plan and enact investigation-based discussions.

Table 4-3: Self-Identified Characteristics of the Focal Interns

Name	Ms. Andrews	Ms. Chase	Ms. Kramer	Ms. Lawrence	Ms. Sawyer	Ms. Zabel
Area of Focus	Science	Social Studies	ELA	ELA	ELA	Mathematics
Student Teaching Placement	Grade 5	Grade 4	Grade 1	Grade 5	Grade 2	Grade 2
Prior experiences with science education (course work or research experience)	College-level chemistry (5 semesters), physics (1 semester), biology (6 semesters), earth science (1 semester)	College-level chemistry (1 semester)	Undergraduate internships with four research labs, post-undergrad research work in biology and psychology	College-level chemistry (1 semester) and physics (1 semester	College level biology (1 semester), astronomy (1 semester)	College level chemistry (3 semesters)
Prior experiences with science teaching	No prior experience teaching science	No prior experience teaching science	No prior experience teaching science	No prior experience teaching science	No prior experience teaching science	No prior experience teaching science
Undergraduate field of study	Kinesiology	Not reported	Psychology	Computer Science	Not reported	Not reported

Study Methods

This study used qualitative case-study methodologies (Miles et al., 2014; Stake, 2000), and drew on multiple data sources. The collection of data occurred over 4 months during the teacher education program. I used these methods to describe the variation in how interns used tools designed to support learning to plan and enact investigation-based science discussions and describe the variation in the interns' plans and enactments of those discussions. Table 4-4 details the timeline for data collection.

Table 4-4: Sequence of Collection for All Data Sources

Timeline	Type of Data Collected
December: Prior to course meeting	Card sorting activity peer teaching Knowledge and beliefs about science teaching pre-course survey
January-February: During course meetings	Science ideas conversations Videorecord of all course meetings Lesson plan of peer teaching (Engage) Videorecord of enactment of peer teaching (Engage) Interview 1 Videorecord of co-planning session for peer teaching (Experience) Lesson plan of peer teaching (Experience) Video record of enactment of peer teaching (Experience) Video record of co-planning session for peer teaching (Explain) Lesson plan of peer teaching (Explain) Video record of enactment of peer teaching (Explain) Revised card sorting activity peer teaching Revised lesson plan for peer teaching Card sorting activity lesson in field experience Lesson in field experience lesson plan
February: Post course	Video record of enactment of lesson in the field Reflection for lesson in the field Post-course tool use survey
February-March: Post Course	Interview 2

Data Collection and Sources

Many of the data sources for this study came from the already existing course assignments for the science methods course and the associated reflective teaching experience. These included the science ideas conversation assignment, card sorting activity and lesson plans for both the peer teaching and lesson in field experience (LiFE) lessons, and video records of the enactments of the peer teaching lessons and LiFE lesson. In addition to these data sources, the interns completed a pre-course survey to allow me to gain insight into their knowledge and beliefs about science teaching and a post course survey to gain insight into their use of tools. Additionally, I captured videorecords of all course meetings.

Each of the focal interns also participated in two interviews. The first interview took place during the science methods course, and the second occurred after the science methods course. I also observed the focal interns as they taught their LiFE lessons to elementary students, and I collected field notes during these observations.

I describe the data and their purpose in Table 4-5. A detailed description of how these data were used to answer the research questions are described in the data coding and analysis section.

Table 4-5: Outline of Data Sources

Source	Group	Total Collected	Purpose
Pre-course Survey	All Interns	22	To describe interns' prior experiences with science and science teaching, beliefs about science teaching generally, and knowledge and beliefs about science practices, specifically argumentation.
Card sorting activity	All Interns	66 (three per intern)	To describe interns' knowledge of scientific content related to the structure and function of plant stems or the transfer of heat energy (the areas of focus of the peer teaching lessons) and the content area focus of their LiFE lesson
Science Ideas Conversation	All Interns	22	To describe interns' knowledge of content and students related to the structure and function of plant stems or the transfer of heat energy.
Lesson plans	All Interns	44 (2 per intern)	To describe interns' planned use of tools to enact investigation-based discussions. To describe interns' subject matter knowledge and pedagogical content knowledge for teaching investigation-based discussions.
Video records of course assignments	Focal Interns (n=6)	12 (2 per intern)	To describe interns' use of tools. To characterize interns' investigation-based discussions.
Reflections on course assignments	All Interns	22	To describe interns' knowledge and beliefs toward investigation based discussions. To identify the tools interns draw upon to plan and enact investigation-based discussions.
Post-course Tool Survey	All Interns	22	To describe interns' use of tools and rationales for tool use.
Interviews	Focal Interns (n=6)	15 hours (2 interviews per intern)	To describe interns' knowledge and beliefs toward investigation based discussions. To identify the tools interns draw upon to plan and enact investigation-based discussions, and describe interns' rationale for use of tools.

Pre-course Survey. Interns completed a survey in the fall prior to the science methods course. The purpose of this survey was to characterize interns' knowledge and beliefs about investigation-based discussions, and science practices. Interns answered questions allowing me to characterize their prior experiences with science and science teaching, knowledge and beliefs about science teaching generally, and knowledge and beliefs about science practices (specifically argumentation). The survey included the Teacher Beliefs about Effective Science Teaching (TBEST)[5] (Smith, Smith, & Banilower, 2014), and questions about the practice of argumentation developed by McNeill and colleagues (2015). See Appendix J for this survey.

Card sorting activity. The overall purpose of this activity (Appendix D) was to describe interns' knowledge of scientific content related to the focus areas (structure and function of plant stems or the transfer of heat energy) for the peer teaching lessons (the first card sort) and the content area focus of their lesson in field experience (the second card sort). The first card sort, aligned with the peer teaching topics, occurred at two time points: first prior to the start of methods course and again after completing the peer teachings. The second card sorting activity was aligned with the interns' topic for the lesson in field experience (LiFE) lesson and was completed prior to teaching the LiFE lesson.

Science ideas conversation. The science ideas conversation assignment (Appendix K) served to describe interns' knowledge of content and students related to structure and function of

[5] The TBEST survey measures beliefs along three factors: learning-theory aligned science instruction, confirmatory science instruction, or all-hands-on all the time science instruction. Fit indices provide evidence for appropriateness of the three-factor solution across all grade ranges. Cronbach's alpha reliabilities for each grade range were above 0.70. Cognitive interviews suggest validity, and administration mode (paper or online) produces no difference in score – providing evidence for reliability and validity (Smith et al., 2014)

plant stems or the transfer of heat energy[6]. This assignment involved anticipating students' ideas about the focal topic, eliciting student thinking about the topic during a one-on-one interview, and then summarizing the characteristics of the students' thinking. Interns conducted this conversation with a student in their field placement classroom and completed the conversation during their time in the field. The analysis of the conversation was completed as homework.

Lesson plans. During the science methods course, interns were asked to construct two lesson plans. For the first lesson plan, associated with the peer teaching assignment, the interns analyzed a lesson from existing curriculum materials using criteria from the teacher education program. Interns were assigned either the lesson "Experimenting with Celery Stems" (referred to as the Stems lesson) or "Hot Water, Cold Water: Transferring Heath Energy" (referred to as the Energy lesson) and each lesson's corresponding unit – either *Collecting and Examining Life* or *Energy*. The lesson and unit each intern was assigned depended on the intern's field placement classroom grade level. Interns in a kindergarten through second grade field placement classroom were assigned the Stems lesson. Interns in a fourth through fifth grade field placement classroom were assigned the Energy lesson. Half of the interns placed in third grade field placement classrooms were assigned the Stems lesson and the other half were assigned the Energy lesson. A summary of the *NGSS* cross cutting concept, potential investigation question, data analysis, and evidence-based claim for each of the peer teaching lessons are provided in Table 4-6.

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[6] The focal topic of the interview is dependent on the lesson assigned for the peer teaching assignment.

Table 4-6: Cross cutting concept, potential investigation question, data analysis, and evidence-based claim for peer teaching lessons

Lesson	Experimenting with Celery Stems	Hot Water, Cold Water: Transferring Heath Energy
NGSS cross cutting concept	Structure/Function	Energy
Potential investigation question	What will happen to a celery stem when it is placed in red water and clear water? (Big Idea: The structure and function of a stem)	What happens to a bag of hot water when it is placed in a container of cold water over time? (Big Idea: Heat energy transferred)
Potential data analysis	Comparison of observations of the celery stem and cross-section before and after the stem is placed in water. Use of a data chart to compare similarities and differences	Creation of a line graph to depict change in temperature of hot water and cold water over time. Comparison of multiple graphs.
Evidence-based claim[7]	*Claim*: Both stems (in red and clear water) got stiff and the leaves and tubes of the stem placed in red water turned red. *Evidenc*e: I observed that the celery was flexible before I placed it in the water and stiff after it was in the water for three days. I observed that the leaves of the celery in red water turned red after three days and red water was also in the tubes. *Reasoning*: Based on my observations I think the stems holds up the leaves and transports water from the base of the stem to the leaves.	*Claim:* Over ten minutes, the hot water decreases in temperature and the cold water increases in temperature. *Evidence:* Over ten minutes, I observed the hot water temperature decrease from X degrees Celsius to Y degrees Celsius, and the cold water temperature increase from A degrees Celsius to Y degrees Celsius. At the end of the ten minutes, both the hot water and cold water were Y degrees. Reasoning: Heat energy transfers from the hot water to the cold water until both volumes of water have the same measure of heat energy (thermal equilibrium).

[7] The evidence-based claims provided in Table 4-6 use the claim-evidence-reasoning framework outlined in Zembal-Saul and colleagues' (2013) *What's your evidence: Engaging K-5 children in constructing explanations in science*. Throughout the text, the claim is defined as the answer to the investigation question. The claim must be supported by multiple pieces of evidence from the investigation and reasoning. Reasoning is defined as the larger scientific principle or big idea the lesson intends to support students to understand.

Then, utilizing the *instructional planning template* for teaching science (Appendix B) interns planned for each of the three elements of the *EEE framework* for peer teaching. The interns were required to co-plan for each element of the *EEE framework* and submit the instructional planning template prior to each in-class peer teaching. Interns also submitted a revised *instructional planning template* detailing their plan for teaching all three elements of the *EEE framework*, after completing the final peer teaching.

To complete the second lesson plan, associated with the lesson in field experience (LiFE) assignment, interns analyzed a lesson from existing curriculum materials using criteria from the teacher education program. Interns were asked to develop their LiFE lesson plan using the *instructional planning template* for teaching science. The purpose of the two lesson plans was to describe interns' planned use of tools to enact investigation-based discussions and interns' subject matter knowledge and pedagogical content knowledge for teaching investigation-based discussions when prompted by an *instructional planning template*.

Video records of course assignments. During the science methods course interns completed three peer-teaching enactments, one per element of the *EEE framework* (See Appendix L for assignment description). These enactments ranged from 10 to 25 minutes in length. During the peer teachings, each intern enacted one of the elements of the *EEE framework* while a small group of his or her peers and a teacher educator took on the role of elementary students (Davis, 2016). Interns were expected to stay in "teacher role" during these enactments and used the teaching moves and representations they would use with elementary students. After the enactment, the interns and teacher educator discussed the productive teaching moves as well as problems of practice that occurred in the enactment. All the enactments were video recorded to characterize the focal interns' investigation-based discussions, looking specifically at the types of talk, how knowledge of science practice and content surface, and the ways in which interns capitalized on student contributions made in different aspects of the enactment. The video records of the peer teachings were also used to describe the interns' use of tools during their enactments.

For the LiFE assignment, interns planned, taught, and reflected on an entire investigation-based science lesson (See Appendix M for assignment description). Interns selected a lesson from pre-existing curriculum materials with the guidance of their mentor teacher. As part of the assignment, interns were required to make video records of their enactment. These video records allowed me to characterize the focal interns' enactments of investigation-based discussions, again looking closely at the types of talk used, how knowledge of science practice and content surfaced, the ways in which interns capitalized on student contributions, and interns' use of tools during the enactment.

Reflections on course assignments. After enacting the LiFE lesson, interns reflected on the planning and enactment of their investigation-based science lesson (See Appendix N for reflection template). Interns were asked to consider their representation of the scientific content and science practices, student learning, and their own learning about science teaching. Additionally, using an online video sharing tool (Edthena), interns were asked to identify areas of strength and missed opportunities/teaching moves in need of revision for each element of the EEE framework, and to provide rationale for their decisions. These reflections allowed me to describe interns' knowledge and beliefs about investigation-based discussions.

Post-course tool use survey. In addition to reflecting on their lesson enactments, interns were asked to complete a survey to characterize interns' use of tools provided during the science methods course. Interns were asked to rate the usefulness of each of the tools provided during the methods course and asked to justify the rating they gave each tool (See Appendix N for tool use survey). This survey allowed me to gain insight into the participants' perspective with each intern reporting which tools he or she used most frequently and found most useful for his or her teaching practice.

Interviews. Researchers interviewed the focal interns twice during the course of the study. The first interview occurred during the science methods course. The second interview was conducted after completion of the science methods course. The interviews had a semi-structured format with follow up questions to probe intern thinking (Fontana & Frey, 1994). I designed the interviews to describe interns' knowledge and beliefs toward investigation-based discussions and identify the types of tools the interns draw upon to plan and enact investigation-based discussions (See Appendix O for interview protocols).

Because the first interview took place during the course, a second researcher conducted the interview with the focal participants. The researcher asked how interns planned to teach elements of lessons that corresponded with the time of the interview (e.g., if the interview took place after the Engage and Experience peer teaching the interviewer asked about planning for those elements specifically), how the intern envisioned investigation-based science discussions, and what tools they drew upon to plan and enact their lessons.

During the second interview I asked similar questions about investigation-based science discussions and intern tool use. In addition, by drawing on data collection methods from cognitive science that have been adapted for educational research, I made use of stimulated recall methodologies (Gass & Mackey, 2000; Meade & McMeniman, 1992). During the interview, I asked the intern to watch the video of her enactment with me. To keep the interview open-ended in hopes of gaining insight into the intern's decision making process and beliefs about her own teaching (Nespor, 1985) I instructed each intern to pause the video record when she saw herself making a decision that may have shaped the investigation-based discussion and tell what she was thinking at that point. I also instructed the intern to pause the video record if she saw anything on the video she wanted to comment about. Finally, after we watched the video together, if there were specific aspects of the video I had clarifying questions about (such as questions about what the students were doing at that point in the lesson, or what the intern's decision making process was at a specific point not mentioned by the intern), I went to the relevant point in the video and asked specifically about those segments.

Data Coding and Analysis

This section describes the data analysis used to address the three main research questions:

1. What tools do interns use to plan and enact investigation-based discussions, and how does that use surface in the plans and enactments? How do the interns report their use of the tools?
2. What are the characteristics of interns' investigation-based discussions, and more specifically:
    a. What types of talk do interns use?
    b. How does intern knowledge of science practice and content surface?
    c. What are the ways in which interns capitalize on student contributions?
3. How do interns' knowledge and beliefs (specifically about scientific content, science practices, and investigation-based science discussions) and use of tools relate to one another and to characteristics of interns' plans and enactments of investigation-based discussions?

This section also provides detail on the analytic questions that guided the coding of the data and considers each research question separately while providing coding schemes that were useful in my analysis.

Question 1 Data Coding: Characterizing Tool Use

To describe how interns' tool use surfaced in the lesson plans, I coded for the frequency of tool use and the context in which the intern used each tool. For example if the intern used several science-specific talk moves from the *talk moves tool* to develop questions for use during the Explain element of the peer teaching lesson, the instance of tool use was coded as one instance of use of the *talk moves tool*, in the context of the Explain element. I also characterized how the tool was being used. To do so, I adapted the typology of tools scheme Windschitl and colleagues (2012) describe. Table 4-7 provides a brief description of these typologies as well as examples from the science methods course.

Table 4-7: Typology of Tools (adapted from Windschitl, et al., 2012)

Type of tool	Purpose of Tool	Example of Tool from Methods Course
Core tool	Tool to organize overall purposes, goals and direction of the lesson. Becomes a referent for shared language across the teaching community.	EEE Framework
Priming Tool/ Planning tool	Prepares teachers for situated purposeful interaction with learners around important science ideas. Becomes basis for shared language in teaching community about features of practice such as talk moves.	Instructional Planning Template Skeleton Lesson Planning Template Monitoring Tool Talk moves tool
Face to face tool	Directly mediates interactions among teacher, students, and scientific ideas. Scaffolds students to participate more fully in scientific reasoning and talk. Allows an intern to learn from each other's pedagogical "problem-solving" artifacts. These tools can be adapted to suit individual teacher's/student's needs.	Claim-Evidence-Reasoning Exemplar Talk moves tool Monitoring Tool

To characterize how interns described their use of the tools, I calculated average usefulness scores using the ratings interns provided on the end-of-course survey. Additionally, to characterize the justification the interns provided for their rating I engaged in open coding (Charmaz, 2006; Emerson, Fretz, & Shaw, 2011; Maxwell, 2012) of the open-end survey responses. I then looked for instances when interns provided justification for why each tool was useful. I engaged in focused coding using categories that emerged from the interns' responses. Through this type of coding, I developed categories that were more descriptive of the participants' meaning. Table 4-8 provides the most common coding categories for each tool, along with a brief description and example of when each code was applied. The interviews with the focal interns were coded using these same coding categories.

Table 4-8: Intern Justification for Use of Tools

Tool Type	Most common rationales given	Example of when code was applied
EEE Framework		
	Keeping goals in mind	*"This framework not only holds me responsible for planning the explain portion of the lesson (which gets left out often), but it also reminds me of what I need to include."*
	Organize the lesson	*"This framework helped me organize my lesson."*
	Manageable	*"The EEE framework allowed the lesson to be chunked into manageable sections for planning."*
Lesson Planning Template		
	Keeping goals in mind	*"The template helps me to internalize parts of the lesson plan and write down the things that are most important to have written down for science teaching."*
	Aligned with the EEE framework	*"Instead of having to fit the EEE framework into the existing template, it was nice to have the template already adapted to the unique nature of science teaching."*
Skeleton Planning Template		
	Keeping goals in mind	*"The skeleton elicits completion of key pieces of a lesson… It focuses the teacher's attention on what matters in a successful science lesson."*
	Practical	*"It is a very useful way of succinctly making your thinking evident through planning… it's practical."*
Card Sorting Activity		
	Understanding content for lesson	*"It challenged me to synthesize science concepts and generated the answers I needed answers to close conceptual gaps for the lesson content."*
	Understanding the big ideas	*"Preparing for the lesson by creating a flowchart really helped me methodically lay out the interrelation between various concepts in the unit."*
Talk Moves Tool		
	Planning questions to make students describe thinking	*"The talk moves encourage clarification, engagement, and explanation."*
	Coherent with other courses	*"These have been emphasized in so many ways throughout the program and having another application was good. It made science methods cohesive with other courses in the program."*
Alternative Ideas Tool		
	Anticipating students ideas	*"These helped me think about student knowledge and how I can use these ideas to guide my lesson.."*
	Difficult to find for LiFE	*"I see this being useful, but for the lesson I taught I did not encounter ideas in the resources provided that related to my topic."*
Monitoring Tool		
	Formatively assessing students	*"I was able to use this as a way to see if my students were able to meet my learning goals."*
	Keeping me accountable	*"This helps me direct my attention during the enactment… to attend to students' participation."*
CER Template		
	Scaffolding own learning of CER for lesson	*"Seeing this example helped me learn how to write a C-E-R statement because I hadn't seen this model before."*
	Keeping me accountable for discussion	*"Using this along with the EEE framework… forces you to do the reasoning piece, making the lesson more than just an experiment."*
	Scaffolding student learning of CER for lesson	*"The CER worksheet helped to structure student thoughts around scientific concepts. Using this as a thread throughout science teaching scaffolds student learning of scientific concepts."*

Question 1 Inter-rater Reliability

Two researchers coded the frequency of tool use in the lesson plans and the context of tool use and performed an inter-rater reliability check of at least 20% of the data for each coding scheme used. Inter-rater reliability exceeded 95% for all coding schemes used. A single researcher coded the post-course survey data, rationales provided within the open-ended survey responses, and interview data. Two researchers then reviewed the coded data together and discussed instances of disagreement about the codes. The two researchers reached 100% agreement through these discussions.

Question 1 Data Analysis

For the qualitative data, I entered the codes into a data matrix to look for patterns in interns' tool use for both the peer teaching lesson plan and the LiFE lesson plan. I compared interns' tool use in the two plans to depict variability and determine if patterns existed across both sets of lesson plans. Similarly, I looked for patterns in the interns' rationale for tool use in the end-of-course survey and interviews. After finding differences and similarities in the rationales of tool use provided by interns, it was my goal to highlight the patterns found by providing readers with typical examples of the types of rationales interns provided when describing why they used certain tools.

Thus, I used the data from both the interns' lesson plans, end-of-course survey, and focal interns' interviews to describe intern tool use. By providing detailed descriptions of the frequencies of tool use as well as typical examples of rationales I aim to shed light on the ways in which interns draw upon certain types of tools and reasons why interns found the tools useful.

Question 2 Data Coding: Characterizing Investigation-Based Discussions

Research Question 2 focuses on the characteristics of interns' investigation-based discussions, specifically the types of talk interns used, the ways in which the interns' knowledge of science content and practice surfaced, and how the interns capitalized on student contributions.

Types of talk coding. To analyze the types of talk interns used during investigation-based discussions, I analyzed the video records of lesson enactments for the six focal teachers. I drew on qualitative and quantitative discourse analysis (Chi, 1997; Gee, 2013; Green & Wallat, 1981; Mortimer & Scott, 2003) to complete a taxonomical analysis of the discourse (Brown & Spang, 2008; Green & Wallat, 1981). By creating event maps of the enactments (See Appendix P for focal intern LiFE lesson enactment event maps) I was able to see the distinct phase units (a series of segments of talk, for example the talk that occurs when reviewing the previous class activities) in the lesson. I marked times within the video-records for phase units in which the interns engage in whole-class discussions, and the phase units were transcribed verbatim.

I coded the phase units for teacher-student interactions by dividing the phase units into interaction sequences. Interaction sequences consisted of units of dialogue that began when a speaker made a metacognitive statement or asked a question, and that statement or question was followed by a statement from another speaker. Then, I analyzed the teacher talk within the interaction sequences for type of talk using Mortimer and Scott's (2003) descriptions of authoritative and dialogic talk (see Table 4-9 for a description of the codes). Appendix Q provides an example of this coding.

Table 4-9: Types of Teacher Talk

Types of teacher talk	Description	Features
Authoritative[8]	Teachers introduce and focus on the normative science perspective through question and answer sequences to help students understand scientific phenomena.	• Teacher monologue or teacher-student interaction with only one student during interaction sequence ○ Authoritative teacher-student interaction sequences tend to be short (~30 seconds – 1 minute in length) • Teacher dominates time of talk and direction of conversation • Evaluation of student response • Student hands raised but not acknowledged • No or few non-normative student ideas entertained • Limited or no use of talk moves
Dialogic	Teachers encourage students to share and engage with diverse perspectives, and help students to understand how different perspectives relate to each other and the normative scientific perspective.	• Teacher students interaction with multiple students during interaction sequence ○ Dialogic teacher-student interaction sequences tend to be longer than the authoritative sequences (~1 minute-3 minutes) • Students dominate talk time and direction of conversation • Limited teacher evaluation of student response (rather a press for student to student agreement/disagreement) • Students hands raised and teacher facilitates entry into conversation • Most ideas entertained and teacher supports students to collectively determine idea that is supported by evidence • Frequent use of talk moves

Knowledge of science content and practice coding. To describe how intern knowledge of science practices and content surfaced in the lesson plans and during the enactments of the

[8] Teachers need to make purposeful shifts between the two types of talk during investigation-based discussions to help guide student understanding of scientific phenomena (Scott et al., 2006). Both authoritative and dialogic talk are needed to support students to learn science content. With the goals of the lesson in mind, teachers can shift into authoritative discourse productively, scaffolding student understanding and keeping the lesson on track progressing toward the learning goals while still allowing space for students to do the intellectual work and discuss their ideas dialogically.

investigation-based discussions, I analyzed the lesson plans of all interns enrolled in the science methods course and video records of the focal interns' enactments. I coded the lesson plans and interaction sequences from lesson enactments by marking the instances when the interns engage students in science practices and discussions of scientific content and practices. I coded those instances using the coding scheme described in Table 4-10 and by classifying the content areas of focus using the *NGSS*'s list of disciplinary core ideas (e.g., structure and function, growth and development of organisms, conservation of energy and energy transfer, etc.). I also coded for the accuracy of those instances utilizing the coding scheme described in Table 4-11.

Table 4-10: Codes for scientific practices

Code	Definition
Asking questions and defining problems	Students ask or intern proposes questions about the natural world – questions can be driven by curiosity about the world, inspired by the predictions of a model, theory, or previous investigations.
Developing and using models	Students use models including: diagrams, replicas, mathematical representations, analogies, or computer simulations. Models are used to represent a system to aid in development of questions and explanations, generate data that can be used to make predictions, or to communicate with others
Planning and carrying out investigations	Students carry out an investigation to describe a phenomenon or to test a theory of how the world works. Investigation is a systemic inquiry with the purpose of gathering data to advance knowledge.
Analyzing and interpreting data	Students or intern organizes or interprets data through tabulation, graphing, or statistical analysis, identifying significant features and patterns, and identifying sources of error. Intern uses particular representations of data to make the invisible, visible.
Using mathematics	Students or intern uses mathematics to represent physical variables and their relationships to make quantitative predictions.
Constructing explanations	Intern describes explanation as the goal of science and often attempts to answer a scientific question. Intern describes that explanations include a claim that relates how variables relate to one another and to scientific reasoning or connections to a bigger scientific principle. Intern supports students to make evidence-based claims
Engaging in argument from evidence	Intern fosters argumentation as a process for reaching agreements about an explanation and allows students to listen to, compare, and evaluate others' ideas and methods.
Obtaining, evaluating, and communicating information	Intern supports students to read, interpret, and produce scientific text. Intern supports students to use tables, diagrams, models, displays, etc. as a way to communicate scientific information to others.

Table 4-11: Coding for language and representations of science practices and scientific content

Category	Definition	Sub codes
Appropriate to discipline	Language and representation is appropriate for the science discipline	Accurate – language and/or representation conveys the practice or content in a scientifically accepted way Non-normative – language and/or representation conveys alternative ideas of the practice or content
Age appropriate	Age appropriate language and/or representations	Age appropriate – language and/or representations are mostly age appropriate Age inappropriate – the language and/or representations are either above or below what a student at the target age could comprehend

Types of talk and knowledge of science content and practices analysis. Following coding of the types of talk and instances when knowledge of science content and practices surfaced, I looked at each intern's investigation-based discussion as a whole determining the frequency of each of the codes. Quantifying the codes allowed me to make comparisons of the overall characteristics of the interns' investigation-based discussions during the peer teachings and the LiFE lesson. This analysis also allowed me to make comparisons of one intern's investigation-based discussion to another intern's investigation-based discussion at similar time points during the methods course (cf. Boeije, 2002). By using both qualitative and quantitative approaches to analyzing discourse, I aim to provide rich descriptions of the types of talk the interns use during their investigation-based discussions.

Utilizing interaction sequences as the unit of analysis to mark the instances during the investigation-based discussion when the interns and students discuss science practices and content or engage in science practices allowed me to compare the type of teacher talk occurring during engagement and/or discussion of specific science practices and content. For example, did the accurate statements in which the intern drew upon her knowledge of science content and practice occur only during more authoritative interaction sequences? Building on the work of Carlsen (1987), this analysis aimed to provide deeper insight into how intern knowledge of science content and practice and engagement of students in those practices may shape the course of investigation-based discussions.

Capitalizing on student ideas coding. To describe the ways in which interns capitalize on student contributions, I analyzed lesson plans for all interns, and video records of lesson enactments of the six focal teachers. I utilized coding schemes (See Tables 4-12 and 4-13) that consider productive practices that support student engagement in discussion and marked instances in the data sources when interns planned for or enacted practices used to facilitate investigation-based discussions.

The coding schemes were developed utilizing Cartier and colleagues' (2013) five-practices framework for facilitating productive task-based discussions, Windschitl and colleagues' (2012) four practices for ambitious science teaching, and the teaching frameworks and practices used within the science methods course. The coding schemes consider the teaching practices research has shown to be particularly important for both planning and enacting productive investigation-based discussions that capitalize on student contributions (e.g., Boerst, Sleep, Ball, & Bass, 2011; Cartier et al., 2013; Ross, 2014; Windschitl et al., 2012).

Specifically for the peer teaching and LiFE lesson plans, I looked for evidence of engagement in several of the practices by looking closely at sections of the instructional planning template that prompted interns to consider using the practices. For the lesson enactments, the video records were divided into 2-minute time segments drawing on Borko and colleagues' (2008) discussion that this length enables analysis of teaching practices. Using partial-interval time sampling, I marked the 2-minute time segments that showed evidence of engagement in the practices for productive investigation-based discussions. Then, for each practice, I looked at all of the two minute time segments showing evidence of engagement in the practice and used the coding scheme detailed in Table 4-13 to evaluate the use of the practice during each investigation-based science lesson. Additionally, I used the stimulated recall interviews to triangulate my findings within the lesson enactments.

Capitalizing on student ideas analysis. Emergent patterns of how interns engaged in these teaching practices were identified within and across the interns, and these patterns provided insight into how interns capitalized on student contributions when planning and enacting investigation-based discussions. These analyses help me not to make causal claims, but rather to explore the possible relationships between intern characteristics, tool use, and the interns' abilities to plan and enact investigation-based discussions. Using the coding scheme to highlight evidence of productive teaching practices for investigation-based discussions that capitalize on student contributions allowed me to make comparisons within individual focal teacher's lesson plans and enactments.

Table 4-12: Coding of Lesson Plans for Productive Practices for Capitalizing on Students' Ideas During Investigation-Based Discussions

Elements of plan	No Evidence (Score of 0)	Some Evidence (Score of 1)	High Evidence (Score of 2)
Considers students' initial ideas in all elements of the lesson	No evidence of how three elements of EEE framework within the lesson will work together to support students' understanding	Consideration of returning to students' ideas contributed in the Engage element during the Explain element or revisiting during experience, but not all three	Consideration of how student contributions during the Engage element will impact monitoring practices during Experience element, and returning to those ideas during the Explain element (e.g., returning to predictions in each element)
Considers content storyline or big ideas	No evidence of how lesson content fits into big ideas	Vaguely describes connections between the lesson content and the big ideas, and connections may be non-normative or copied from curriculum materials	Specifically describes the connections between the lesson content and the big idea and the description is scientifically accurate. Intern has to identify correct reasoning and describe connections at a higher level than students would have to know.
Considers investigation trajectory and connection with big ideas	No evidence of how the investigation (its evidence and claims) will progress throughout the lesson and no evidence of connection between the investigation and DCIs	Consideration of important data students will need to collect and notice or important evidence needed for the claim for the investigation, but little or no connection to the DCI or bigger picture content ideas that the investigation aims to help students understand	Consideration of important data and evidence students will need to collect and notice and connection between the data/evidence from the investigation and connection to the DCI or bigger picture content ideas the investigation aims to help students understand (in essence this is using the investigation to teach to the scientific point). Intern must connect the investigation to reasoning
Preparing for students' scientifically accurate ideas	No evidence of anticipating students' scientifically accurate ideas	Describes the ideas but the ideas are vague	Specifically describes correct thinking/idea students may use
Anticipating students' incorrect or incomplete thinking	No evidence of anticipating students' incorrect or incomplete thinking	Describes at least one incorrect way students may think about the scientific phenomena (alternative idea about content) or difficulty students may have carrying out the investigation (investigation struggle) but does not describe the multiple ways students may struggle (content or practice)	Describes ways students may think about the scientific phenomena (alternative idea about content) and difficulties students may have carrying out the investigation (investigation struggle) and makes an attempt to describe the multiple ways students may struggle (content and practice)
Monitors students' work during investigation	No evidence of a plan for monitoring students while they carry out the investigation	No monitoring tool and plans to "circulate and observe" or includes a blank monitoring tool without anticipated student ideas	Includes a monitoring tool with anticipated student ideas

Table 4-12 Continued: Coding of Lesson Plans for Productive Practices for Capitalizing on Students' Ideas During Investigation-Based Discussions

Elements of plan	**No Evidence (Score of 0)**	**Some Evidence (Score of 1)**	**High Evidence (Score of 2)**
Questions students to elicit, challenge, or extend students' thinking	Specific example questions do not exist	Provides example questions but little evidence of when or how those questions should be used (generic – e.g., Tell me more about that…)	Provides several example questions to ask students, and includes appropriate context of when that question should be used (e.g., what evidence can you use to support that? - science specific)
Plan follows logical use of science practice	No logical flow of analysis, model construction/argumentation, explanation construction	Mostly in logical order but not explicit or intern ignores a practice (e.g., does not allow space for argumentation to occur – very teacher directed movement to explanation)	Logical order and explicit planned student engagement in each practice needed in an investigation-based discussion (i.e., analysis, explanation, argumentation)
Selects/sequences and draws attention to ideas purposefully	No evidence of selecting and sequencing	Lists important ideas that need to come up but does not list a strategy of how to mark them as they come up. Does not seem to have a purposeful sequence of how to discuss the ideas.	Lists important ideas that need to come up and lists a way to highlight them for students (e.g., seeing that the cold water temperature changes in all graphs and circling that change) and they are discussing the ideas in a logical order (e.g., the intern states – get students to notice one idea at a time --- look at all the cold water lines first, then all the hot water lines first) – this sequencing helps to make all of invisible visible
Chooses a representation to highlight students' ideas	No evidence of the type of representation that will be used to organize and highlight students' contributions	Provides a representation to organize students' contributions (observations, other data) but this representation does not help to make the invisible visible (e.g., using the data chart for the heat lesson)	Provides a representation that organizes students' contributions and the representation helps students to notice important patterns in the data. (e.g., using a graph for the heat lesson and comparing across graphs)

Table 4-13: Coding of Lesson Enactments for Productive Practices for Capitalizing on Students' Ideas During Investigation-Based Discussions

Elements of enactment	**Example of Teacher Engagement in Practice**
Considers students' initial ideas	Returns to the students' ideas contributed in the Engage element during the Explain element Student contributions during the Engage element seem to impact monitoring practices during experience element, and intern returns to those ideas during the Explain element
Considers content storyline or big ideas	Helps students to make connections between the lesson content and the big ideas, but connections may be non-normative or unclear Helps students to make connections between the lesson content and the big idea, and the connections are clear and scientifically accurate
Monitors students' work during investigation	Circulates and observes and asks students a few questions, but questions do not push student thinking forward. Attempts to use monitoring tool to keep track of student ideas, is able to make sense of patterns of student ideas, and asks questions that push student thinking forward
Questions students to elicit, challenge, or extend students' thinking	Uses example questions but use is inappropriate or does not advance students' thinking. Uses example questions and use is appropriate and seems to push students' thinking forward.
Makes connections across students' ideas and disciplinary core ideas	Connections between student thinking and DCI exist, however, intern may assume all students will think the same way • Example: teacher makes connections between one student's (usually a student that is "correct") thinking and the DCI – does not involve multiple students' thinking Attempts to address key student ideas that are represented differently but there is no clear connection between scientifically accepted ideas and students' ideas • Example: teacher switches from eliciting students' ideas to telling how scientists think about that idea without making links between the two Supports students to make connections between student developed representations and the scientifically accepted ideas
Selects and sequences ideas purposefully	Teacher selects students to share specific ideas that need to come up during the discussion, but there is no evidence of purposefully sequencing ideas to push toward learning goals • Example: teacher selects students to share ideas she indicated as important for the discussion but does so at random Teacher selects and sequences students' ideas/representations and selecting and sequencing push the discussion forward toward learning goals
Chooses a representation to highlight students' ideas	Provides a representation to organize students contributions (observations, other data) but this representation does not help to make the invisible visible (e.g., using the data chart for the heat lesson) Provides a representation that organizes students' contributions and the representation helps students to notice important patterns in the data. (e.g., using a graph for the heat lesson and comparing across graphs)
Draws attention to or marks key ideas	Teacher clearly marks the many important pieces of data and/or students' ideas, and representation used helps to make the invisible, visible

Question 2 inter-rater reliability. To ensure the trustworthiness of the claims related to Research Question 2, a second researcher coded 20% of the data using the previously detailed coding schemes. Inter-rater reliability exceeded 96% for all coding schemes used. For instances of disagreement, two researchers reviewed the coded data together, and discussed instances of disagreement about the codes. The two researchers reached 100% agreement through these discussions.

Question 3 Data Coding: Characterizing Relationships

Research question three focuses on how interns' knowledge and beliefs about scientific content, science practices, and investigation-based science discussions and use of tools relate to one another (the participatory relationship) and to characteristics of interns' plans and enactments of investigation-based discussions. Coding for interns' tool use and characteristics of plans and enactments of investigation-based discussions has been detailed in previous sections. The following section describes the coding used to describe additional characteristics of intern knowledge and beliefs about science content, science practices, and science teaching.

Intern knowledge and beliefs about science content, science practice, and science teaching coding. To provide further detail about intern knowledge and beliefs about science content, science practices, and science teaching, I analyzed the focal interns' responses to relevant questions in the pre-course survey and course assignments. I analyzed interns' surveys (Smith et al., 2014) to determine if their beliefs about teaching science more generally were aligned with hands-on, learning theory, or confirmatory approaches. The hands-on approach considers doing hands-on activity above all other aspects of science instruction. The learning theory approach looks at alignment between teachers' beliefs about science teaching and current learning theories. The confirmatory approach considers science investigations as a way to confirm facts students have already learned. Additionally, I used the interviews to triangulate my findings from the interns' surveys. Sections of focal intern pre-course surveys (McNeill et al., 2015) were also used to determine if interns' knowledge and beliefs about the scientific practice of argumentation (which is central to investigation-based discussions about science content) were aligned with the goals of the science methods course and the *NGSS*.

To further characterize interns' knowledge and beliefs about science content related to the peer-teaching and LiFE lessons, I analyzed focal interns' card sorting activities by classifying the content areas of focus using the NGSS's list of disciplinary core ideas (e.g., structure and function, growth and development of organisms, conservation of energy and energy transfer, etc.). Similar to the coding of interns' lesson plans, I coded appropriateness of language, and accuracy in the representations of the scientific content using the codes in Table 4-11 (Kademian, Arias, Davis & Palincsar, in press; McDiarmid, Ball, & Anderson, 1989; McNeill, 2009). Additionally, I used interviews to triangulate findings.

Question 3 Data Analysis. After applying previously described coding schemes to interns' survey responses and additional course assignments, I compiled the coding for each intern into a data matrix. Additionally, I created event maps (Appendix P) for each of the focal interns' lesson enactments (cf. Brown & Spang, 2008). I identified emergent patterns within and across the focal interns' event maps, and these patterns provide insight into how interns' knowledge and beliefs about scientific content, science practices, and investigation-based science discussions and use of tools relate to one another and to characteristics of interns' plans and enactments of investigation-based discussions.

Use of Remillard's Participatory Framework to depict relationships. To develop a model that depicts the relationship among interns' characteristics, tool use, and plans and enactments of investigation-based discussions, I utilized aspects of Remillard's (2005) participatory relationship framework describing the interaction between teachers and curriculum materials. Similar to Remillard (2005), I hypothesized that interns' characteristics shape how interns utilize the tools, and the use of tools can then also shape the characteristics of the intern. Both interns' characteristics and tool use will shape the plans and enactments of investigation-based discussions. For example, if an intern has strong knowledge of the science practice of constructing explanations, she will likely see use of the *C-E-R template* as supportive for her students. She will plan to use the *C-E-R template*, and as a result her students may have additional opportunities to engage in explanation construction during the investigation-based discussion enactment.

Additionally, I hypothesized the investigation-based discussion enactments may also shape interns' characteristics and tool use. For example, if an intern chooses to use the talk moves tool to press students to justify their claims, and in doing so, the tool helped her students to better engage in argumentation and explanation construction, she will be more likely to continue to use the talk moves tool in future lesson enactments. Figure 4-1 depicts these hypothesized relationships.

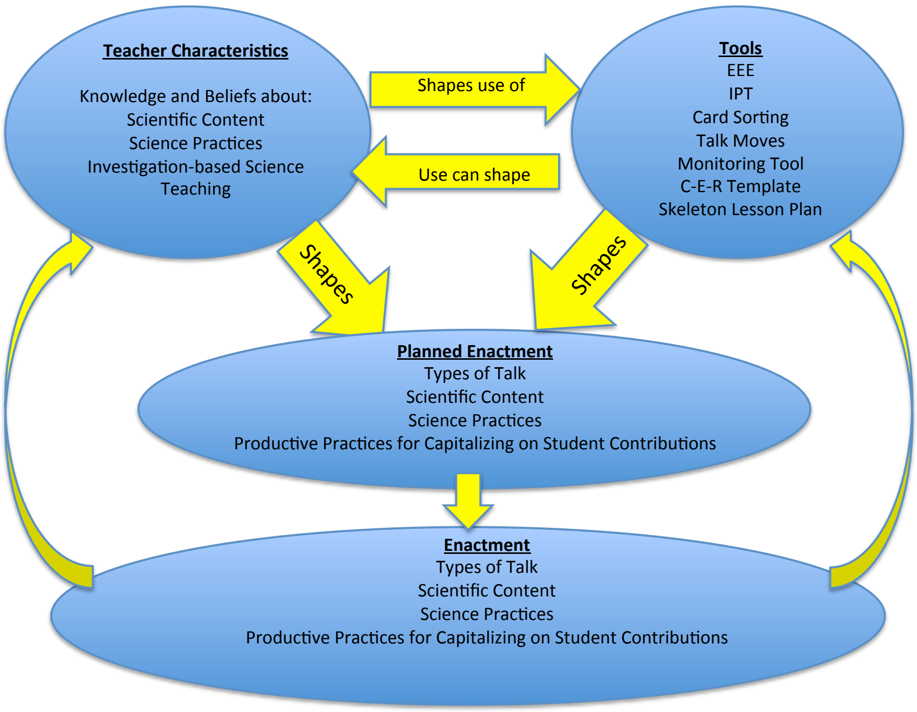

Figure 4-1: Hypothesized teacher-tool relationships (Adapted from Remillard's (2005) participatory relationship).

In Chapter 8, I develop versions of this figure for each focal intern. By looking across multiple data sources, I use these figures to provide rich descriptions of how relationships between intern knowledge and beliefs about science content and science practices, knowledge and beliefs about investigation-based discussions, and tool use shape the plans and enactments of such discussions.

Conclusion

This chapter described the research context, participants, and methodologies used in this study. This study used qualitative case-study methodologies to better understand how interns' knowledge and beliefs about science teaching and use of tools relate to one another and to characteristics of interns' plans and enactments of investigation-based discussions. I developed coding schemes based on the literature to code intern lesson plans and lesson enactments within elementary classrooms. I also coded and analyzed other course assignments from the interns' science methods course and drew on interviews with six focal interns to answer the study research questions and triangulate my findings.

The next chapters provide the results of my analyses. Chapter 5 describes interns' use of tools to plan and enact investigation-based discussions. Chapter 6 focuses on interns' planned use of productive practices for capitalizing on student contributions. Chapter 7 provides detailed descriptions of focal interns' engagement in the productive teaching practices, use of dialogic and authoritative voice, and student engagement in science practices during lesson enactments. Chapter 8 looks closely at the relationships that existed between focal interns' characteristics and their planned and enacted lessons. Chapter 9 discusses these four sets of findings in light of the literature and describes implications of the study.

CHAPTER 5

USE OF TOOLS DESIGNED TO SUPPORT BEGINNING TEACHER KNOWLEDGE FOR SCIENCE TEACHING

In this chapter, I present findings related to the interns' use of tools designed to support development of knowledge and practice of facilitating investigation-based discussions. Based on my analysis of the interns' lesson plans, end-of-course surveys, and analysis of the focal interns' enactments and interviews, I make four major assertions:

a) Interns used a range of different tools when planning investigation-based lessons.
b) Interns used similar tools to plan both the peer teaching lesson and the LiFE lesson and use of specific tools supported interns to use additional productive teaching practices.
c) Focal interns used similar tools in their enactments for both the peer teaching lesson and the LiFE lesson and use of specific tools supported focal interns to use additional productive teaching practices.
d) Interns justified their use of tools in similar ways and justifications of tool use included but were not limited to (1) tools helped to keep the goals of science teaching in mind, (2) tools were coherent with the goals of the methods course and the teacher education program, and (3) tools helped to attend to learners' ideas and needs.

In this section, I address these assertions first by describing interns' use of tools evident in both the peer teaching lesson plans and the LiFE lesson plans and comment on the similarities and differences across the plans. Then, I describe focal interns' use of tools during their peer teaching and LiFE lesson enactments. Finally, I discuss the common justifications interns provided for use of specific tools.

Evidence of Tool Use Within Peer Teaching Plans

Figure 5-1 provides a summary of the percentage of interns whose peer teaching plans showed evidence of use of each type of tool provided during the science methods course. Unsurprisingly, all interns used the tools that were required as part of the science methods course (*EEE Framework*, *Lesson Planning Template*, and the *Card Sort* tool). Use of the *EEE framework* and *lesson planning template* seemed to support interns to plan to elicit students' initial ideas about scientific phenomena, pose an investigation question, engage students in data collection while facilitating small group work, and support students to construct evidence-based claims. Additionally, using the *EEE framework* and *lesson planning template*, interns were prompted to make connections between likely student ideas and the disciplinary core ideas and direct students to notice important pieces of data that could serve as evidence for a scientific claim. In the following sections I provide examples of how interns used each of the tools to plan investigation-based lessons.

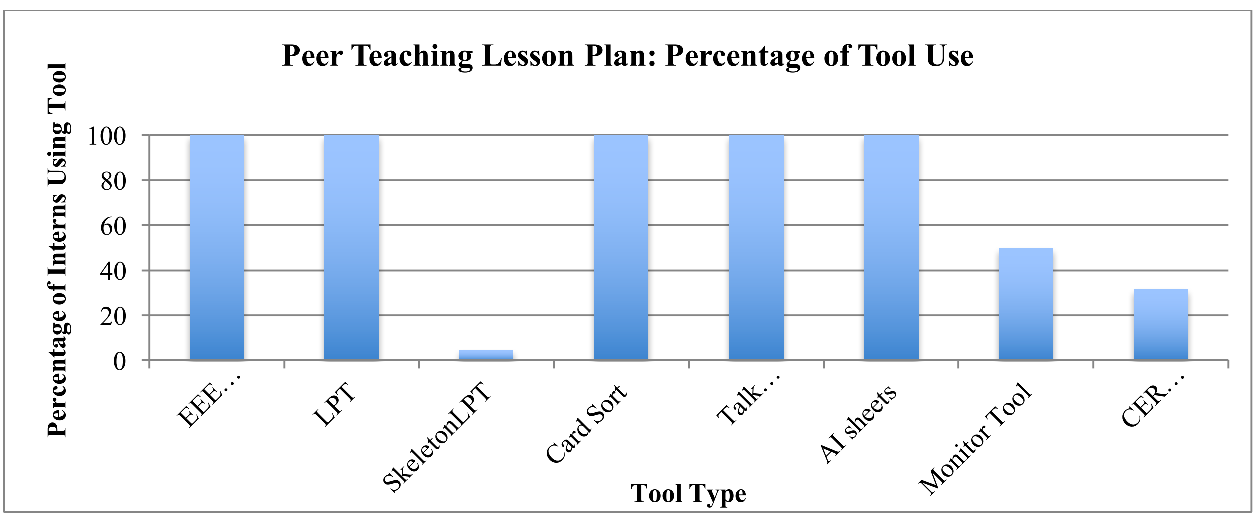

Figure 5-1: Percentage of interns using each type of tool within the peer teaching plan

Alternative Ideas Tool

All of the interns' peer teaching lesson plans showed evidence of use of the *alternative ideas tool*. Within the *lesson planning template*, interns were prompted to consider possible alternative ideas students may have, but they were not prompted to find the ideas in reputable sources (e.g., research-based alternative ideas lists). Without prompting, 100% of the interns cited research-based alternative ideas students were likely to have on the topics of stem function in plants or energy transfer. By including common alternative ideas in their plans, interns likely anticipated how students might be thinking about the scientific phenomenon that was the focus of the investigation. Additionally, use of the *alternative ideas* tool may have supported interns to think critically about how to characterize student thinking and notice nuances in student ideas.

Talk Moves Tool

Similar to interns' use of the *alternative ideas tool*, 100% of interns' peer teaching plans included at least one science-teaching specific talk move from the *talk moves tool*. For example, several interns included, "Given your thinking so far, what do you predict will happen during our investigation? Why?"; "How are you recording your observations so they are accurate?" or "What claim can you make based on the data you have so far?". Eight of the 22 interns used science-teaching specific talk moves in all three elements of the *EEE framework*, and ten out of 22 interns used science-teaching specific talk moves in both the Experience and Explain elements of their peer teaching plan. Use of these open-ended science specific questions from the *talk moves tool* as a *priming tool* likely allowed for increased opportunities for teacher-student and student-student discussion during the investigation-based lesson.

Monitoring Tool

Approximately 50% of the interns' plans showed evidence of use of the *monitoring tool*. The interns who utilized the *monitoring tool* as a *priming tool* were also the only interns who referenced potential alternative ideas within their actual lesson plan rather than solely listing them in the attending-to-learners section (see Appendix B) at the beginning of the planning template. Within the template, when prompted to consider student responses to key questions being asked in the lesson, several interns using the *monitoring tool* included alternative ideas as possible responses. Interns who did not use the *monitoring tool* only considered scientifically accurate responses to the questions they planned to pose. Like the use of the *alternative ideas tool*, the *monitoring tool* seemed to support interns to think critically about how to characterize student thinking and notice nuances in student ideas.

Use of Other Tools

In addition to the use of tools mentioned previously, several interns' plans showed evidence of use of other tools provided during the methods course. For example, one intern created a *skeleton lesson planning template* (Appendix C) to summarize the important pieces of data she wanted students to notice during the investigation. Additionally several of the interns created a claim-evidence-reasoning worksheet based on the *claim-evidence reasoning template* to be used with students during the investigation. The *C-E-R template* helped to organize student data, and interns planned to have students use the worksheets as a reference during the whole-class discussion. Use of both of the *C-E-R template* and *skeleton lesson planning template* likely helped interns to press students to provide evidence for their claims and helped support interns to facilitate the investigation-based discussion.

Finally, I found evidence of interns' use of tools from the course that had not been anticipated. These included a teacher-educator provided *argumentation checklist* to help interns use productive teaching practices for fostering argumentation. For example, one intern listed questions she could use to "play Devil's advocate" to challenge students' arguments, and press them to justify their thinking with evidence. Playing Devil's advocate is one teaching move Simon and colleagues (2006) describe as necessary for fostering argumentation in elementary classrooms.

Evidence of Tool Use Within LiFE Plans

Figure 5-2 provides a summary of the percentage of interns whose LiFE plans showed evidence of use of each type of tool provided during the science methods course. Again, unsurprisingly, all interns used the tools that were required as part of the science methods course (*EEE Framework*, *Lesson Planning Template*, and the *Card Sort* tool). Similar to the peer teaching plans, use of the *EEE framework* and *lesson planning template* seemed to support interns to plan to elicit students' initial ideas about scientific phenomena, pose an investigation question, engage students in data collection while facilitating small group work, and support students to construct evidence-based claims. However, several of the interns' LiFE lesson plans included less detail about how they would support students to engage in each element of the EEE framework. For example, several interns included a script[9] of the investigation-based discussion in their peer teaching plans; whereas in their LiFE plans the same interns provided a list of questions they planned to asked students, but did not include likely student responses.

[9] A script was not required as part of the peer-teaching or LiFE lesson assignments.

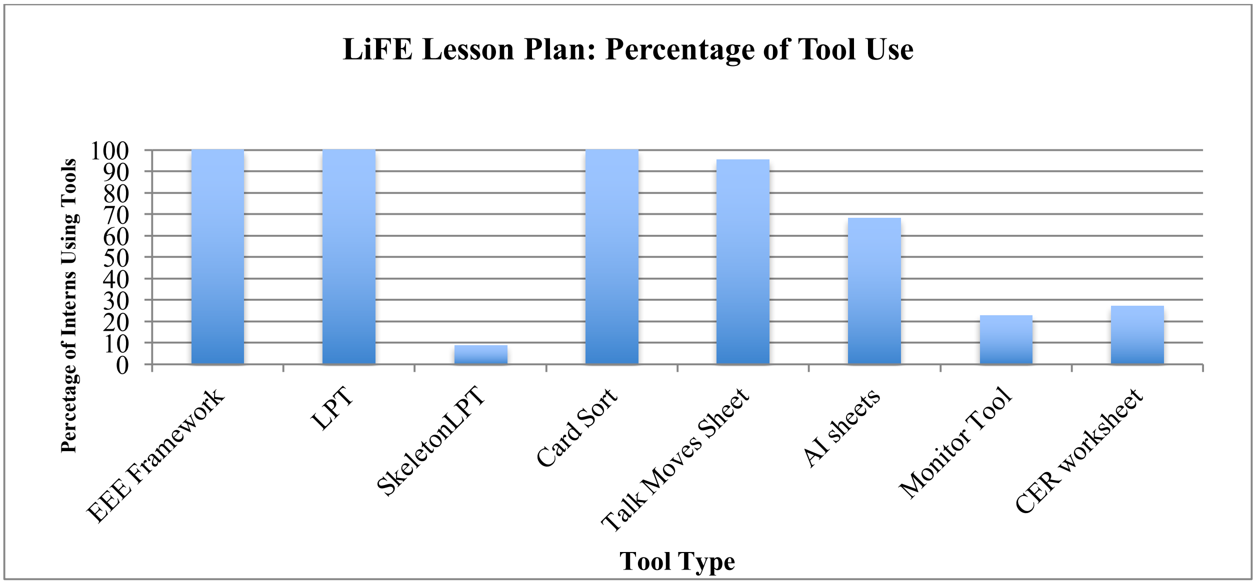

Figure 5-2: Percentage of interns using each type of tool within the LiFE lesson plan

Alternative Ideas Tool

Like in the peer teaching lesson plans, the majority of the interns' LiFE lesson plans showed evidence of use of the *alternative ideas tool*. Again, interns were prompted to consider alternative ideas students may have within the *lesson planning template*, but were not prompted to use research-based sources to find those ideas. Close to 70% of the interns cited research-based alternative ideas. This is lower than the percentage of interns who cited research-based alternative ideas for the peer teaching plan. This may be due to some of the content areas of focus for the interns' LiFE plans not being included in the alternative ideas lists provided during the methods course. In order to find research-based alternative ideas for content areas not included in these lists, interns would have needed to locate these through their own research.

Talk Moves Tool

Close to 95% of interns' LiFE plans showed evidence of use of the *talk moves tool* using a science-teaching specific talk move at least once within the plan. The *talk moves tool* was used as a *priming tool* to plan open-ended questions and anticipated student responses during the investigation. Four of the 22 interns used science-teaching specific talk moves in all three elements of the EEE framework. Five of the 22 interns used science-teaching specific talk moves within the Experience and Explain elements of the plan. Six of the 22 interns used science-teaching specific talk moves during the Engage and Explain elements of the plan. Many of the science-teaching specific talk moves used within the Engage element were focused on prompting students to make scientific predictions about the investigation question for the lesson.

Monitoring Tool

Approximately 23% of interns' plans showed evidence of the use of the *Monitoring Tool*. Like the peer teaching plan, interns using the *Monitoring Tool* were the only interns who referenced potential common alternative ideas students may have within their actual plan rather than listing them solely in the attending to learners section. When prompted to consider students' responses to key questions, interns who did not use the *Monitoring Tool* only considered scientifically accurate responses.

Use of Other Tools

Similar to the peer teaching plans, several of the interns created a claim-evidence-reasoning worksheet based on the *claim-evidence reasoning template* to be used with students during the investigation. The C-E-R template helped to organize student data, and interns planned to have students use the worksheets as a reference during the whole-class discussion.

Similarities and Differences Across Lesson Plans

The percentages of interns using different types of tools were similar in both the peer teaching plans and the LiFE plans. As previously stated, 100% of interns' plans showed evidence of use of the *EEE framework*, *lesson planning template*, and *card sort tools* for both plans. Using these tools was required during the methods course. Most interns' plans showed evidence of use of both the *alternative ideas tool* and the *talk moves tool.* For both the peer teaching lesson plans and the LiFE plans, over 25% of interns' plans showed evidence of use of the *claim-evidence-reasoning template* to create a student handout. Additionally, although the use of the *monitoring tool* declined (50% of peer teaching plans and 23% of LiFE plans), in all instances of use it seemed to support the interns to consider potential alternative ideas students may have about science phenomena within their step-by-step plans. Focal interns' use of tools during their lesson enactments is described in the next section.

Evidence in the Enactments: Peer Teaching

Similarities existed across the types of tools the focal interns used in their enactments for the peer teaching lesson. All six focal interns used several talk moves provided by the *talk moves tool* throughout their lesson enactments. Additionally, four of the focal interns (Ms. Andrews, Ms. Kramer, Ms. Chase, and Ms. Sawyer) encouraged students to use the versions of the *C-E-R template* they had created for their peer teaching lesson. Ms. Sawyer utilized a version of the *monitoring tool* while students were making observations during her peer teaching lesson enactment. The following sections provide further detail of each focal intern's tool use. For each focal intern, I summarize the overall frequency of tool use. Segments of lesson enactment transcripts are also included to provide evidence of each intern's typical tool usage.

Ms. Andrews

As a reminder, Ms. Andrews was assigned the Energy lesson for her peer teaching assignment designed to help students begin to understand the concept of heat energy transfer from a warmer object to a cooler object. During her enactment, Ms. Andrews utilized talk moves from the *talk moves tool* in 45.1% of the two-minute segments of her enactment, and encouraged students to use the *C-E-R template* in 29.0% of the two-minute segments of her enactment. Figure 5-3 provides the specific time segments when each of the tools was used.

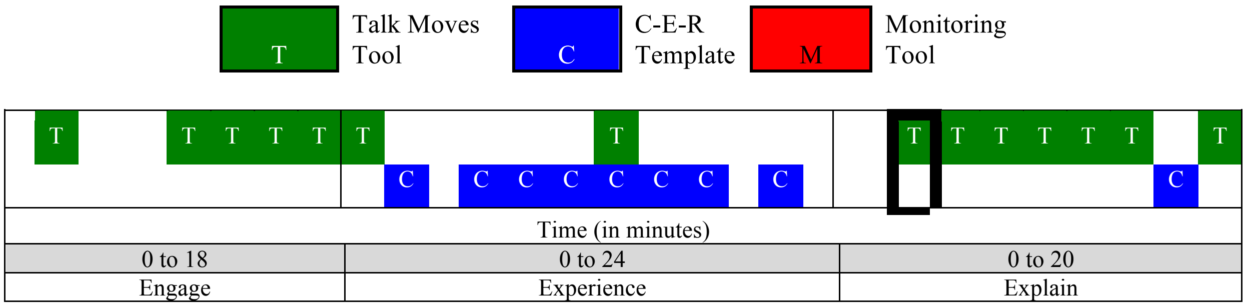

Figure 5-3: Ms. Andrews's Tool Use During Peer Teaching Enactment

Ms. Andrews used the talk moves from the *talk moves tool* to elicit students' initial ideas about the investigation question, and supported her students to look for patterns in their data after the investigation. For example in the segment outlined in black in Figure 5-3, Ms. Andrews asked her students to notice similarities and differences in four groups' graphed temperature data:

> Ms. Andrews: We don't have the data sheets, but we are just looking at trends today so we are going to look at all four of these together. *What are some things you notice*[10] about either one individual graph or all four of these?
>
> Student 1: They all look like a greater than sign. That one looks like an open mouth.
>
> Student 2: That one up there is the only one that does not look quite like the others.
>
> Student 3: That one looks weird.
>
> Ms. Andrews: Let's start thinking about this for a second. Why might this one look weird?... *What might have happened to make group two's data look different*?
>
> Student 1: Maybe something happened with their thermometer.
>
> Student 2: They pulled it out of the water.

[10] Talk moves are italicized

Ms. Andrews: I agree maybe something happened during the experiment. Do you think we can still use this data?

Student 2: No

Ms. Andrews: [Student 2] says no. [Student 2] *can you tell us more about that?*

Student 2: Well because if you pull the thermometer out, then you basically have to start all over again because you already ruined everything else.

Ms. Andrews: Okay. *Does anyone have a different idea* from what [Student 2] said?

Student 3: Well I was wondering if group two knows what happened with their data.

Ms. Andrews: Group two moved their thermometer.

Student 4: Oh so they sort of fixed it.

Ms. Andrews: Well why don't we look more across all of the graphs and then decide if we should use it.

In this segment, Ms. Andrews asked students what they noticed about the graphs. Use of an open-ended question allowed students to engage in the intellectual work of noticing patterns within data. Additionally, when students noticed differences in the graphs, Ms. Andrews pressed her students to provide reasoning as to why one of the graphs might "look weird" rather than explaining to students that group two moved their thermometer. Later in the segment, Ms. Andrews pressed her student to explain why he thought the group two data should not be used and provided space for other students to agree or disagree with his reasoning by using the talk move "does anyone else have a different idea?". Use of this talk move allowed students to discuss their thoughts and likely created an opportunity for students to engage in argumentation.

In the majority of segments when the tools were used, the tools were used independently from one another. However, in one segment (Experience element minutes 12-14), Ms. Andrews directed students to utilize the *C-E-R template* to organize their data and keep track of their roles during the investigation (e.g., one student was assigned the role of "recorder of the data") and used talk moves to probe students' thinking about how they could make sure they were being accurate in their readings of the thermometers placed in the warm and cold water.

Students continued to use the *C-E-R template* to record their data during the investigation. Ms. Andrews also prompted students to use the *C-E-R template* to write down ideas for a claim that would answer the investigation question in the Explain element of her peer teaching lesson. Use of the *C-E-R template* provided an opportunity for students to construct an evidence-based claim, and likely allowed Ms. Andrews to formatively assess her students' understanding of heat energy transfer.

Ms. Lawrence

As a reminder, like Ms. Andrews, Ms. Lawrence was assigned the Energy lesson for her peer teaching assignment. During her enactment, Ms. Lawrence utilized talk moves from the *talk moves tool* in 63.0% of the two-minute segments of her enactment, mostly in the Explain element. Ms. Lawrence did not use the *C-E-R template* or the *monitoring tool* during her peer teaching enactment. Figure 5-4 provides the specific time segments when the *Talk Move Tool* was used.

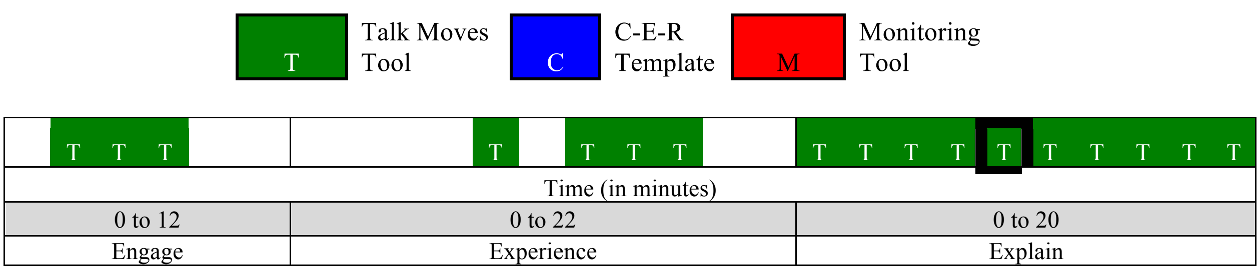

Figure 5-4: Ms. Lawrence's Tool Use During Peer Teaching Enactment

Similar to Ms. Andrews, Ms. Lawrence used the *talk moves* listed on the *Talk Moves Tool* to press students to justify their ideas and be more specific about the claims they were making. For example, in the segment outlined in black in Figure 5-4, Ms. Lawrence used talk moves to support her students to construct a scientific claim to answer their investigation question:

Ms. Lawrence:	Now that we have looked at our data, let's look a little closer at what the data tells us. When we look at the four sets of data. Let's think about what kind of claim we can make to answer our investigation question… *What kind of claim can we make about the patterns?*
Student 1:	The water changes temperature.
Ms. Lawrence:	*Can you be more specific?*
Student 1:	Well the hot water starts really hot and then it cools down, and the cold water starts really cold and then it warms up.
Ms. Lawrence:	Is it fair to say the hot water cools down? And the cool water warms up?
Student 1:	Yes.
Ms. Lawrence:	*What are some other thoughts? What other claims can we make about what we saw?*
Student 2:	So they get to be the same. Like we said that it changes and I agree, but it's not any old change. They end up being the same.
Ms. Lawrence:	Ahh, can you show us on the graphs what you mean?
Student 2:	Like these two. The hot goes down like [Student 1] said and the cold goes up like she said but it ends up at the same point.
Ms. Lawrence:	Ahh. *Is everyone noticing what [Student 2] is pointing out?* That the graphs will come together. That the cold water and the warm water temperatures will meet at a certain point? *Does anyone notice anything different about it?*
Students:	Yes
Ms. Lawrence:	Let's add [Student 2's] statement. The temperatures change until they become the same. *Does that capture what you said [Student 2]?*
Student 2:	Yes.

In this segment, Ms. Lawrence's use of the talk move "what claims can we make about the patterns?" facilitated students to make claims based on the evidence they were noticing in the graphs, and asking students to be more specific prompted students to include further detail in their claims. Additionally, by revoicing the students' statements (a general talk move listed on the *talk moves tool*), Ms. Lawrence insured she was capturing students' thoughts accurately without making assumptions about meaning. The use of open-ended questions from the *talk moves tool* and revoicing of student statements was typical in Ms. Lawrence's peer teaching lesson enactment.

Ms. Chase

Like Ms. Andrews and Ms. Lawrence, Ms. Chase taught the Energy lesson. During her enactment, Ms. Chase utilized talk moves from the *talk moves tool* in 54.8% of the two-minute segments of her enactment. Of the focal interns teaching the Energy lesson, she encouraged students to use the *C-E-R template* most frequently, pointing students' attention toward the template in 32.3% of the two-minute segments of her enactment. Figure 5-5 provides the specific time segments when each of the tools was used.

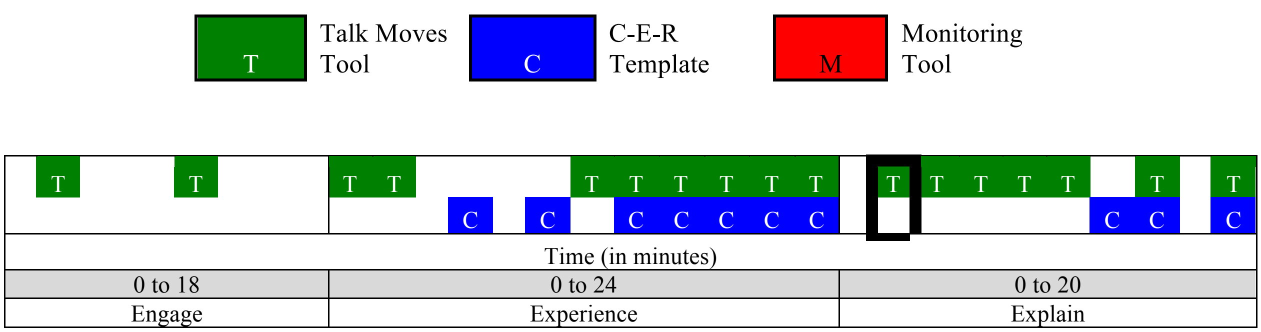

Figure 5-5: Ms. Chase's Tool Use During Peer Teaching Enactment

Ms. Chase also used the talk moves listed on the *talk moves tool* to press students to justify their ideas. Similar to Ms. Andrews, in minutes 2 to 4 of the Explain element (outlined in black in Figure 5-5), Ms. Chase pressed her students to come up with a reason as to why one group's data was different than the other three groups:

Ms. Chase: *What are the trends that you notice in the graphs*?

Student 1: Number two stinks.

Ms. Chase: *Tell me more about why you think* number two stinks.

Student 1: Their numbers are bouncing all over the place.

Student 2: Did they heat it up?

Ms. Chase: They didn't heat it up. What else could they have done? *Why is it different? I want you to try to think of a reason that their graph could look different*…. Think of a reason why there might have been some jumps in temperature.

In this segment, rather that telling the students why group two's data were different than the rest of the group, Ms. Chase used the talk moves to ask students why they thought group two's data were different. Use of the talk moves "tell me more…" and "why is it different?" pushed students to do the intellectual work of determining potential reasons for the anomalous data.

Ms. Chase also prompted students to use the *C-E-R template* to record their data as they were carrying out the investigation, and in the Explain element she encouraged students to use the *C-E-R template* to write down ideas for a claim that would answer the investigation question in the Explain element of her peer teaching lesson. Use of the *C-E-R template* provided an opportunity for students to construct an evidence-based claim, and like Ms. Andrews, allowed Ms. Chase to formatively assess her students' understanding of heat energy transfer. Similar to the *C-E-R template* provided to the interns in the methods course, Ms. Chase's *C-E-R template* also prompted students to apply what they had learned in the lesson by asking them to respond to the prompt, "On a summer day, imagine you have a cold glass of lemonade with ice cubes. Based on what we just learned about heat energy transfer, is the ice cube cooling down the lemonade or is the lemonade warming up the ice cube?". By including an application question on her *C-E-R template*, Ms. Chase was provided an additional opportunity to formatively assess her students' understanding of heat energy transfer.

Ms. Kramer

As a reminder, Ms. Kramer was assigned the Stems lesson for her peer teaching assignment, designed to help students begin to understand the function of a stem. During her enactment, Ms. Kramer utilized talk moves from the *talk moves tool* in 45.2% of the two-minute segments of her enactment, and encouraged students to use the *C-E-R template* in 16.1% of the two-minute segments of her enactment. Figure 5-6 provides the specific time segments when each of the tools was used.

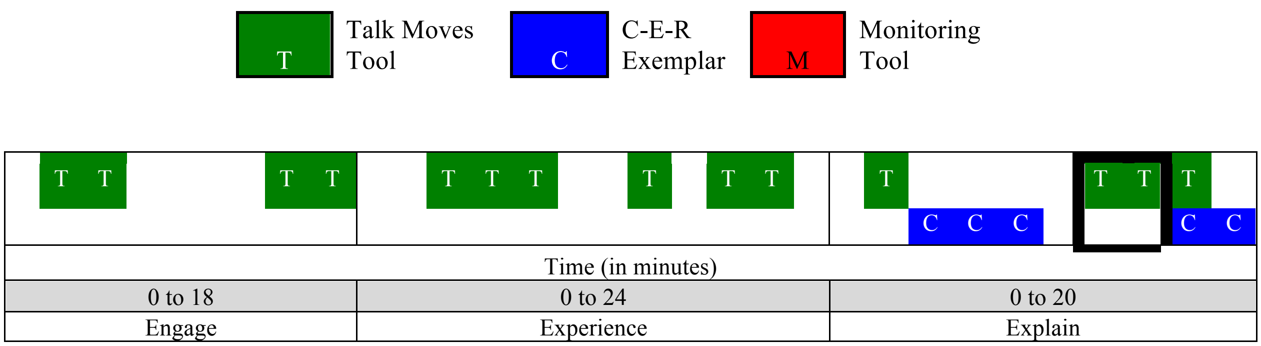

Figure 5-6: Ms. Kramer's Tool Use During Peer Teaching Enactment

Ms. Kramer used talk moves from the *talk moves tool* to press students to provide reasoning for their claims. In minutes 12 to 16 of her Explain element (outlined in Figure 5-6), she asked students to think about why the celery got red and stiff after three days of being in the water with red food coloring:

Ms. Kramer: So [the celery] turns red and it turns stiff is our claim. This is what happens here. So now, we want to think about our reasoning for this. *Why does this happen?* Knowing what we know about living organisms, why is it important? *Why* does it happen? What is happening here in our pictures? *Why* does [the celery] turn red and turn stiff?

Student 1: Why is it getting stiff and red? Because it was in water, red water. Something had to be done to it! When we first put it in the red water, three days later, so the water helped it get stiff and red. So somehow the water had to get inside the celery to help it get red up here.

Mrs. Kramer: *Does someone want to add on* to what [Student 1] said?

Student 2: I think that the celery drinks the water and is red and stiff.

Ms. Kramer then reminded the students about their observations of the cross sections of the celery.

Ms. Kramer: *What did you notice* when you cut into your celery?

Student 3: I noticed those red dots and we talked about how they looked like tubes.

Ms. Kramer: So thinking about cutting open our celery and looking at the tubes we have in there. *And like [Student 1] was saying* the water must have gone into the stem *and [Student 2] is thinking about* the celery drinking the water. *How* might the water have gone into the stems?

Student 1: Those holes! The tubes.

Ms. Kramer: *Can you tell me more* [Student 1]? What about the tubes? *How* did the water get all the way up into the leaves?

Student 1: Oh yeah! They are like straws. So the water went up those tubes and that is why they are red because the water is red and the tubes go all the way up to the leaves.

In these segments, Ms. Kramer used open-ended questions to prompt students to consider why the leaves of the celery turned red. After one student offered an explanation, she used the talk move "does someone want to add on" to include other students in the discussion, pressing them to expand on the initial reasoning that was shared. Then by reminding students of their observations and asking them to remember what they had noticed about the cross-section of the celery, Ms. Kramer guided students to provide scientifically accurate reasoning as to how the water moved up through the stems into the leaves.

Following this discussion, Ms. Kramer and her students summarized the reasoning they agreed upon as a class, and she prompted the students to write the reasoning on the *C-E-R template* she created for the peer teaching lesson. Similar to how Ms. Andrews and Ms. Chase used the *C-E-R template* to assess their students' understanding of heat energy transfer, having the students write their reasoning on the *C-E-R template* provided Ms. Kramer an opportunity to formatively assess her students' understanding of the function of the stems.

Ms. Zabel

Ms. Zabel also taught the Stems lesson for her peer teaching assignment. During her enactment, Ms. Zabel utilized talk moves from the *talk moves tool* in 53.6% of the two-minute segments of her enactment. Ms. Zabel did not use the *C-E-R template* or the *monitoring tool* during her peer teaching enactment. Figure 5-7 provides the specific time segments when the *talk moves tool* was used.

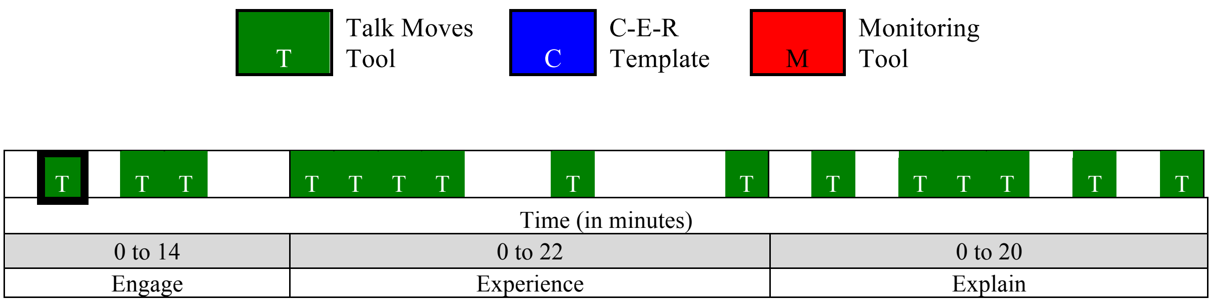

Figure 5-7: Ms. Zabel's Tool Use During Peer Teaching Enactment

Ms. Zabel used talk moves from the *talk moves tool* throughout her lesson to probe her students to describe what they were observing and encourage students to listen to one another. For example, from minutes 2 to 4 in her Engage element (outlined in Figure 5-7), Ms. Zabel posed an open-ended question asking her students to consider the function of stems in plants:

Ms. Zabel: Let's talk about what we think the stem does in a plant. What do you think a stem does in a plant?

Student 1: Makes it taller.

Student 2: Holds up the flower.

Ms. Zabel: *Tell me more about that.*

Student 2: It holds it up in the air because without a stem the flower would just be on the ground.

Ms. Zabel: Okay. *Anyone have a thought about what [Student 2] just said*?

Student 3: When they are dying they are on the ground. The stem is sad.

Ms. Zabel: Flowers are sad, hummm. When [Student 3] says sad *what do you think she means by that*?

Student 4: It's wilted.

Ms. Zabel: Wilted. That's a word that you might not have heard of before.

Ms. Zabel then helped students to understand that scientists usually do not use human emotions to describe what they observe, but rather use words to describe exactly what they see.

In this segment Ms. Zabel used the talk moves to elicit students' initial ideas about the functions of a stem. Then, when one student began to anthropomorphize the stem, describing it as "sad", she allowed the other students to comment on what they think the student meant when she declared the stem is "sad". Use of the talk move "what do you think she means by that?" allowed the students time to think about what was being discussed. Then, another student was able to rephrase the third student's comment in a scientifically accurate way describing the stem as wilted rather than sad. In addition to revoicing and asking students to rephrase other's ideas, Ms. Zabel used the talk move "tell me more about that" frequently during her peer teaching enactment, pressing students to elaborate on their ideas.

Ms. Sawyer

Like Ms. Kramer and Ms. Zabel, Ms. Sawyer taught the Stems lesson. During her enactment, Ms. Sawyer utilized talk moves from the *talk moves tool* in 67.9% of the two-minute segments of her enactment and encouraged students to use the *C-E-R template* in 25% of the two-minute segments of her enactment. Ms. Sawyer also used the *monitoring tool* in 21.4% of the two minute segments of her enactment. Figure 5-8 provides the specific time segments when each of the tools was used.

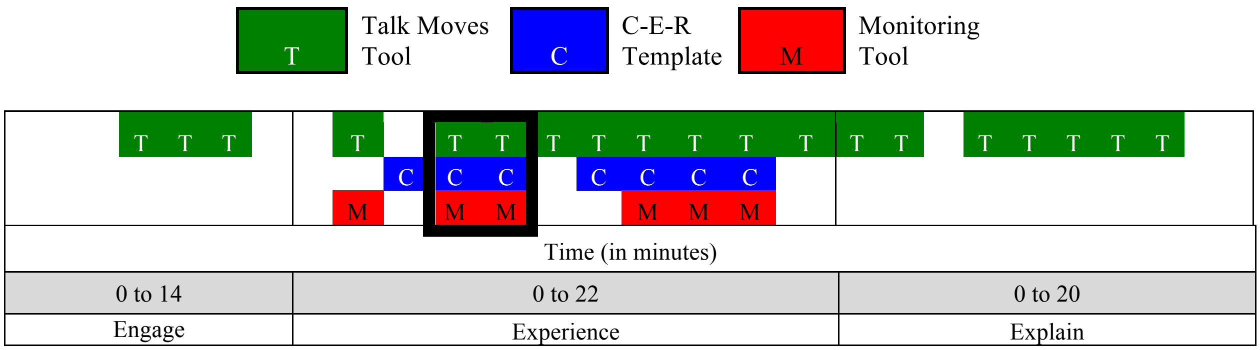

Figure 5-8: Ms. Sawyer's Tool Use During Peer Teaching Enactment

During the Experience element, Ms. Sawyer circulated around the peer teaching group as her students were drawing their observations of the celery stems. In minutes 6 through 10 (outlined in Figure 5-8) of her Experience element, Ms. Sawyer used talk moves from the *talk moves tool* and prompted students to record their observations on their *C-E-R template*. As she was circulating she used her *monitoring tool* to record comments about the students' drawings and checked to see if the drawings were clear, complete, accurate, and labeled.

Ms. Sawyer: [Student 1] can you *tell me about your drawing*?

Student 1: This is my piece of celery and this is the leaves on my celery and this is the water.

Ms. Sawyer: Okay *what's another step that we could add to make sure somebody who has no idea what we are doing in class knows what we are doing in this investigation.*

Student 1: Uh, I could label it.

Ms. Sawyer: And remember all the parts of the plant that we know that we could label.

Student 1: Oh yeah!

Ms. Sawyer: [Student 2] I have a few questions about your drawing. It's a beautiful drawing. I do like it. *But let's think about how we draw as scientists. Remember we said that we want them to be very accurate.* Is that celery smiling at us? *Does it actually* have a smiley face?

Student 2: I guess not, but I think it's happy because it's in the water.

Ms. Sawyer: That's very interesting. *Sometimes as scientists we have to choose between what we see and what we infer or what we are guessing about it.* So we want to make sure we draw what we see. So you might be guessing that the celery is happy, but that is not exactly what we see

Student 2: Oh so I shouldn't draw the smiley faces.

By using her *monitoring tool* to keep track of students' ideas while they were making observations, Ms. Sawyer was able to formatively assess her students' thinking in the moment. This may have allowed Ms. Sawyer to begin to structure the investigation-based discussion, noting which students had accurate understandings and which students had productive alternative ideas. Additionally, by asking her students about what they were drawing and what they could do to help someone who hadn't done the investigation be better able to understand what they had been observing, she pushed her students to be more systematic in their data collection.

Evidence in the Enactments: Lesson in Field Experience (LiFE)

Similarities existed across the types of tools each focal intern used in her peer teaching and LiFE lesson enactments. Additionally, similarities existed across the types of tools interns used in enactments for the lesson in field experience. Similar to the peer teaching enactments, all six focal interns used several talk moves provided by the *talk moves tool* throughout their lesson enactments. Only one of the focal interns (Ms. Andrews) encouraged students to use the versions of the *C-E-R template* she had created for her lesson in field experience. Ms. Zabel briefly utilized a version of the *monitoring tool* while students were making observations during her LiFE lesson enactment. The following sections provide further detail of each focal intern's tool use. Again, for each focal intern, I summarize the overall frequency of tool use. Then, segments of lesson enactment transcripts are included to provide evidence of each intern's typical tool usage.

Ms. Andrews

Ms. Andrews's LiFE lesson was focused on supporting students to understand the spread of disease within a community (see Appendix P for the event map of this lesson). During her LiFE lesson enactment, Ms. Andrews used talk moves from the *talk moves tool* in 35.5% of the two-minute segments of her enactment, and she encouraged students to use the *C-E-R template* in 45.2% of the two-minute segments of her enactment. Figure 5-9 provides the specific time segments when each of the tools was used.

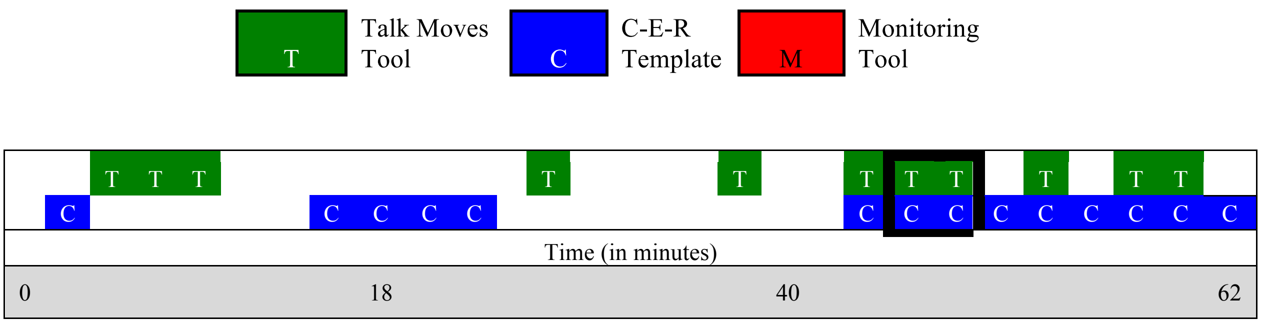

Figure 5-9: Ms. Andrews's Tool Use During LiFE Enactment

Toward the end of the lesson (minutes 46 to 50 outlined Figure 9), Ms. Andrews helped students to make an evidence-based claim answering the question "How does disease spread through a community?". Ms. Andrews used talk moves from the *talk moves tool* to support students to listen to each other's ideas and rephrase ideas in their own words. She then directed their attention to the *C-E-R template* she created for the lesson to prompt students to write their claims in their own words:

Ms. Andrews: Now, let's go back to our investigation question. How does disease spread through a community? *So how can we answer this question? This is going be our claim. What claim can we make that answers this question?* So what happened every time when someone new got infected? What happened in order for a new person to get infected?

Student 1: We had to pour the milk, and if you traded it with an infected person it would infect you and then they would infect two more people.

Ms. Andrews:	Okay. [Student 2]. *Can you restate* what [student 1] just said? It was really important. I want to make sure everyone heard it.
Student 2:	I could not hear him.
Ms. Andrews:	Okay. [Student 1], say it again.
Student 1:	When you trade with an infected person you get infected off them.
Ms. Andrews:	Okay. [Student 2], *can you say it in your own words*?
Student 2:	Every time you trade you traded with someone you could have gotten an infection.
Ms. Andrews:	So you only got the infection if—
Student 2:	You traded with someone that had it.
Ms. Andrews:	You traded with someone that had it. So everybody look at the next box. It says claim, answer to the investigation question. You're going put it in your own words. How does disease spread through a community? So remember in real life you're not trading milk with people, what are you trading?
Student 3:	Infection.
Student 4:	Bodily fluid, bodily fluid, body fluid.

Students continued to use the *C-E-R template* to record multiple pieces of evidence that supported their claim. Use of the talk moves facilitated students' listening to each other during the investigation-based discussion. Additionally, rather than Ms. Andrews telling the students the evidence-based claim, she posed questions positioning students to construct the claim based on what they had observed during the investigation. Finally, use of the *C-E-R template* provided an opportunity for students to construct a claim based on multiple pieces of evidence, and likely allowed Ms. Andrews to formatively assess her students' understanding of how disease spreads through a community.

Ms. Lawrence

Ms. Lawrence's LiFE lesson was focused on supporting students to understand what happens to light when it reaches a transparent object by placing a straw in a bottle of vegetable oil and a bottle of water (see Appendix P for the event map of this lesson). During her LiFE lesson enactment, Ms. Lawrence utilized talk moves from the *talk moves tool* in 63.3% of the two-minute segments of her enactment. Unlike Ms. Andrews, Ms. Lawrence did not craft a *C-E-R Exemplar* for her lesson, but instead she relied on the worksheets provided in her field placement's curriculum materials. Ms. Lawrence also did not make use of the *monitoring tool* during her LiFE lesson enactment. Figure 5-10 provides the specific time segments for when talk moves from the *talk moves tool* were used.

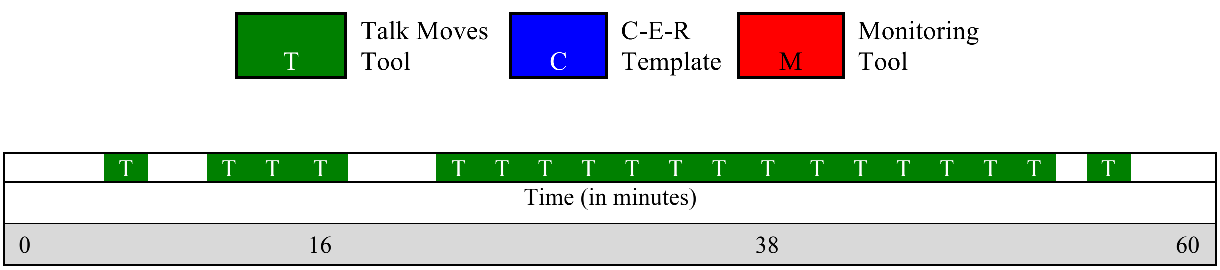

Figure 5-10: Ms. Lawrence's Tool Use During LiFE Enactment

Similar to her peer teaching lesson enactment, Ms. Lawrence used the talk moves listed on the *talk moves tool* to press students to justify their ideas and be more specific about the observations they were making. For example, when eliciting students' observations of the straw placed in the bottle of oil (minutes 44-48 outlined in Figure 5-10), Ms. Lawrence used several talk moves:

Ms. Lawrence:	*What else did you notice? What did you notice*, [Student 1]?
Student 1:	The is oil translucent and water is transparent.
Ms. Lawrence:	Hmm. So you think maybe the oil was translucent? *Why do you think that?*
Student 1:	Because I can see a little bit of some light pass through the straw.

Ms. Lawrence: Aha. So was the oil translucent or was the straw translucent?

Student 1: The straw was translucent.

Ms. Lawrence: Ah, so let's change this to be the straw. Our straw was translucent. *Did anyone else notice that? Did you notice that some of the light passed through the straw?*

Students: Yes!

Ms. Lawrence: *You noticed that too*?

Student 2: No.

Ms. Lawrence: *You noticed something different*?

Student 2: Yeah.

Ms. Lawrence: *What did you observe*?

Student 2: When we looked in the oil, the straw, it was like really fat at the bottom and [inaudible].

Ms. Lawrence: You're saying the straw looked bent, kind of like we saw in the water? *Is that what you're saying*, [Student 2]?

Student 2: No, it's like fat at the bottom. And then it gets skinnier as you go up.

Ms. Lawrence: Okay. *So that's what [Student 3] was saying*. The straw was bigger and then when it was under the oil, and it was skinnier on top.

In this excerpt, when the student described the oil as being translucent rather than transparent, rather than telling the student that she was incorrect, Ms. Lawrence used the talk move "Why do you think that?" to ask the student why she thought the oil was translucent. The student elaborated telling Ms. Lawrence the light passed through the straw, and eventually came to the conclusion the straw was translucent and the oil was transparent. By asking the student to explain further, Ms. Lawrence gained a better understanding of the student's thinking and asked a follow up question to guide the student to think about the straw versus the oil. Then, by asking the other students if they saw similar observations, Ms. Lawrence allowed space for students to disagree with each other and additional observations to be shared. Ms. Lawrence's use of talk moves such as "why do you think that?" and "tell me more about that" was typical during her LiFE enactment.

Ms. Chase

Ms. Chase's LiFE lesson was focused on supporting students to understand the process of condensation (see Appendix P for the event map of this lesson). During her LiFE lesson enactment, Ms. Chase used talk moves from the *talk moves tool* in 56.0% of the two-minute segments of her enactment. Unlike her peer teaching lesson, Ms. Chase did not craft a *C-E-R template* for her LiFE lesson. Like Ms. Lawrence, Ms. Chase relied on the worksheets provided within her field placement's curriculum materials. Ms. Chase also did not make use of the *monitoring tool* during her LiFE lesson enactment. Figure 5-11 provides the specific time segments for when talk moves from the *talk moves tool* were used.

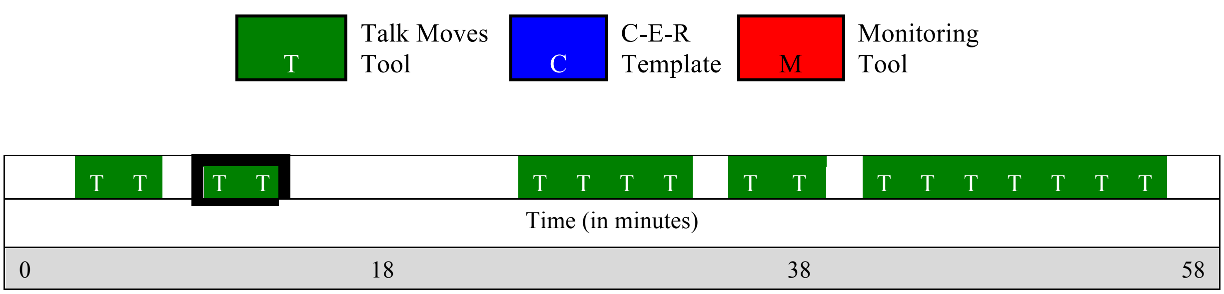

Figure 5-11: Ms. Chase's Tool Use During LiFE Enactment

Similar to her peer teaching lesson, Ms. Chase used the *talk moves* listed on the *talk moves tool* to press students to justify and explain their ideas. For example, at the beginning of her lesson (minutes 10 through 14 outlined in Figure 5-11) Ms. Chase posed the investigation question and asked students for hypotheses as to why water droplets form on the outside of cold surfaces.

Ms. Chase: So our question is why do water droplets appear on cold surfaces? *Does* *anybody have any predictions for why that happens?* Take a second and think and then raise your hand for me okay. *What do you think?* Ooh, [Student 1], *what do you think?*

Student 1: I think it's because—since it's so cold that when a sunbeam or any type of light that's—a light or any type of lights that hot or it's just kind of warm, I think the beam from it goes down then it shines its light on the frozen thing, whatever is frozen. And it starts to unfreeze, and I think the water that's frozen inside pops out through the ice and then water droplet melts the ice, which is making the water escape.

Ms. Chase: *So what I understood you say is* that the light melts the ice and then the water comes out of the ice and that's where the water droplets come from?

Student 1: Yeah.

In this excerpt Ms. Chase asked students to explain why water droplets form on the outside of cold surfaces. The student explained his thinking and Ms. Chase responded by using a talk move to rephrase the student's thinking ensuring she understood his meaning. Then Ms. Chase asked a follow up question to probe the student's thinking further. Ms. Chase goes on to elicit additional hypotheses from students and draws attention to similar aspects of students' thinking (e.g., the water forming the droplets coming from inside the glass).

Rather than trying to correct the student's thinking at the beginning of the lesson, Ms. Chase allowed the alternative idea to persist and did not explain that the water droplets form when water vapor in the air outside the can is cooled and a phase change occurs. She used the talk moves to probe students' thinking further, perhaps allowing her to notice the nuances in their responses. This use of talk moves to probe students thinking further was typical throughout Ms. Chase's LiFE lesson enactment.

Ms. Kramer

Ms. Kramer's LiFE lesson was focused on supporting students to understand how fish move and breathe (see Appendix P for the event map of this lesson). During her LiFE lesson enactment, Ms. Kramer utilized talk moves from the *talk moves tool* in 58.6% of the two-minute segments of her enactment. Ms. Kramer did not craft a *C-E-R template* for her LiFE lesson and also did not make use of a m*onitoring tool* during her LiFE lesson enactment. Figure 5-12 provides the specific time segments for when talk moves from the *Talk Moves Tool* were used.

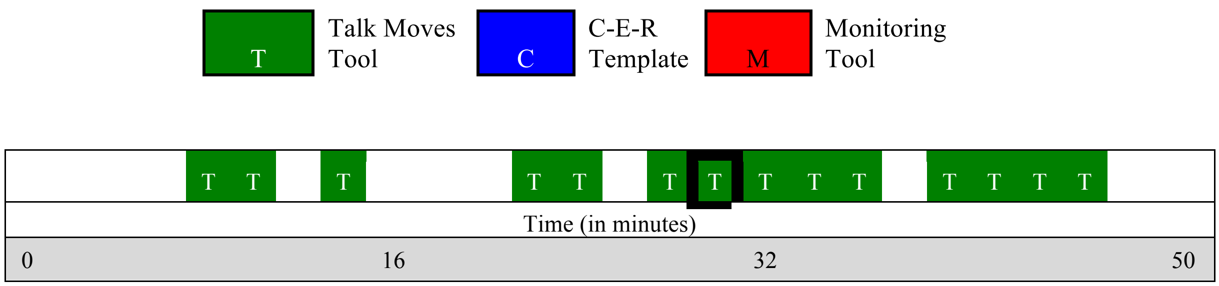

Figure 5-12: Ms. Kramer's Tool Use During LiFE Enactment

Ms. Kramer used talk moves from the *talk moves tool* to press students to provide evidence from their observations when trying to answer the question of how fish breathe. For example, when students were making initial claims about how fish move and breathe (minutes 30 to 32 outlined in Figure 5-12), Ms. Kramer prompted students to add on to others' ideas and observations.

Ms. Kramer: So fish open their mouths up and down. *What's something else that somebody noticed or could add on* to what [Student 0] said about their mouths? [Student 1]?

Student 1: They use their mouths to get the air and then their gills—after they breathe it in the gills get the rest of the water out.

Ms. Kramer: *How do you know that? What did you see*?

Student 1: I was observing the fish and they opened their mouths and then the gills moved.

Ms. Kramer: And when the fish open their mouths *what did you see happen* with the gills?

Student 1: They opened—after the fish closed its mouth the gills would open up.

Ms. Kramer: So first they use their mouths to get air. Then their gills open.

In this segment, Ms. Kramer asked a student to add on to another student's observation of the fish mouths opening and closing. After the second student offered additional information, Ms. Kramer used a talk move to press the student to explain how he knew the fish used their mouths to get air by directing him back to his observations. In doing so, she supported the student to use his observations as evidence for his claim that the fish use their mouths and gills to breathe. Following this interaction, Ms. Kramer asked other students what they had observed about the movement of the fish mouth and gills, eventually asking students if they agreed that both the mouth and the gills were important for the fish's ability to breathe under water. By using talk moves to press students to justify their ideas with evidence from their observations and helping the students to see similarities across their ideas, the students were supported in making evidence-based claims about how fish breathe. Use of talk moves to press students to justify or provide evidentiary support for their ideas was common during Ms. Kramer's investigation-based discussion; however, these exchanges typically only occurred between Ms. Kramer and a single student at a given time.

Ms. Zabel

Ms. Zabel's LiFE lesson was focused on supporting students to understand black is a mixture of other colors by placing a coffee filter with a black line drawn on the end in water (see Appendix P for the event map of this lesson). During her LiFE lesson enactment, Ms. Zabel used *talk moves* from the *talk moves tool* in 50.0% of the two-minute segments of her enactment. Ms. Zabel briefly made use of a *monitoring tool* during her LiFE lesson enactment, but she did not craft a *C-E-R template*. Figure 5-13 provides the specific time segments for when talk moves from the *talk moves tool* and *monitoring tool* were used.

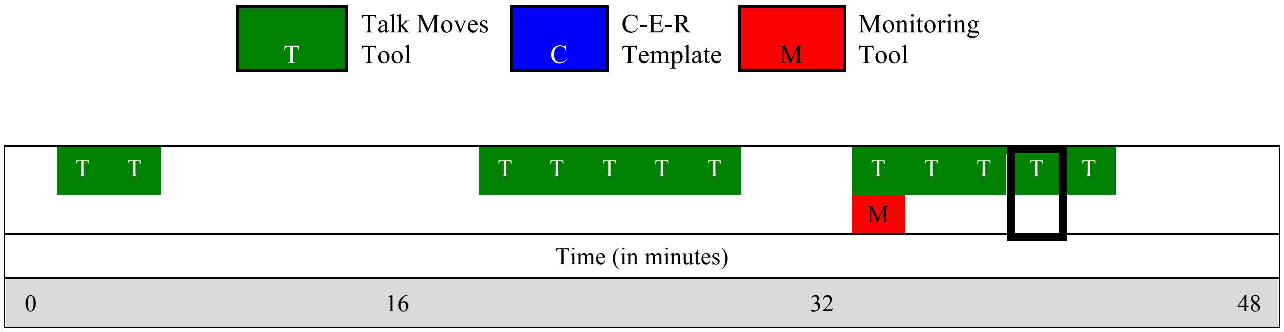

Figure 5-13: Ms. Zabel's Tool Use During LiFE Enactment

Similar to Ms. Kramer, Ms. Zabel used talk moves from the *talk moves tool* to elicit students' observations to support their claims describing what happened to the black line when they placed the filter paper in water. Ms. Zabel began to elicit observations by asking her students to tell her about the colors (minutes 40 to 42 outlined in black in Figure 13).

Ms. Zabel: I know you have lots of ideas. So go ahead. *Tell me about* the colors.

Student 1: I saw a rainbow, orange, red and yellow. Black is a shade and you use all the colors in the rainbow to make black. And then, when you put it in the water, the rainbow comes back.

Ms. Zabel: *So tell me more about that.* What do you think about that? Darren's saying there's all these colors in the rainbow makes black. *Tell me more. What does that make you think about?*

Student 2: The water was evaporating and it touched the paper. So, so it was evaporating slowly. And when it touched the black, it started going up and down. And it started to change colors.

Several students then commented that they thought the water was making all the colors of the rainbow separate apart from one another and appear on the paper. Ms. Zabel drew attention to the idea several students had raised that black was a mixture of all the colors. Her use of the talk moves "tell me more…" and "What does that make you think about?" was typical during Ms. Zabel's enactment. Ms. Zabel used the science-teaching specific talk moves less frequently than the other focal interns. Use of the general talk moves pushed students to do the intellectual work of sharing their ideas that black was a mixture of all the colors; however Ms. Zabel struggled to use talk moves to connect students' ideas. These struggles will be described in further detail in Chapters 7 and 8 of this dissertation.

Ms. Zabel also briefly utilized a *monitoring tool* as she was circulating between small groups while students were carrying out the investigation. In the video record of her enactment, she can be seen writing on the *monitoring tool* after speaking to a small group of students. Following this interaction, however, she set the tool down and did not pick it up again for the remainder of the lesson.

Ms. Sawyer

Ms. Sawyer's LiFE lesson was focused on supporting students to understand that sound is made when objects vibrate (see Appendix P for the event map of this lesson). During her LiFE lesson enactment, Ms. Sawyer used *talk moves* from the *talk moves tool* in 57.1% of the two-minute segments of her enactment. Like Ms. Lawrence, Ms. Chase, Ms. Kramer, and Ms. Zabel, Ms. Sawyer did not craft a *C-E-R template* for her LiFE lesson. Ms. Sawyer also did not create a *monitoring tool* for her LiFE lesson. Figure 5-14 provides the specific time segments for when talk moves from the *talk moves tool* were used.

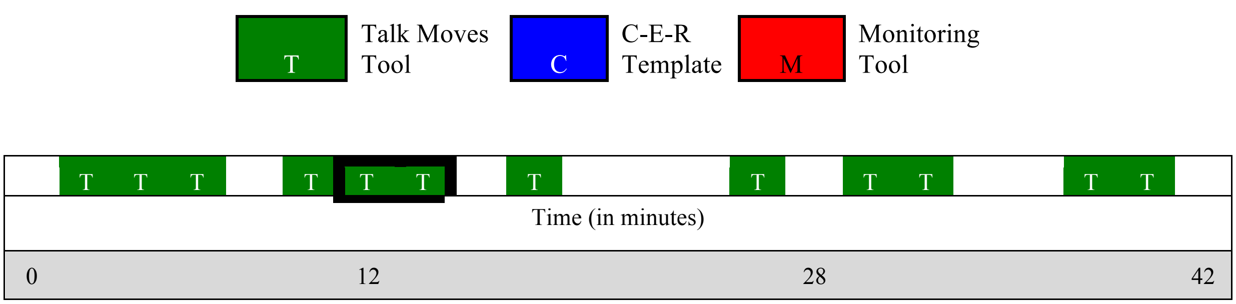

Figure 5-14: Ms. Sawyer's Tool Use During LiFE Enactment

At the beginning of her lesson, Ms. Sawyer asked her students to consider how sounds are made. She then asked students to experiment with materials (e.g., striking a ruler on a table, or humming) and describe what they were noticing when the sounds were made (minutes 10 to 14 outlined in Figure 5-14). She used talk moves from the *talk moves tool* to support students to describe what they were hearing. When one student brought up the idea that something in her throat was moving, Ms. Sawyer drew attention to this idea by asking the student to repeat what she said. Then, Ms. Sawyer used talk moves to encourage students to provide evidence to support how they knew something was vibrating.

Ms. Sawyer: So the first one is just humming. All right, everybody give it a try.

[Students humming]

Ms. Sawyer: Three, two, one, and done. *How would you describe* humming? *How would you* describe it, [Student 1]?

Student 1: It was really loud.

Ms. Sawyer: Loud, great way to describe it. *How else would you describe* it? [Student 2]?

Student 2: I would describe it as kind of noisy.

Ms. Sawyer: [Student 3], *how would you describe* it?

Student 3: Something coming out of your mouth but your mouth is still closed and be like vibrating.

Ms. Sawyer: [Student 3] had a really cool idea. *Will you say that nice and loud so that everybody can hear it*, [Student 3]? *….Say it nice and loud so they can hear.*

Student 3: That it would be like something that's in your mouth but your mouth would be closed and it would be something that's going to be in your throat that's going to make noise.

Ms. Sawyer: Something in your throat vibrating? So I want you to try humming again and touch your throat, see how it feels. Go hmmm.

[Students humming]

Ms. Sawyer: Three, two, one and done. Thank you. How did that feel? How did that feel? [Student 4], how did it feel?

Student 4: Like it was moving.

Ms. Sawyer: Like it was moving. Did it kind of feel like it was vibrating? Thumbs up if you felt like it was vibrating in your throat. …*And how did we know? How did we know?* ...

Student 5: We used our hands.

Ms. Sawyer: So you felt it. How else?

Student 6: We felt it and heard it.

In this excerpt, Ms. Sawyer modeled how students would conduct their investigation with different materials. She used questioning to support students to notice important observations that later helped her students to make the claim that all sounds are made when something is vibrating. When one student began to describe that her vocal chords were moving when humming, Ms. Sawyer encouraged the student to repeat her idea so all students could hear her. Ms. Sawyer then encouraged the students to hum again, guiding them to notice particular features during data collection. Finally, by asking how her students knew, she encouraged them to justify their claims with evidence from their observations. By modeling data collection in a whole group setting, and using talk moves to encourage students to elaborate on and support their ideas, Ms. Sawyer was able to set expectations for the data collection students would complete in their small groups.

Similarities and Differences in Tool Use Across Lesson Enactments

Tables 5-1 and 5-2 provide a summary of the frequency of tool use during focal interns' peer teaching and LiFE lesson enactments.

Table 5-1: Summary of Focal Interns' Tool Use During Peer Teaching Enactment

Focal Intern	Ms. Andrews (Energy Lesson)	Ms. Lawrence (Energy Lesson)	Ms. Chase (Energy Lesson)	Ms. Kramer (Stems Lesson)	Ms. Zabel (Stems Lesson)	Ms. Sawyer (Stems Lesson)
Type of Tool	Frequency of use (given in percentages two minute segments when tool use was present)					
Talk Moves Tool	45.1%	63.0%	54.8%	45.2%	53.6%	67.9%
C-E-R Exemplar	29.0%	0.0%	32.3%	16.1%	0.0%	25%
Monitoring Tool	0.0%	0.0%	0.0%	0.0%	0.0%	21.4%

Table 5-2: Summary of Focal Interns' Tool Use During LiFE Enactment

Focal Intern	Ms. Andrews (Energy Lesson)	Ms. Lawrence (Energy Lesson)	Ms. Chase (Energy Lesson)	Ms. Kramer (Stems Lesson)	Ms. Zabel (Stems Lesson)	Ms. Sawyer (Stems Lesson)
Type of Tool	Frequency of use (given in percentages two minute segments when tool use was present)					
Talk Moves Tool	35.5%	63.3%	56.0%	58.6%	50.0%	57.1%
C-E-R Exemplar	45.2%	0.0%	0.0%	0.0%	0.0%	0.0%
Monitoring Tool	0.0%	0.0%	0.0%	0.0%	4.2%	0.0%

Similarities existed across the types of tools the focal interns used in their enactments for the peer teaching and LiFE lesson enactments. Most notably, for both lessons, all six focal interns used several *talk moves* provided by the *talk moves tool* throughout their lesson enactments. Use of the talk moves allowed the interns to support their students to construct scientific claims based on multiple pieces of evidence. Use of the talk moves also helped students to consider alternative explanations, be more systematic in their data collection, and allowed the students to do the intellectual work of finding patterns in the data they collected. As predicted, the *talk moves tool* served as both a priming tool – for use in planning as described in previous sections – as well as a face-to-face tool with the focal interns using the talk moves to directly question students.

Differences also existed in the types of tools used in the peer teaching and LiFE lesson enactments. For the peer teaching lesson, four of the focal interns (Ms. Andrews, Ms. Kramer, Ms. Chase, and Ms. Sawyer) encouraged students to use the versions of the *C-E-R template* they had created for their peer teaching lesson. In contrast, only one intern (Ms. Andrews) created and used a *C-E-R template* for her LiFE lesson. For both the peer teaching lesson and the LiFE lesson enactments, use of a *C-E-R template* seemed to have supported the students to record their data during the investigation and use that data as evidence when constructing evidence-based claims. Additionally, use of the *C-E-R template* likely allowed interns to formatively assess students' understanding of scientific content at the conclusion of the lesson. Several of the other focal interns (Ms. Chase and Ms. Lawrence) used worksheets provided within the field placement sites curriculum materials. These worksheets likely also helped students to record data, but they were not aligned with the claim-evidence-reasoning framework for explanations stressed in the science methods course.

Finally, only Ms. Sawyer utilized a version of the *monitoring tool* while students were making observations during her peer teaching lesson enactment. By using her *monitoring tool,* Ms. Sawyer was able to keep track of students' ideas while they were making observations, and use of the tool likely supported Ms. Sawyer to formatively assess her students' thinking in the moment. While other focal interns (e.g., Ms. Zabel) expressed that she thought the *monitoring* *tool* would be useful, there was limited or no evidence of the interns using this tool in their enactments.

Intern Reported Use and Justification

Next I highlight findings from the end-of-course survey to describe intern reported usefulness of the tools. By looking at the intern justification for usefulness of the tools, I provide evidence for why interns used certain tools when planning investigation-based science lessons.

Intern Reported Usefulness

Figure 5-15 provides a summary of the average usefulness score for each tool for all interns (0=did not use; 1= not at all useful; 2= neutral; 3 = somewhat useful; 4 = very useful). Table 5-3 provides a summary of frequency of intern reported use of tools. Interns rated the *EEE framework* and the *lesson planning template* as the most useful tools provided during the methods course. On average interns also rated the *alternative ideas tool* and *Claim-Evidence-Reasoning template* as somewhat useful, with 50% of the interns reporting both tools as very useful. The *talk moves tool* received an average intern rating of approximately 2.5 (between neutral and somewhat useful), with only 16 of the interns reporting having used the *talk moves tool* to plan and/or enact their investigation-based lessons. When considering only those interns who reported using the *talk moves tool* (N=16), however, the average usefulness score for the *talk moves tool* was 3.5. Additionally for the interns who reported using the *monitoring tool*, the majority rated the *monitoring tool* as either somewhat useful or very useful. Table 5-3 shows the frequency of interns who self-reported using each tool. For the *skeleton lesson planning template*, *monitoring tool*, and *C-E-R template,* interns reported using the tools at a higher frequency than there was evidence of use in their lesson plans. For example, 100% of interns reported using the *C-E-R template* in either their peer teaching or LiFE lesson enactment;

however fewer than 30% of the lesson plans showed evidence of the tool. This may mean that interns used the tools, but did not include them with the lesson plans they submitted for the methods course. Alternatively, interns may have misunderstood what was meant by the tool (e.g., interns may have thought I was referring to the sentence stems for the C-E-R statement rather than the entire template).

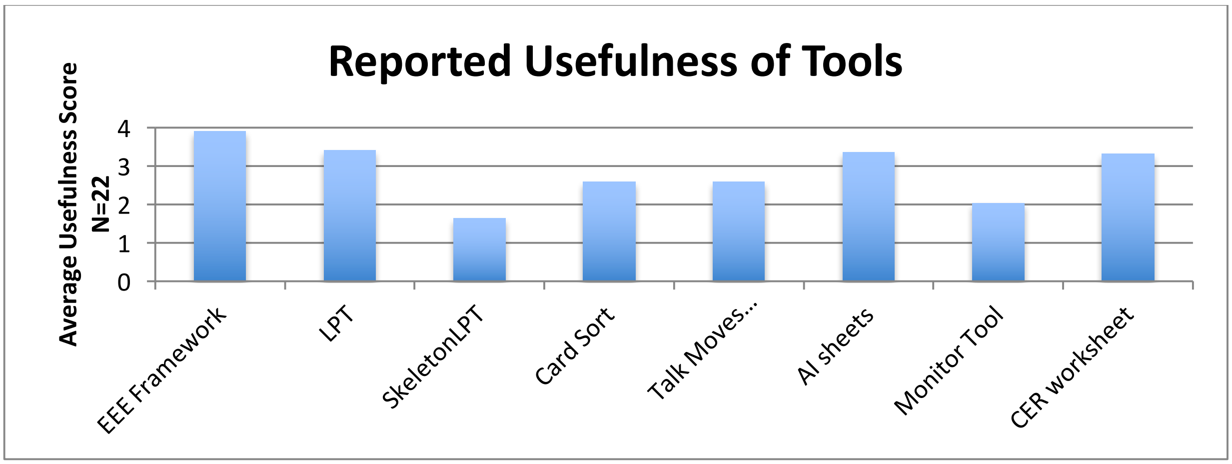

Figure 5-15: Reported Usefulness of Tools (0 = did not use; 1 = not at all useful; 2 = neutral; 3 = somewhat useful; 4 = very useful)

Table 5-3: Frequency of intern reported use of tools

	Tool type							
	EEE Frame-work	Lesson planning template	Skeleton planning template	Card sort	Talk moves tool	Alternative ideas tool	Monitoring tool	CER template
% reporting use	100%	100%	54.5%	100%	72.7%	100%	63.6%	100%

Intern Justification of Use

Table 5-4 provides a summary of the most common justifications provided for interns' tool use and the frequencies of each type of justification. Interns provided different types of justification depending on the type of tool. For the same or similar types of tools, interns justified their use in similar ways.

Table 5-4: Summary of Intern Justification for Tool Use

Tool Type	Most common rationales given	Frequency of response
EEE Framework		
	Keeping goals in mind	77.3%
	Organize the lesson	22.7%
	Manageable	22.7%
Lesson Planning Template		
	Keeping goals in mind	40.8%
	Aligned with the EEE framework	22.7%
Skeleton Planning Template		
	Keeping goals in mind	22.7%
	Practical	18.2%
Card Sort		
	Understanding content for lesson	63.6%
	Understanding the big ideas	36.4%
Talk Moves Tool		
	Planning questions to make students describe thinking	27.2%
	Coherent with other courses	54.5%
Alternative Ideas Tool		
	Anticipating students ideas	63.6%
	Difficult to find for LiFE	31.8%
Monitoring Tool		
	Formatively assessing students	22.7%
	Keeping me accountable	18.20%
CER Exemplar		
	Scaffolding own learning of CER for lesson	36.4%
	Keeping me accountable for discussion	13.6%
	Scaffolding student learning of CER for lesson	22.7%

How interns justified their use of key planning tools. For the *EEE framework*, *lesson planning template*, and *skeleton lesson planning template*, interns most commonly justified use of the tools stating that the tools helped them to keep the goals of science teaching in mind (77.3% of justifications for the *EEE framework*, 40.8% of justifications for the *lesson planning template*, 22.7% of justifications for the *skeleton lesson planning template*). In her end-of-course survey one intern described how and why she used the *EEE framework* explaining,

> The *EEE lesson framework* was SO USEFUL for me in planning my lesson. As I was going through each of the E's, I referred to the sheet that reminded me what I wanted to do with students in each portion as the goal. It was helpful to keep me on track with a successful science investigation and my learning goals for the kids.
> [Intern 9, End of Course survey].

Similarly when describing her use of the *Lesson Planning Template,* another intern stated, “The lesson planning template gives me a structure… it makes it difficult to forget any of the important steps or portions of the lesson” [Intern 1, End of Course Survey].

Ms. Sawyer, one of the focal interns, also expressed that *EEE framework* was useful for her when planning for an investigation-based science lesson stating,

> The *EEE framework* was really helpful for me. The [field placement curriculum materials] are sort of set up like this, but it’s vague. It doesn't say establish an investigation question… it’s more vague. [*The EEE framework*] gave me a way to check off the things that should be in that section. I used the Engage and Explain parts of the sheet a lot.
>
> [Ms. Sawyer, Interview 2].

It seemed that interns appreciated the scaffolding the *EEE framework* and *lesson planning template* provided, prompting them to think about the details of science teaching that would lead them to enacting a successful investigation-based lesson.

Interns also described alignment between the *EEE framework*, the *lesson planning template*, and previous experiences in the teacher education program as being important with one intern stating, “I found this useful because the template was aligned with the template we have been using all year, but with adaptations for science. I appreciated how the template was organized to follow the EEE framework” [Intern 14, End of Course Survey]. For the interns who used the *skeleton lesson planning template*, several described its practicality as a reason for use with an intern commenting, “It’s practical, and I can imagine still using this once I enter my own classroom” [Intern 11, End of Course Survey]. Through these survey responses, it seemed interns valued coherence both between their experiences within the teacher education program and within their experiences in the science methods course. In addition, interns seemed to appreciate tools that were practical and tools they could use during their student teaching experiences and first years in their own classrooms.

How interns justified conceptual tool use. Interns used similar justification when discussing why the *card sort* was a useful tool. The majority of interns (63.6%) described completing the *card sort* for their lessons as a way to familiarize themselves with the content for the lesson. Rating the *card sort* as "very useful" one intern described that the *Card Sort* "challenged [her] to synthesize concepts and generated questions [she] needed to answer to close conceptual gaps [about the science content]" [Intern 10, End of Course Survey]. However, not all interns rated the *card sort* as very or somewhat useful. Although one intern rated the *card sort* as "not at all useful" and commented that the final product (a concept map) didn't help her organize her thoughts, she stated that the discussions with her peers about the science content were very useful in helping her understand how the content of her lesson connected with other scientific phenomena [Intern 12, End of Course Survey].

Several other interns discussed the importance of refreshing or relearning the content so they could feel comfortable teaching science, and described the *card sort* as one method of doing so. Ms. Chase, one of the focal interns, commented on the format of the activity specifically stating, "The actual activity didn't connect it for me, but the discussion did. It led to us looking things up and building on ideas and pulling from their own experiences…and the Ah-ha! moments when you came around and talked with us and drew this picture and getting to experience the content ourselves" [Ms. Chase, Interview 2]. Given the range of ratings of the *Card Sort Tool's* usefulness and the intern comments about why the tool was useful, it seems that in general interns valued the opportunity to review or re-learn the science content before teaching. Providing alternative ways for the interns to show their understanding of the science content (e.g., drawings, charts, summary essay) may have made this tool more useful.

How interns justified use of tools to gain awareness of student ideas. The most common justification (54.5% of justifications) for use of the *talk moves tool* was coherence with other courses in the teacher education program. Despite evidence of use of science-teaching specific talk moves in their plans, and the science methods course being the only course during which they have exposure to the set of science-teaching specific talk moves, several interns commented they did not feel the need to refer to the tool very much because it was already familiar. Other interns expressed having the talk moves tailored specifically to science teaching as helpful, and having seen similar but not subject-specific talk moves before made using the science specific talk moves "feel intuitive" [Intern 16, End of Course Survey].

Additionally several interns (27.5%) described the *talk moves tool* as useful because it helped them to plan questions to allow students to describe their thinking. One intern commented the talk moves helped her to "encourage clarification, [student] engagement, and explanations" and described that the science-specific talk moves directed students to do the work of scientists [Intern 10, End of Course Survey]. Explaining that using the *talk moves tool* to craft questions to ask her students helped her to think about the important aspects of the lesson, Ms. Andrews explained, "The biggest thing would be the questions. [Crafting the questions] helped me to think about what the students might be thinking about while they are doing it and what I want them to notice. It made me look at the content a little closer... to figure out the important things I want to stick with them" [Ms. Andrews, Interview 2].

Interns used similar justification when describing how the *alternative ideas tool* was useful for planning and enacting investigation-based science lessons. Many interns (63.6%) discussed using the *alternative ideas tool* to anticipate students' ideas about scientific phenomena. One intern, who used the *alternative ideas tool* to create her *monitoring tool* stated,

> The [*alternative ideas tool*] helped me think about student knowledge and how I could use these ideas to guide my lesson. It gave me an idea of what I could say to help guide a conversation where these alternative ideas are present so that every kid feels honored, but at the end of the lesson they have an accurate idea of the science.
> [Intern 13, End of Course Survey].

Similarly, another intern commented that the *alternative ideas tool* helped her realize how common the alternative ideas are, and anticipating that the ideas were also likely common in her classroom helped her to be better prepared to teach the lesson. Ms. Kramer also expressed that the *alternative ideas tool* helped her to anticipate and prepare for common alternative ideas students may have saying,

> Without this… there would be a lot more moments where I hadn't prepared or anticipated for some responses because it wasn't on my radar… knowing to plan for those things so that you can answer questions if they come up and what the misconceptions are and how to address them and plan for that so you aren't like, 'oh I don't know'
> [Ms. Kramer, Interview 2].

Several of the interns (31.8%) commented they had difficulty finding alternative ideas for their LiFE lesson topics within the *alternative ideas tool*. Many of the interns providing this justification for the usefulness of the *alternative ideas tool* also were the same interns who rated the tool as neutral. Interns' comments about the difficulty finding alterative ideas for their lesson topic provide support as to why there was less evidence of use of the *alternative ideas tool* within the interns' LiFE lesson plans.

As a reminder, only 50% of interns' peer teaching plans and approximately 30% of interns' LiFE plans showed evidence of use of the *monitoring tool.* Approximately half of the interns stated they did not use the *monitoring tool* in the end of course survey. Several interns who did use the *monitoring tool* stated it helped them to formatively assess their students as the lesson progressed. One intern stated "[the monitoring tool] was very useful because it helped me to assess my students' understanding of the science content during the lesson" [Intern 20, End of

Course Survey]. Despite not using the tool, several interns commented the *monitoring tool* would be useful during future science lessons, with one intern explaining,

> While I did not use the *monitoring tool* myself, I definitely want to design and use one like the model shown to use in the future… the *monitoring tool* will be extremely useful in assessing students and knowing who gets it and who doesn't, and who to call on during the 'explain' element to move the discussion forward.
>
> [Intern 9, End of Course Survey]

Other interns made similar remarks, despite not having used the tool themselves.

Interns who did use the *monitoring tool* also seemed to appreciate that it held them accountable for checking in with all students at some point during the lesson. One intern commented that in the past she had struggled monitoring all students, and the *monitoring tool* allowed her to see which students she had yet to talk with while students were making observations.

Several interns (36.4%) justified their use of the *Claim-Evidence-Reasoning template* because they perceived it scaffolded their own learning. When commenting on his use of the *C-E-R template* to scaffold his own understanding one intern stated, "This was pretty helpful because I had a really hard time coming up with a C-E-R statement for my lesson. This helped me to think about the parts and was a great scaffolding tool for me" [Intern 17, End of Course Survey]. Another intern stated the template helped her become more familiar with the parts of a scientific explanation remarking, "The example was useful because I was unfamiliar with how to construct a scientific claim based on evidence" [Intern 13, End of Course Survey]. It seems several interns perceived the *C-E-R template* as supportive for their own learning of both the scientific content for their lessons as well as some of the science practices.

In addition, interns justified their use of the *C-E-R template* because it scaffolded their students' learning and held them accountable for the explain element of the lesson. One intern stated the template "was a great scaffold for my students… the worksheet is really something that helps keep them organized with their scientific thoughts and keeps the scientific language for the science practices directly in front of them" [Intern 19, End of Course Survey]. Another intern commented on how the template gave her lesson direction and that using the template "forces you to do the reasoning piece… so the lesson is more than just an experiment" [Intern 3, End of Course Survey]. It seems that interns perceived the *C-E-R template* as a tool that could both help support student learning and also as a tool to help focus the investigation-based discussion on sensemaking.

Summary of Justifications for Tool Use

Interns justified their use of tools in similar ways and justifications of tool use included supporting interns to keep the goals of science teaching in mind and supporting interns to attend to learners' ideas and needs. Interns also ascribed importance to tool alignment with the course goals as well as the goals of the teacher education program. Additionally, despite evidence of use of the science-teaching specific talk moves from the *talk moves tool* in interns' lesson plans, many interns stated they did not use the *talk moves tool* when planning or enacting their lessons because the moves were already very familiar. Finally, interns described that using several of the tools supported their own learning. In respect to the *card sort tool*, interns described using the tool to help them understand the scientific content. When commenting on the usefulness of the *claim-evidence-reasoning template,* several interns stated using the tool supported their own learning of the scientific content for their lessons and science practices.

Conclusion

This chapter described the interns' use of tools designed to support the development of knowledge and practice of science teaching specific to facilitating investigation-based discussions. This chapter provided evidence of interns' use of the tools provided by the science methods course to plan their investigation-based science lessons, focal interns' use of those same tools to enact investigation-based science lessons and insight into the ways interns justified their use of those tools. In the next chapter, I describe the characteristics of interns' plans for investigation-based discussions, including the ways in which interns planned to engage in productive teaching practices that capitalize on student contributions.

CHAPTER 6

USE OF PRODUCTIVE PRACTICES TO CAPITALIZE ON STUDENT CONTRIBUTIONS IN LESSON PLANS

Chapter 5 considered the tools interns used to plan and enact investigation-based science lessons, addressing Research Question 1. In this chapter, I discuss characteristics of interns' plans for investigation-based discussions, addressing Research Question 2. Based on a part of my analysis of interns' lesson plans for both their peer teaching and LiFE lessons, I make the following assertions:

a) Interns used a range of teaching practices that are productive for capitalizing on student contributions.
b) Interns used productive teaching practices for capitalizing on student contributions more frequently and with more sophistication in their peer teaching lesson plans versus their LiFE lesson plans.

In this section, I address these assertions first by describing interns' use of productive practices for capitalizing on student contributions evident in the peer teaching lesson plans and LiFE lesson plans and comment on the similarities and differences across the plans. I also describe how differences in sophistication of planned teaching practice may have contributed to strengths and missed opportunities in lesson enactments. The enactments themselves are discussed in Chapter 7. Then, for each teaching practice I provide detailed evidence from focal interns' lesson plans describing the planned use of productive practices for capitalizing on student contributions.

Evidence of Planned Use of Productive Teaching Practices

Figure 6-1 provides a summary of the average score given for each of the planned teaching practices within interns' peer teaching lesson plans and LiFE lesson plans. As a reminder, the plans were evaluated using a coding scheme that considers the teaching practices research has shown to be particularly important for planning productive investigation-based discussions that capitalize on student contributions (Boerst, Sleep, Ball & Bass, 2011; Cartier et al., 2013; Ross, 2014; Windschitl et al., 2012) including:

(1) considering students' initial ideas (*initial*)

(2) considering the content storyline or big ideas (*content*)

(3) considering the investigation trajectory (*invest*)

(4) preparing for students' scientifically accurate ideas (*accurate*)

(5) anticipating students' alternative or incomplete ideas (*alternative*)

(6) preparing to monitor student work during the investigation (*monitor*)

(7) planning questions to elicit, challenge, or extend students' thinking (*questioning*)

(8) logical flow of engagement in science practices (*logical*)

(9) selection of specific ideas to draw attention to during the discussion (*select*)

(10) planning to use a representation to highlight students' ideas (*representation*).

A score of 0 was given to plans that contained no evidence of the teaching practice. A score of 1 was given to plans that showed some planned engagement in the teaching practice (e.g., intern planned to circulate and observe students as they carried out the investigation). A score of 2 was given to plans that showed high evidence and increased sophistication of planned engagement in the teaching practice (e.g., intern planned to circulate and observe students as they carried out the investigation, and a monitoring tool with anticipated student ideas was included in the plan). Table 4-12 in Chapter 4 provides the evaluative criteria for each teaching practice.

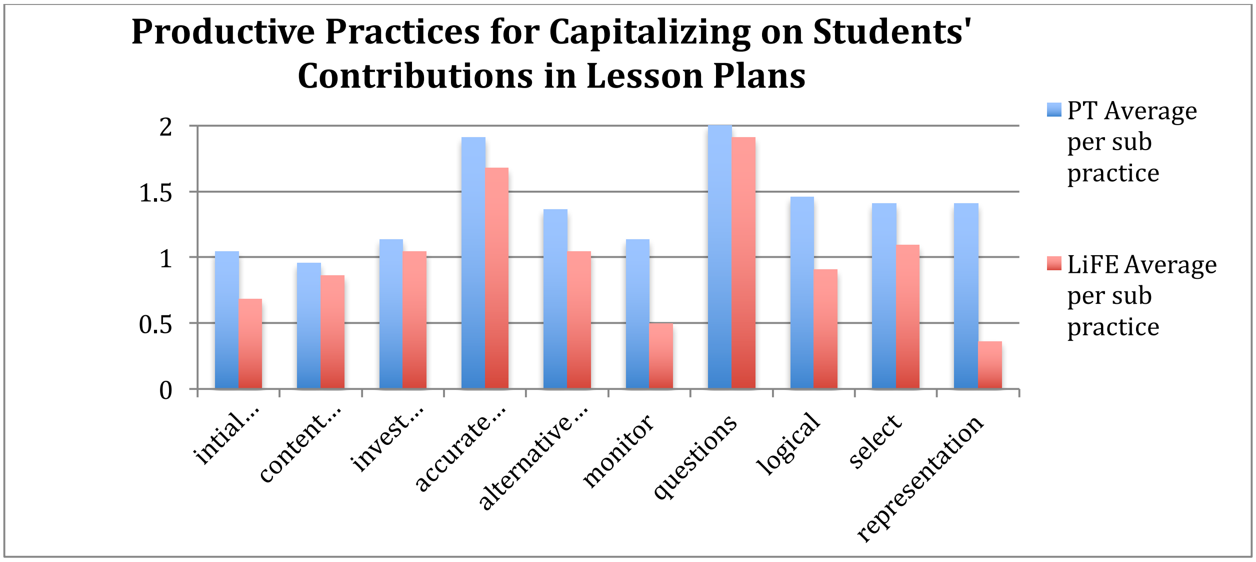

Figure 6-1: Productive Teaching Practices in Lesson plans

Summary of Evidence in the Plans

On average, interns' peer teaching plans showed at least some evidence of planned engagement in each of teaching practices (M=13.82, SD =3.13). All interns' peer teaching lesson plans showed at least some evidence of considering the investigation trajectory, preparing for students' scientifically accurate ideas, anticipating students' alternative or incomplete ideas, planning questions to elicit, challenge or extend students' thinking, using a logical follow of engagement in science practices, and selection of specific ideas to draw attention to during the discussion. In contrast, several interns' plans did not consider students' initial ideas or the content storyline of the lesson. Additionally, not all interns included plans for monitoring student work during the investigation or plans for using a representation to highlight students' ideas.

Similar to the peer teaching plans, the LiFE Lesson plans, on average, showed at least some evidence of planned engagement in each of teaching practices (M=10.09, SD =2.54). However, fewer interns used the teaching practices. Of the interns who used the teaching practices, they frequently used them with less sophistication in the LiFE lesson plans than in the peer teaching lesson plans. All interns' LiFE lesson plans showed at least some evidence of preparing for students' scientifically accurate ideas and planning questions to elicit, challenge or extend students' thinking. All but one intern selected specific ideas to draw attention to during the investigation-based discussion. In contrast to the peer teaching plans, several of the interns did not consider the investigation trajectory, did not anticipate students' alternative or incomplete ideas, and did not plan to follow a logical trajectory of engagement in science practices. Similar to the peer teaching lesson plans, several interns did not plan to consider students' initial ideas throughout the plan or consider the content storyline of the lesson. Additionally, few interns included plans for monitoring student work during the investigation or plans for using a representation to highlight students' ideas.

Interns' planned engagement in each teaching practice in both the peer teaching lesson plans and LiFE lesson plans is considered in the following sections. Table 6-1 summarizes of the percentage of interns that provided no, some, or high evidence of each teaching practice for both the peer teaching and LiFE lesson plans.

Table 6-1: Summary of evidence in the lesson plans

	Percentage of interns with *no* evidence of practice Score = 0		Percentage of interns with *some* evidence of practice Score =1		Percentage of interns with *high* evidence of practice Score =2	
	Peer	LiFE	Peer	LiFE	Peer	LiFE
Initial Ideas	13.6	45.5	68.2	40.9	18.2	13.6
Content Storyline	4.5	18.2	95.5	77.3	0.0	4.5
Investigation Trajectory	0.0	13.6	86.3	68.2	13.7	18.2
Accurate Ideas	0.0	0.0	9.1	31.8	90.9	68.2
Alternative Ideas	0.0	0.0	63.6	95.5	36.4	4.5
Monitoring	27.3	59.1	31.8	18.2	40.9	22.7
Questioning	0.0	0.0	0.0	4.5	100.0	95.5
Logical flow of science practices	0.0	9.1	54.5	90.9	45.5	0.0
Sequencing	0.0	4.5	59.1	81.8	40.9	13.6
Representation	0.0	68.2	13.4	27.3	63.6	4.5

In the following sections, I present findings related to each of the productive practices.

Considering Students' Initial Ideas

In the peer teaching lesson plans, 15 interns planned to elicit students' initial ideas about the scientific phenomena of focus in the Engage element and planned to revisit those ideas either in the Experience element or the Explain element. For example, several interns planned to have students make predictions about the investigation at the end of the Engage element and then reminded students of those predictions at the beginning of the Experience element of the peer teaching lesson. Four interns planned to elicit students' initial ideas about the phenomena in the

Engage element, planned to question students about their initial ideas while monitoring their work during the Experience element, and planned to revisit students' initial ideas and predictions in the Explain element. The remaining interns' peer teaching plans either showed no evidence of planning to elicit students' initial ideas about the phenomena in their plans or showed the intern planned only to elicit students' ideas in the Engage element but did not consider students' initial ideas in any of the other elements of the lesson.

In the LiFE plans, nine interns planned to elicit students' initial ideas about the scientific phenomena of focus in the Engage element and planned to revisit those ideas either in the Experience element or the Explain element. Three interns planned to elicit students' initial ideas and return to those ideas in both the experience and explain elements. Ten interns either failed to plan to elicit students' initial ideas about the scientific phenomena in their LiFE plans, or only did so at the beginning of the Engage element.

Consideration of students' initial ideas at multiple points in the lesson plan may be an indication that interns were planning to prioritize student ideas and contributions during the lesson. Repeatedly considering and reminding students of their initial ideas also likely allowed for additional time during the lesson for student discussion and sharing of ideas. Finally, considering students' ideas at multiple points in the plan may have prompted interns to contemplate how data gathered during the investigation may or may not contradict students' initial ideas.

Considering the Content Storyline

The majority of interns (21 of 22) provided some evidence of consideration of the content storyline of the peer teaching lessons. Interns seemed to be less able to provide detailed descriptions of the lesson's connections to larger scientific concepts. For example, one intern teaching the Energy lesson described the unit as being "about energy. Students are learning about the different types of energy and about energy transfer and transformation" [Intern 2, Peer Teaching Plan]. Similarly, several interns described how the lesson fit into the larger curricular unit using text directly from the curriculum materials rather than explaining how the phenomenon connected to other scientific concepts.

I observed similar patterns when looking at interns' consideration of the content storyline in their LiFE Lesson plans. Like the peer teaching plans, the interns' description of the lesson connections to larger scientific concepts were often vague (17 of 22 interns), with several interns using text directly from curriculum materials being used in their field placements. One intern, however, described connections between her first grade lesson on the formation of frost on the outside of an aluminum can and the larger scientific concept of the water cycle stating, "Although students have been recording weather conditions, students have not discussed how any of the weather phenomena occur. Despite this, this lesson will explore a piece of the water cycle. Students will ultimately be able to connect this experience to the processes of evaporation and condensation. Water that evaporates into the air can condense (under certain conditions, i.e., low temperature) to form frost and/or dew" [Intern 12, LiFE Lesson Plan]. The remaining four interns provided no evidence in their plans detailing how their LiFE lesson connected to larger scientific concepts.

Consideration of the content storyline of the lesson likely allowed interns to anticipate connections students may be able to make to previous lessons or experiences. Additionally, interns that considered the content story line may have been better able to recognize accurate student contributions during the investigation-based discussion that would help students begin to construct mechanistic explanations of the scientific phenomenon.

Considering the Investigation Trajectory

All of the interns provided at least some evidence of considering the investigation trajectory in their peer teaching lesson plans. The majority of interns (19 of 22) described the important pieces of data students needed to collect and notice while carrying out the investigation. These interns also described how these data could be used as evidence to support the scientifically accurate claim for the investigation. For example, several of the interns teaching the Stems Lesson described that students needed to notice and describe that the tubes within the celery stem turned red when the celery was placed in red water and that the tubes turning red was an indication that the water had moved up the stem. These same interns, however, did not connect the evidence to the disciplinary core idea that the stem had a specific function allowing the plant to remain alive. The remaining interns (3 of 22) not only described the important pieces of data the interns needed to notice and described how these data could be used as evidence to support the scientifically accurate claim for the investigation, but they also made an explicit connection to the disciplinary core idea for the lesson and/or larger scientific concepts that students may have provided as reasoning for their claim.

Similarly, in their LiFE lesson plans, the majority of interns (15 of 22) provided some evidence of considering the investigation trajectory, but did not explicitly plan to connect the investigation to the larger scientific concept or disciplinary core idea. For example, one intern who was planning to have his 5th grade students investigate the relationship between the number of times a rubber band is twisted and the distance a rubber band mousetrap car would travel, stated he expected his students to notice with more twists of the rubber band the greater the distance the car traveled. The same intern, however, did not specify how he would help to support his students to begin to understand his target disciplinary core idea: the conversion of potential energy to kinetic energy [Intern 2, LiFE Lesson Plan]. Four of the 22 interns described the important pieces of evidence they expected students to use and explicitly planned to connect the investigation to a disciplinary core idea. For example, Ms. Chase (a focal intern) planned to connect her students' observations of the water on the outside of a sealed aluminum can filled with red water with the mechanism of condensation and the water cycle to describe how clear water droplets form on the outside of the can. The remaining interns (3 of 22) failed to identify key pieces of data students could use as evidence for their claims.

Inability to identify the key pieces of data students could use as evidence and connections between the lesson and the larger scientific concepts may limit a teacher's ability to recognize important contributions made by students during investigation-based discussions. Prior research by Windschitl and colleagues (2012) has described the consideration of larger scientific concepts as a necessary precursor for a teacher to engage in other productive teaching practices that capitalize on students' ideas. Although some of the teachers did not plan to press their students for the mechanistic explanation of the phenomenon because it may have been beyond their target performance expectation (e.g., expecting 5th grade students to understand the particulate nature of matter to explain heat energy transfer), it was likely important for the teacher to be able to recognize how the investigation connected to the larger scientific concepts. By considering both the content storyline for the lesson and also how the investigation could help students progress toward an understanding of bigger picture ideas, interns may have been better able to capitalize on student contributions that either supported students to progress toward a more accurate understanding or provided an important contradictory idea that fostered argumentation among students.

Preparing for Accurate Ideas

For their peer teaching lesson plans, the majority of the interns (20 of 22) were able to prepare for students' scientifically accurate ideas including a claim-evidence-reasoning statement that was appropriate for the grade level of students and the investigation the students would be carrying out. The statements included three pieces of evidence students could have gathered by carrying out the investigation and reasoning appropriate for students' grade level. The remaining two interns' plans contained claims that were supported by a single piece of evidence.

In the LiFE lesson plans, the majority of interns (15 of 22) included anticipated student claim-evidence-reasoning statements with three pieces of evidence students would be able to observe when carrying out the investigation. The remaining interns (7 of 22) included claim-evidence-reasoning statements that were vague, included only one piece of evidence, or were scientifically inaccurate. For example, one intern who was supporting her students to carry out an investigation to determine the characteristics of a rock anticipated that her students would make the following claim, "I think that to decide if an object is a rock it must be observed closely and compared to other objects" [Intern 5, LiFE Lesson Plan]. This anticipated claim was vague and did not answer the intern's investigation question, "What are the characteristics of a rock?" Additionally, the same three interns that struggled to consider the investigation trajectory were not able to anticipate scientifically accurate ideas students should understand after completing the investigation.

Anticipation of students' scientifically accurate ideas provides interns with a clear trajectory for the lesson. By anticipating these ideas in their plans, interns were likely able to recognize when students contributed aspects of the scientifically accurate ideas during the investigation-based discussion. An inability to anticipate students' scientifically accurate ideas in the lesson plan may have led to an enactment that lacked scientific purpose, and missed opportunities to capitalize on scientifically accurate student contributions during the investigation-based discussion. Therefore, the investigation-based discussion may have been centered only on sharing observations rather than constructing evidence-based claims.

Anticipating Alternative Ideas

Within their peer teaching lesson plans, all of the interns were able to identify a least one research-based incomplete or alternative idea students may have had about the scientific phenomena. This is likely because interns were provided with a list of common alternative ideas students were likely to hold about plant biology and energy. Additionally, 8 of 22 interns listed multiple alternative ideas students may have about the scientific content and listed several ways students might struggle with engaging in science practices. For example, several interns commented that students might have difficulty drawing clear, concise, and accurate scientific drawings of the celery stems and planned to monitor students' drawings for these features. Another intern made a note in her plan "that students often match their observations to their predictions" and planned to press students to record the temperatures of the water exactly as they were being measured [Intern 17, Peer Teaching Lesson Plan].

Fewer interns were able to identify at least one research-based alternative idea students may have about the science content of focus for their LiFE lesson plan. However, the interns who were unable to find a research-based alternative idea still provided a potential alternative idea students may have about the science content. Only one intern listed multiple alternative ideas her students may have about the science content and several ways students may struggle to engage in scientific practices [Intern 3, LiFE Plan].

By including alternative ideas about the science content in their plans, interns likely anticipated how students might be thinking about scientific phenomenon that was the focus of the investigation. Additionally, by planning that students will likely have alternative ideas, interns were likely better prepared to use students' scientifically inaccurate claims in productive ways during the investigation-based discussion. For example, rather than dismissing them as inaccurate, interns may have been able to follow the contribution with evidence contributed by another student that contradicted the claim. Additionally, interns may have been able to use the alternative ideas as alternative claims to formatively assess student understanding.

Monitoring Student Work

Across both the peer teaching lesson plans and the LiFE lesson plans, interns' plans to monitor student work during the investigation varied greatly. Within the peer teaching plans, seven of 22 interns described that they planned to "circulate and observe" students while they carried out the investigation. Two of these seven interns who planned to circulate and observe their students made reference to using a monitoring tool, however the tool was blank and did not include any alternative ideas. Five of the seven interns who planned to circulate and observe their students as they collected data did not include a monitoring tool and did not include a plan as to how to make sure they would check in with each student as they were carrying out the investigation. Nine of the 22 interns included a monitoring tool with anticipated alternative ideas in their plans for the peer teaching lesson. The remaining six interns did not include any plans for monitoring students in their peer teaching lesson plans.

In the LiFE plans, fewer interns included plans for monitoring students as they collected data during the investigation. Five of 22 interns included a monitoring tool in their plans for their LiFE lesson, however only two of those monitoring tools included anticipated alternative ideas. The monitoring tools that did not list alternative ideas consisted of a roster of their students' names and spaces to keep track of students' ideas during the investigation. Four interns planned to "circulate and observe" students as they carried out the investigation, and thirteen interns listed no plans for monitoring students as they carried out the investigation.

By writing explicit plans to monitor students as they were carrying out the investigation, interns may have been better able to keep track of how students' thinking may have been shifting over the course of the investigation and use of a monitoring tool maybe have further supported this practice. By writing students' ideas down while circulating, interns may then have been able to use those ideas to guide the investigation-based discussion. Limited plans to monitor may have resulted in the intern allocating more time to a single group of students during the enactment and limited awareness of how students were thinking about the scientific content.

Questioning to Elicit, Challenge, or Extend

Planned use of questions to elicit, challenge or extend student thinking was the most consistently utilized teaching practice across both the peer teaching and LiFE lesson plans. In the peer teaching plans, all of the interns planned questions to elicit, challenge, or extend student thinking. Moreover, all of the interns planned to use questions that were science-teaching specific. This was likely due to 100% of the interns utilizing the science-teaching specific talk moves tool.

I observed similar types of questions in the interns' LiFE lesson plans. In the LiFE plans, 21 of 22 interns listed at least one science teaching specific question or talk move to elicit, challenge, or extend students' thinking. The remaining intern planned to use general talk moves (e.g., tell me more about that) to elicit student thinking [Intern 5, LiFE Plan].

Similar to the practice of considering students' initial ideas at multiple points in the lesson plan, planning for questions to elicit, challenge, or extend student thinking may be an indication that interns were planning to prioritize student ideas and contributions during the investigation. By planning to repeatedly check in with students to gauge their thinking, it is likely interns planned to allow additional time during the lesson for students to share their ideas and discuss those ideas with their peers. Emphasis on the use of questions to invite additional student voices into the discussion rather than evaluative teacher-student dialogue may have had the potential to shift the discussion from a largely initiate-response-evaluate pattern to one featuring a dialogic teacher voice and increased student participation.

Logical Flow of Engagement in Science Practices

In the peer teaching plans, ten of 22 interns had explicit plans to engage students in analysis of their data, argumentation, and explanation construction in the Explain element of their plans. For example in her Energy lesson, Ms. Andrews, a focal intern, planned to have her students look for patterns in graphical data. She planned to ask students questions about specific features of the graphs, supporting students to notice key similarities and differences and recording contributions on the board. Then, she planned to engage students in argumentation by asking questions fostering justification of ideas and student listening. She listed several strategies for productive student engagement in argumentation (Simon, et al., 2006) and explanation construction in her plan including positioning, construction, and evaluation of claims. The remaining interns (12 of 22) explicitly planned to engage student in analysis of their data and also planned to support students to construct evidence-based claims, however, they did not plan to engage students in argumentation.

Planned student engagement in only data analysis and explanation construction was more prevalent in interns' LiFE lesson plans. The majority of interns (20 of 22) planned to support their students to analyze their data and construct evidence-based claims, and no interns explicitly planned to engage their students in argumentation. One intern planned to provide students with an explanation before she supported students to analyze their data [Intern 18, LiFE Plan], and the remaining intern did not describe plans for supporting students to analyze data [Intern 5, LiFE Plan].

It is likely that limited planning for students to engage in argumentation likely resulted in limited engagement in argumentation in the lesson enactments, and missed opportunities for student participation in the investigation-based discussion. By engaging students in analysis of their data followed by argumentation and explanation construction, students were likely provided opportunities to contribute to the investigation-based discussion. By finding patterns, sharing their ideas, listening to one another, and working together to construct claims, students may have more actively engaged in the intellectual work of scientists. The teacher may also have been less likely to need to shift into authoritative voice providing the claim for the students.

Sequencing and Selection of Specific Ideas

In the peer teaching plans, nine of 22 interns described plans for sequencing, selecting, and drawing attention to key ideas that needed to arise during data analysis during the investigation-based discussion. For example, several interns' plans for the Energy lesson described the need to support students to see that all groups' temperature data started at similar temperatures and ended at similar temperatures after ten minutes and listed a plan to circle these points on the graphs to emphasize this data. Similarly, several interns planning for the Stems lesson described needing students to analyze one observational drawing at a time before looking across all drawings for patterns. For example, one intern planned to have students look at the celery in the clear water first, listing observations made on day one and then on day three, followed by the celery placed in red water, and finally the cross sections, circling things that had changed between day one and day three for each drawing [Intern 17, Peer Teaching Plan].

Thirteen of the 22 interns were able to list important ideas they needed to elicit during the investigation-based discussion for the peer teaching lesson. However, these interns did not seem to have a purposeful sequence for the ideas, nor did they include plans for marking the ideas for emphasis.

Fewer interns (3 of 22) described plans for sequencing, selecting, and drawing attention to key ideas that needed to arise during the investigation-based discussion in their LiFE lessons. The majority of interns (18 of 22) listed key ideas that needed to arise when students analyzed their data, but did not plan to sequence the ideas in a specific way and did not plan to emphasize any of the ideas by marking. The remaining intern, who was same intern that did not include plans to have students analyze their data, also did not list key ideas that needed to arise during data analysis [Intern 5, LiFE Plan].

By planning to support students to notice key ideas by sequencing ideas in a specific order during data analysis, interns may have better supported students to notice key patterns in their data. Then, by marking the key pieces of data as students contributed ideas, students' attention may have been focused on key pieces of data that could be used as evidence to support their claims.

Use of a Representation

Intern planned use of representations to highlight students' ideas differed in the peer teaching lesson plan and the LiFE lesson plan. The majority of interns (17 of 22) planned to use a representation to organize data students described during the investigation-based discussion. All eleven of the interns teaching the Energy lesson planned to use representations that likely supported students to notice important patterns in the data (i.e., line graphs showing change in temperatures).

Three of the interns teaching the Stems lesson also planned to use representations that likely would help students to notice important patterns in the observational data. These interns included a chart that provided space for students to record and compare their observations of the two types of celery and the cross sections before and after the three-day period as well as space for students to describe what they thought had changed over the three days. Within their plans, the interns included both a blank copy of the data chart as well as a completed copy with the ideas they planned to elicit from their students.

Three other interns teaching the Stems lesson planned to use a T-chart to record student observations of the celery stems on day one and day three of the investigation. Although this chart helped interns record student observations, the chart likely did not function to make patterns in the data more obvious to students. The remaining five interns teaching the Stems lesson did not list plans to use a representation during the investigation-based discussion to help organize and record students' contributions.

Fewer interns provided plans for using a representation for their LiFE lessons. The majority of interns (15 of 22) did not include any plans for using a representation to support students to organize their ideas and find patterns in the data. Six interns provided a representation, but like several interns' peer teaching plans, the representation did not function to make patterns in the data more obvious for students. One intern provided a representation in his plan that would likely support students to see patterns in their observations of cactus stems, providing space for students to record their observations of one type of stem at a time before and after the stems had been placed in water [Intern 6, LiFE Plan]. His representation for his LiFE lesson to support students to record their observations and then recognize patterns in their observations was very similar to the representation he created for his peer teaching plan. The similarities in type of data for both his peer teaching plan and LiFE plan may have allowed him to easily adapt his representation from his peer teaching lesson for his LiFE lesson.

Use of a representation likely supported students to notice patterns in the data that otherwise may been difficult for them to observe. By using a representation, interns may have been better able to scaffold students' analysis of their data, drawing attention to important pieces of data that could then be used as evidence to support a claim. Without the use of a representation students may have struggled to observe patterns within the class data set, and the interns may have needed to explain the trends for their students, limiting students' opportunities to engage in data analysis and contribute to the investigation-based discussion.

Taking a Closer Look: Strengths and Weaknesses of Focal Interns' Plans

The next section provides evidence from the focal interns' lesson plans for both the peer teaching and LiFE lesson plans. For each focal intern I describe both the strengths and missed opportunities in each of the plans. The focal interns provide typical examples of how all interns planned to engage in the productive teaching practices, and like all interns enrolled in the science methods course, the peer teaching lesson plans showed greater sophistication as compared to the LiFE plans. Table 6-2 provides a summary of the focal interns' planned engagement in each of the productive practices for capitalizing on student contributions. Within Table 6-2, shading indicates greater sophistication in planned engagement in each teaching practice.

Table 6-2: Focal Interns' Planned Engagement in Productive Teaching Practices

	Andrews		Lawrence		Chase		Kramer		Zabel		Sawyer	
Lesson Type	PT	LiFE	PT	LiFE	PT	LiFE	PT	LiFE	PT	LiFE	PT	LiFE
Initial ideas	1	2	2	1	1	1	1	0	1	0	1	0
Content storyline	1	1	1	1	1	1	1	1	1	0	1	1
Investigation trajectory	2	2	1	1	2	2	1	1	1	1	1	1
Preparing accurate ideas	2	2	2	1	2	2	1	1	2	2	2	2
Alterative ideas	1	1	2	1	1	1	1	1	1	1	2	1
Monitoring	1	0	2	1	2	0	1	0	1	1	2	1
Questioning	2	2	2	2	2	2	2	2	2	2	2	2
Logical flow	2	1	2	1	1	1	1	0	1	1	1	1
Sequencing and selection	1	1	2	1	1	2	1	0	1	1	1	1
Use of a representation	2	1	2	0	2	0	0	0	0	0	2	1
Total	15	13	16	10	15	12	10	6	11	9	15	11

2 = High evidence; 1 = Some evidence; 0 = No evidence

Ms. Andrews

In both of Ms. Andrews's plans she showed high evidence of considering the investigation trajectory, preparing for students' accurate ideas about the science content, and planned questioning to elicit, extend, and challenge student thinking. Ms. Andrews's peer teaching plan showed high evidence of a use of a representation and logical flow through the scientific practices (data analysis, argumentation, and explanation construction). Both plans showed at least some evidence of engagement in consideration of students' initial ideas, considering the content storyline, anticipating alternative ideas, and selecting and sequencing student ideas.

Plan strengths. Using her knowledge of the accurate explanations of the scientific phenomenon, and considering the investigation trajectory in her peer teaching lesson, Ms. Andrews was able to connect multiple pieces of evidence to the disciplinary core idea that energy is transferred from place to place. Additionally, Ms. Andrews described supporting students to notice that all four groups' data showed the two bodies of water reaching a similar temperature after ten minutes as being connected to the concepts of thermal equilibrium and conservation of energy [Andrews, Peer Teaching Lesson Plan]. Ms. Andrews made similar connections between the disciplinary core ideas and the investigation in her LiFE lesson plan.

In both plans, to help support students to express their ideas, she planned to use questions to extend student thinking. For example, in her plan for her Explain element of her peer teaching lesson plan to support students to construct evidence-based claims, Ms. Andrews planned to ask students, "What does the evidence tell us about heat energy?" and "Using our evidence, how can we answer our investigation question?" [Andrews, Peer Teaching Lesson Plan, p.14].

Additionally, for her peer teaching plan, she explicitly planned to engage her students in argumentation, showing high evidence of logical flow through the science practices of analysis, argumentation, and explanation construction. As mentioned previously, Ms. Andrews drew upon the *argumentation checklist tool* to plan to foster argumentation between students. Figure 6-2 shows how Ms. Andrews used the questions listed in the *argumentation checklist* within her plan.

Also within her peer teaching plan, Ms. Andrews planned to use representations (graphical displays of temperature data) making the observable patterns more obvious for students, supporting students to notice patterns and trends in their data. Ms. Andrews's use of a representation, consideration of the investigation trajectory, and planned use of open-ended questions likely fostered student engagement in the investigation-based discussion.

Based on the evidence, how might we answer the investigation question?
[I think when a bag of hot water is placed in a container of cold water the temperatures of the two water volumes will be the same after 10 minutes.]

Talk/Listen	• Based on the evidence, how might we answer this question? • Can you repeat ---'s claim? • Can you say ---'s claim in our own words?
Positioning	• What's another claim that you could make? • Does anyone have a different claim?
Justify	• How can you prove your/---'s claim with the evidence? • How do you know that your claim is true? How does the evidence prove that? • What if I look at my prediction, then said my claim is "I think that the hot water will get colder and the cold water will stay cold"? [Not true, not based on evidence.]
Construct	[Write on board]
Evaluate	• Is ---'s claim a good argument? [A good argument has to be backed up with evidence] • How do you know that ---'s claim is a strong argument? • If I said, "I think that the cold water will get hot." Is that a good claim? Why not? [Incomplete]

Let's go back over our claim and our evidence. We decided that we all liked the claim that "**I think when a bag of hot water is placed in a container of cold water the temperatures of the two water volumes will be the same after 10 minutes.**"

Figure 6-2: Ms. Andrews's use of argumentation checklist in peer teaching plan

Missed opportunities. In contrast, in her LiFE lesson, focused on the spread of disease within a community, the representation included in her plan (see Figure 6-3) supported her students to collect their data but did not function to make the patterns of how disease was transferred throughout the class more obvious. Additionally, in her LiFE plan, Ms. Andrews did not describe any plans to monitor student thinking as the students were carrying out the investigation, nor did she explicitly plan to foster argumentation as she did in her peer teaching lesson plan. By not including plans for monitoring in her lesson plan, using a representation that did not support students to analyze data, and not planning to support students to engage in argumentation likely led to missed opportunities for student engagement in the investigation-based discussion.

Data: Fluid Exchange

Team	1st Round	2nd Round	3rd Round	4th Round
RED				
BLUE				
YELLOW				
GREEN				
PURPLE				

Figure 6-3: Ms. Andrews's LiFE lesson plan representation for data collection

Ms. Lawrence

Like Ms. Andrews, Ms. Lawrence's peer teaching plan showed greater sophistication of planned engagement in the productive practices for capitalizing on student contributions in comparison to her LiFE lesson plan. In fact, Ms. Lawrence's peer teaching plan was the most sophisticated of all the focal interns. In her peer teaching plan, Ms. Lawrence provided high evidence of planned engagement in considering students' initial ideas, preparing for students' accurate ideas, considering students' alternative ideas about the science content and struggles with science practices, planned monitoring, planned use of open-ended questions and logical flow of student engagement in data analysis, argumentation, and explanation construction. In addition, her peer teaching plan showed high evidence of selecting and sequencing students' ideas, and use of a representation. Her LiFE lesson plans showed evidence of all the teaching practices with the exception of use of a representation. Overall however, the evidence of engagement in the teaching practices in her LiFE Plan was less sophisticated than in her peer teaching plan.

Plan strengths. Like Ms. Andrews, in both her plans, Ms. Lawrence planned to use questions to extend student thinking and multiple pieces of evidence to support the claim for the investigation. Additionally, she planned to use a similar graphical representation of student data for her peer teaching lesson.   In contrast to Ms. Andrews, Ms. Lawrence planned to return to students' initial ideas in each element of her investigation-based science lesson, planning to remind students of their initial ideas as they collected data, and returning to those initial ideas at the end of the lesson, prompting students to consider if their ideas had changed.

Ms. Lawrence's plan also showed evidence of planned use of a *monitoring tool* to keep track of students' ideas during the investigation. Her *monitoring tool* (see Figure 6-4) provided scientifically accurate ideas, common alternative ideas, and likely investigation struggles students may have. Anticipation of these ideas likely supported Ms. Lawrence to formatively assess her students in the moment, and may have allowed her to begin to select specific ideas she wanted students to contribute to the investigation-based discussion

Student Group	**Scientifically Accurate Ideas**	**Common Alternative Ideas**	**Investigation Struggles**	**Other**
A	__Heat energy is transferred from the warm water to the cool water. __Temperatures will eventually reach the average over time. __Temperature is the measure of heat *energy.*	__Coldness is transferable __Temperature measures heat __No energy is transferred because they are not in physical contact __Temperature will continue to rise/fall beyond the average	__Did not record temperatures __Was not systematic in recording temperatures (e.g., not every minute, thermometer in different location each time)	

Figure 6-4: Ms. Lawrence's peer teaching lesson monitoring tool

Missed opportunities. Despite the high evidence of planned engagement in the teaching practices in Ms. Lawrence's peer teaching plan, evidence of engagement in the practices was less sophisticated in her LiFE plan. In her LiFE plan, Ms. Lawrence had limited plans for monitoring students while they were carrying out the investigation and limited connections between the investigation and the disciplinary core ideas of focus. Additionally, the claim-evidence-reasoning statement she provided was vague. Her struggles during planning to make connections between the investigation and the disciplinary core idea of what happens to light when it reaches certain objects likely made it difficult to recognize important accurate student contributions during her enactment.

Ms. Chase

Like Ms. Andrews, Ms. Chase also provided strong connections between the investigation and the disciplinary core ideas, and like all other focal interns, she planned to use open-ended questions to elicit challenge and extend student thinking. In her peer teaching lessons, she described sophisticated plans for monitoring student work and planned to use a representation that supported students to see patterns in their temperature data. For all other teaching practices (with the exception of plans for monitoring and use of a representation in her LiFE plan) Ms. Chase provided some evidence of engagement in each practice.

Plan strengths. In addition to her use of open-ended questions and use of a representation in her peer teaching plan, throughout both her peer teaching plan and LiFE plan Ms. Chase made connections between the data students would be collecting and the disciplinary core idea of the lessons. She also connected the data students would be collecting to common alternative ideas, describing how each piece of data contradicted the alternative idea. For example, for her LiFE lesson, she listed that students may think the water condensing on the outside of the cold soda can filled with red water traveled through the can to the outside. To address this alternative idea, she described needing to draw attention to the water on the outside of the can being clear rather than red. Making connections between the evidence and the disciplinary core ideas as well as common alternative ideas students may have likely allowed

Ms. Chase to recognize when common alternative ideas had been contributed to the discussion and determine which pieces of evidence would likely contradict those claims.

Like Ms. Lawrence, Ms. Chase also had sophisticated plans for monitoring students' ideas as they carried out the peer teaching investigation. Her monitoring tool differed from Ms. Lawrence's version, however. Rather than listing accurate scientific ideas, common alternative ideas about content, and investigation struggles, Ms. Chase's monitoring tool only considered accurate scientific content.

Missed opportunities. Similar to Ms. Andrews, Ms. Chase provided no plans for monitoring student work in her LiFE lesson plan. She also provided limited plans for reminding students of the initial ideas throughout the lesson, perhaps limiting students' opportunities to consider how their thinking had changed over the course of the investigation. Additionally, like Ms. Andrews, Ms. Chase did not include plans to support student to engage in argumentation, likely limiting opportunities for students to listen to one another and consider alternate claims. Finally, in her LiFE plan, Ms. Chase did not include a representation to help students visualize patterns in their data.

Ms. Kramer

Of all the focal interns, Ms. Kramer's lesson plans showed the least evidence of sophisticated engagement in the productive teaching practices for capitalizing on student contributions. Like the other focal interns, Ms. Kramer planned to use open-ended questions to elicit, challenge, and extend student thinking. However, this was the only practice Ms. Kramer planned to engage in a sophisticated way. Her peer teaching plan provided some evidence of consideration of students' initial ideas, consideration of the content storyline, investigation trajectory, and preparation for students' accurate and alternative ideas. Her peer teaching plan also provided some evidence of planned engagement in monitoring students as they collected data, and planned engagement in data analysis and explanation construction. Neither of her plans showed evidence of use of a representation.

Plan strengths. Like other focal interns, Ms. Kramer's plans showed her planned use of open-ended questions to elicit, challenge, and extend students' ideas. For example, in her peer teaching plan when students were analyzing their data she planned to ask students, "What do you notice about your group's data? What are the similarities or differences you notice about everyone's observations" [Kramer, Peer Teaching Plan, p.5]. Similarly, in her LiFE plan, Ms. Kramer planned to ask students about patterns in their observations. By planning to use open-ended questions, students may have been provided opportunities to share their ideas with each other, provide justification for those ideas, and connect their ideas to those of other students and the thinking of scientists.

Missed opportunities. In both Ms. Kramer's peer teaching plan and her LiFE plan she made limited connections between the investigation and the disciplinary core ideas. The claim-evidence-reasoning statements she expected her students to construct at the end of the investigations were vague, and some of the evidence provided was inaccurate. For example, for her LiFE lesson focused on helping students understand how fish move and breathe, she expected students to construct the following claim-evidence-reasoning statement containing inaccurate reasoning:

> Claim: I think fish use their bodies and fins to move in water. Fish use their gills to breathe.
> Evidence: I think this because the gill covers open and close while fish move their fins.
> Reasoning: The science idea or principle that helps me explain this is that all animals move and breathe and need certain body parts to move and breathe.
> [Kramer, LiFE Lesson Plan, p. 2]

Although the first grade students may not have been able to provide Ms. Kramer with the scientific reasoning for this investigation, Ms. Kramer's inclusion of inaccurate reasoning may have prevented her from recognizing accurate contributions if a student disagreed with the statement, "all animals move and breathe"[11].

Ms. Kramer also struggled to provide plans for monitoring student work as they were carrying out the investigation and did not plan to use a representation to support students to notice patterns in their data. Finally, Ms. Kramer planned to provide students with the scientifically accurate claim prior to students having opportunities to analyze their data, likely shifting the lesson from being focused on students' contributions and students engaging in the intellectual work of data analysis to a confirmatory science teaching approach.

Ms. Zabel

Similar to Ms. Andrews, Ms. Lawrence, Ms. Chase, and Ms. Kramer, Ms. Zabel planned to use open-ended questions to elicit, challenge, and extend student thinking. Ms. Zabel also crafted scientific claims based on evidence and reasoning for both her Stems peer teaching lesson as well as her LiFE lesson helping students to understand that black is a mixture of all colors. In her peer teaching lesson, Ms. Zabel provided some evidence of considering students' initial ideas about the function of stems, and how the investigation connected to the disciplinary core idea. In both the peer teaching lesson and LiFE lesson plans, Ms. Zabel considered alternative ideas students may have had about the science content and stated she would circulate and monitor students as they collected data. She also planned to engage students in data analysis and explanation construction, but her plan did not show evidence of fostering argumentation.

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[11] Not all animals move, for example, sea anemones and coral. Additionally, not all animals actively breathe. For example, some species of jellyfish diffuse oxygen across their cell membranes.

Finally, Ms. Zabel did not plan to use a representation in either her peer teaching lesson or her LiFE lesson.

Plan strengths. Within both lesson plans, Ms. Zabel planned to use open-ended questions to elicit, extend, and challenge students' ideas. For example, in the Experience element of her LiFE lesson, she planned to question students about their observations asking, "What is happening to the black marker line? Have you drawn exactly what you see? How many colors are on your paper? How many colors are on your drawing?" [Zabel, LiFE Lesson Plan, p.6]. Planning to use these questions likely enabled Ms. Zabel to focus students' observations to be more systematic as they were collecting data.

Additionally, for both lessons, Ms. Zabel provided a scientifically accurate claim based on evidence and reasoning. For example, in her peer teaching lesson, Ms. Zabel anticipated her students would construct the following claim-evidence-reasoning statement:

> Claim: I think the clear and red water moves up the stem through the tubes and into the leaves.
>
> Evidence: I know this because I have seen the limp celery become firm after three days (evidence 1), the tubes of the celery in the red water turned pink after three days (evidence 2), and the leaves of the celery in the red water turned pink after three days (evidence 3).
>
> Reasoning: The science idea or principle that helps me explain this is that the stem has specific function. It carries water and nutrients from the base of the stem (by the roots) all the way to the leaves. It also helps to hold the plant up.
>
> [Zabel, Peer Teaching Lesson Plan, p.2]

Ms. Zabel anticipated a claim her students should be able to make after collecting data. Additionally, the three pieces of evidence support the claim and the scientific reasoning is accurate and appropriate for a first grade student. Having crafted an accurate and well-supported scientific claim, Ms. Zabel was likely able to recognize when students contributed accurate understandings of the phenomenon during the investigation-based discussion.

Missed opportunities. Despite Ms. Zabel's planned use of open-ended questions and anticipation of students' accurate ideas, Ms. Zabel provided little evidence of her plans for monitoring student work during the investigation. The questions she planned to ask students would likely allow her to gain insight into how students were thinking about the phenomena, but she did not specify how she would keep track of those ideas, nor did she describe a plan for making sure to check in with each of her students. Additionally, Ms. Zabel did not plan to engage her students in argumentation in either of her plans, which likely led to fewer opportunities for students to share their ideas and consider alternate claims during the investigation-based discussion. Finally, Ms. Zabel did not plan to use a representation to support students to analyze their data in either her peer teaching lesson or her LiFE lesson.

Ms. Sawyer

Of the focal interns teaching the Stems lesson, Ms. Sawyer's plan showed the most sophistication with regard to planned engagement in the productive practices. In her peer teaching plan, Ms. Sawyer was able to anticipate alternative ideas students may have about both the science content and science practices. Additionally, she planned to use a monitoring tool to keep track of students' ideas throughout the investigation, and planned to use a representation to support students to see patterns in their data. Like the other interns, both of Ms. Sawyer's plans showed evidence of use of open-ended questions to probe student thinking. Also similar to the other focal interns, Ms. Sawyer's LiFE plans to engage in the productive teaching practice for capitalizing on student contributions were less sophisticated than those provided in her peer teaching plan.

Plan strengths. Like Ms. Zabel, Ms. Sawyer also listed an accurate scientific claim supported by evidence and reasoning in both her peer teaching and LiFE lesson plans. Ms. Sawyer also listed open-ended questions throughout both of her plans. Unlike the other two focal interns teaching the stems lesson, Ms. Sawyer anticipated alternative ideas students may have about the science content and struggles students may have during the investigation. For example, Ms. Sawyer described that students may have difficulty drawing the celery stems in an accurate way. Additionally, unlike the other focal interns teaching the Stems Lesson, Ms. Sawyer included a monitoring tool in her lesson plan and described using the monitoring tool to check in with all students to gain insight into how they were thinking about the function of a stem.

Finally, in her peer teaching lesson plan, Ms. Sawyer included a representation to support students to analyze their observations. Ms. Sawyer, along with several other interns in her co-planning group, created a data chart (see Figure 6-5 for an example of the chart with anticipated ideas students would contribute) that provided space for students to record and compare their observations of the two types of celery and the cross sections before and after the three day period as well as space for students to describe what they thought had changed over the three days. Ms. Sawyer's use of the chart would likely allow the patterns in the observational data to become more visible for students. Ms. Sawyer described circling similarities in the data, signifying the importance of those similarities for students.

Chart on the board: (circle ones that are the same between the two charts)
What did you notice that changed?
Who else noticed something similar?

Day One	Red Water Celery	Clear Water Celery
	celery are firmer	celery are firmer
	Red dye stained the tubes and leaves.	The leaves got greener.
	The red dyed water moved from base of the celery stem to the leaves.	The water moved up from the base of the celery stem to the leaves.
	There was water in the celery when we cut it.	There was water in the celery when we cut it.

(reinforce that the same thing is happening to both celeries, but the red coloring helps us see that the water goes up the stem)

Figure 6-5: Ms. Sawyer's peer teaching lesson plan representation

Missed opportunities. Despite Ms. Sawyer's sophisticated plan for her peer teaching lesson, similar to the other focal interns, her planned engagement in the productive practices was less sophisticated in her LiFE lesson plan. In her LiFE plan, Ms. Sawyer only planned to elicit students' initial ideas about how sounds are made at the start of the lesson and did not plan to record their initial ideas or remind students of those ideas at any other point in the plan. Ms. Sawyer planned to circulate and observe students as they carried out the investigation and did not anticipate struggles students may have while carrying out the investigation. Ms. Sawyer also did not provide detailed plans for the type of representation she would be using during the investigation-based discussion. She described using a data chart to record student observations during the discussion but did not include an example representation in her LiFE plan. Finally, Ms. Sawyer did not plan to engage students in argumentation, likely limiting students' opportunities to listen to each other's ideas and consider alternative claims.

Summary of Evidence of Planned Use of Productive Teaching Practices

The focal interns and other interns enrolled in the methods course used a range of teaching practices that are productive for capitalizing on student contributions within their peer teaching and LiFE lesson plans. Interns used productive teaching practices for capitalizing on student contributions more frequently and with more sophistication in their peer teaching lesson plans versus their LiFE lesson plans. Across both sets of plans, the majority of interns were able to anticipate students' accurate scientific ideas. Additionally, the majority of interns were able to craft questions that would elicit, extend, or challenge student thinking, likely drawing on the science-teaching specific talk moves provided during the methods course. By anticipating accurate ideas, the interns may have been better able to capitalize when a student made a contribution that helped to guide the discussion toward construction of an accurate claim. By crafting questions to elicit students' thinking, interns likely provided students more opportunities for students to share their thinking with others.

In contrast, evidence of planning to monitor students while they engaged in carrying out the investigation varied across the two plans, as did planned use of representations to organize and highlight student contributions. Limited plans to monitor student thinking during the investigation may have contributed to a lack of awareness of how students were thinking about the scientific content. Finally, lack of use of a representation may have resulted in students struggling to notice important patterns or trends in their data, and missed opportunities to engage students in the science practices of data analysis and explanation construction. Table 6-3 provides a summary of how high evidence of each practice potentially impacts intern lesson enactment.

Table 6-3: Planned Teaching Practice and Potential Impact on Enactment

Productive Teaching Practice	High Evidence of Use in Plan: Potential positive impact on enactment
Considering initial ideas	Consistently reminding students of initial ideas prompts students to consider how their thinking may have changed (or stayed the same) over the course of the investigation
Considering the content storyline	Strong connection to the content storyline of the lesson allows the intern to make connections between the investigation students are carrying out and other big scientific ideas in the unit
Considering the investigation trajectory	Strong connection between the investigation and the disciplinary core idea allows the intern to support students to notice key pieces of evidence guiding students to an understanding of scientific phenomena
Preparing for accurate student ideas	Preparation of a claim supported by multiple pieces of evidence allows the intern to recognize when those ideas are contributed by students helping to guide students toward a more accurate understanding of the phenomenon
Anticipating alternative ideas	Allows the intern to recognize when common alternative ideas have been contributed to the discussion, potentially allows intern to provide contradictory evidence to foster argumentation guiding students toward a more accurate understanding of the phenomenon
Monitoring student work	Intern may be better able to formatively assess students during the investigation and use knowledge of students' ideas to sequence the discussion
Questioning to elicit, challenge, or extend	Provides increased opportunities for students to share ideas, provide justification, and connect to others' ideas and the thinking of scientists
Logical flow of engagement in science practices	Planning for student engagement in data analysis, argumentation and explanation construction reminds the intern to provide opportunities to engage students in each of the practices allowing the discussion to become more student centered
Sequencing and selection of specific ideas	Allows the intern to elicit specific pieces of evidence or student ideas during the discussion pressing students to consider alterative explanations and then guiding students to a more accurate understanding of the phenomenon
Use of a representation	Makes patterns and trends in the data more obvious for students, allowing them to use the patterns as pieces of evidence to support their scientific claim

Conclusion

This chapter described the interns' planned use of productive teaching practices for capitalizing on student contributions in both the peer teaching and LiFE lesson plans. This chapter described both the strengths and missed opportunities in the lesson plans and considered how the strengths and missed opportunities may have impacted the lesson enactments. In the next chapter, I describe how the focal interns engage in the productive practices for capitalizing on student contributions during their peer teaching and LiFE lesson enactments. Chapter 7 utilizes lesson enactment figures to show time points during lesson enactments when the focal interns utilized the productive teaching practices, dialogic or authoritative voice, and student engagement in science practices.

CHAPTER 7

USE OF PRODUCTIVE PRACTICES TO CAPITALIZE ON STUDENT CONTRIBUTIONS: ENACTMENTS

Chapter 5 considered interns' use of tools to plan and enact investigation-based science discussions, and Chapter 6 described their planned productive teaching practices in both the peer teaching and LiFE lesson plans. In this chapter I describe the focal interns' engagement in productive practices for capitalizing on student contributions within their peer teaching and LiFE lesson enactments, complementing Chapter 6 and continuing to address Research Question 2 Based on my analysis of the videorecords of focal interns' lessons, I make the following assertions.

a) Focal interns used the productive practices and engaged students in science practices in similar ways in both their peer teaching and LiFE lesson enactments.

b) Focal interns differed both in their frequency of use and types of practices used during their lesson enactments.

c) Focal interns' lesson enactments showed evidence of success and strength as well as missed opportunities

d) Combined use of teaching practices throughout lesson enactments led to increased opportunities for students to share their ideas and engage in data analysis, argumentation, and explanation construction. These synergistic productive practices included:

    a. Considering students' initial ideas

b. Questioning students to elicit, extend, and challenge ideas

c. Making connections across students' ideas and the disciplinary core idea

d. Using a representation to organize and highlight students' ideas

As a reminder, the video records of the focal interns' enactments were coded for evidence of teaching practices that research has shown to be particularly important for enacting productive investigation-based discussions that capitalize on student contributions (Boerst, Sleep, Ball & Bass, 2011; Cartier et al., 2013; Ross, 2014; Windschitl et al., 2012) including:

(1) Considering students' initial ideas (initial)

(2) Questioning students to elicit, challenge or extend thinking (questioning)

(3) Monitoring student work during the investigation (monitoring)

(4) Making connections across students ideas and disciplinary core ideas (connections)

(5) Selecting and sequencing student ideas (selecting)

(6) Marking student contributions (marking)

(7) Considering the content story line or big ideas related to the investigation and (big ideas)

(8) Using a representation to organize and highlight student ideas (representation)

Table 4-13 in Chapter 4 provides definitions and examples of each of these codes. Several of the productive practices for planning investigation-based science discussions were not considered when coding the enactments because the codes only applied to planning; thus it was difficult to see evidence of interns engaging in those practices during the enactments (e.g., preparing for students' scientifically accurate ideas). In this chapter I also provide evidence of the type of voice (e.g., authoritative versus dialogic) the intern used throughout her lesson.

To code for the logical flow of engagement in science practices and accuracy of content, I marked the segments of the lesson when interns provided opportunities for student engagement in science practices as well as segments of the lesson when the intern described the scientific content in an inaccurate way. I represent each enactment using a figure to show the teaching practices the intern was engaged in at specific time points during the lesson, the voice used, and the opportunities students had to engage in science practices. Using the representations of the lesson enactments, I highlight the ways in which interns engaged (or did not engage) in the four synergistic productive teaching practices for facilitating investigation-based discussions (considering students' initial ideas**,** questioning students to elicit, extend, and challenge ideas**,** making connections across students' ideas and the disciplinary core idea, and using a representation to organize and highlight students' ideas). Additionally, I use asterisks in the figure to signal when interns described the science content in an inaccurate way. Figure 7-1 provides the legend for the figures. Table 7-1 summarizes the productive practices each focal intern engaged in during the peer teaching and LiFE lesson enactments.

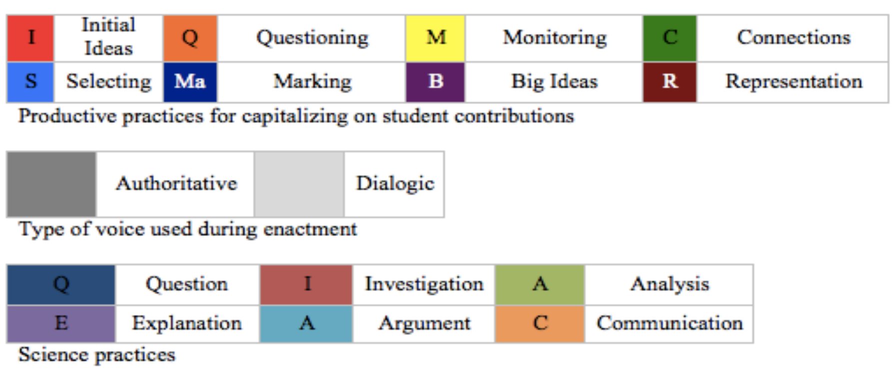

Figure 7-1: Legend for enactment figures detailing teaching practice, voice, and science practices

Table 7-1: Summary of the productive practices for each focal intern's enactment

	Andrews		Lawrence		Chase		Kramer		Zabel		Sawyer	
Lesson Type	PT	LiFE	PT	LiFE	PT	LiFE	PT	LiFE	PT	LiFE	PT	LiFE
Initial ideas	X	X	X	X	X	X	X	X	X	X	X	X
Questioning	X	X	X	X	X	X	X	X	X	X	X	X
Monitoring				X	X	X	X	X	X	X	X	X
Connections	X	X	X	X	X	X		X		X	X	X
Selecting		X		X				X		X		X
Marking	X				X		X	X			X	
Big Ideas	X	X	X	X	X	X	X	X	X	X	X	X
Representation	X	X	X		X			X			X	X

X indicates intern engaged in productive practice during enactment

Ms. Andrews

In both her peer teaching and LiFE enactments, Ms. Andrews engaged in all four of the synergistic productive teaching practices for facilitating investigation-based discussions. At the start of her lessons, Ms. Andrews elicited and reminded students of their initial ideas about the phenomena. Throughout her lessons, Ms. Andrews consistently used open-ended questions to elicit, extend, or challenge student thinking and made connections between students' ideas and the bigger scientific ideas. In both lessons, she also used a representation that supported students to see patterns in the data they had collected during the investigation. Finally, in her peer teaching lesson, she marked important ideas students contributed, and in her LiFE lesson, she selected specifics to share important ideas during the investigation-based discussion.

Productive Teaching Practices: Peer Teaching

Figure 7-2 provides evidence of the time points during which Ms. Andrews engaged in each of the productive teaching practices.

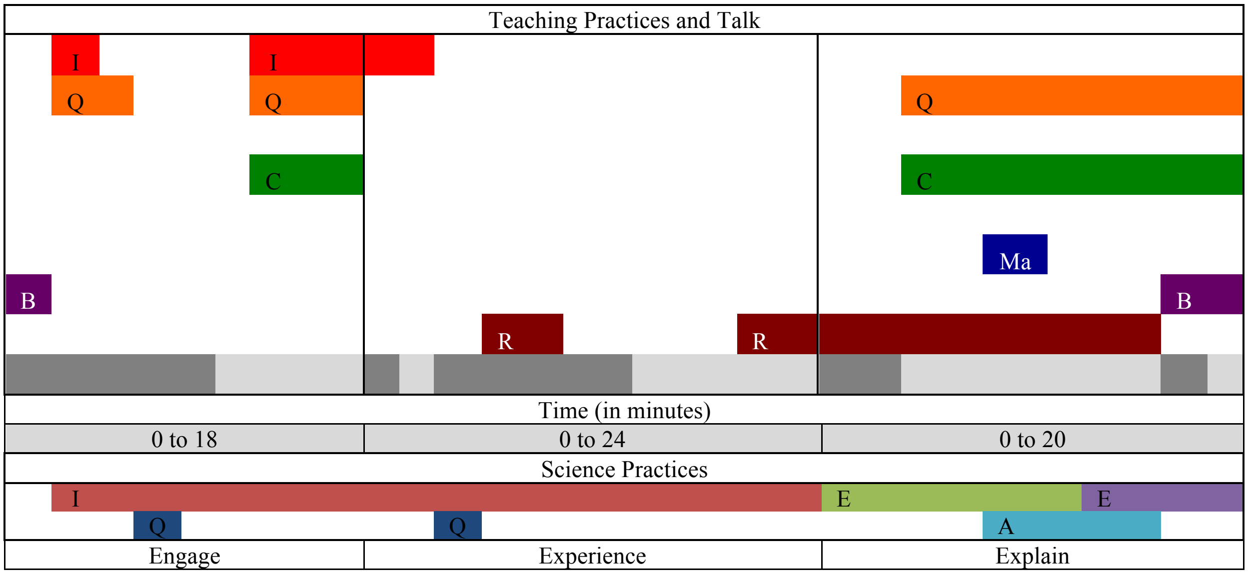

Figure 7-2: Ms. Andrews' Peer Teaching Enactment

At the beginning of her peer teaching lesson, like many of the other focal interns, Ms. Andrews provided students some context for the investigation-based lesson by reminding students of the concept of energy transformation. Similar to Ms. Lawrence's and Ms. Chase's enactments, she utilized a light bulb to probe students' initial ideas of how heat energy transfers from one object (the bulb) to another (the student's hand). Using an authoritative voice, she asked students to make predictions about what one student might feel when holding his hand close to a light bulb. Rather than allowing each student to share his or her ideas with each other and begin to connect their ideas, she called on only one student volunteer to share her ideas with the class [Andrews Peer Teaching Engage 2:00-6:00]. Ms. Andrews then asked the students if they thought the same thing would happen with different types of objects like liquids. This allowed her to shift students to think about heat energy transfer in water. She introduced the investigation question to her students, supporting them to focus explicitly on the phenomenon they would be observing. Then, using a dialogic voice, she asked students to make predictions about the investigation question, allowing students time to think about their response and then share their ideas with a student near them. Ms. Andrews elicited every student's ideas and made connections between students' thinking. By allowing time for students to talk to one another, students were able to actively engage in making a scientific prediction, one component of the larger scientific practice of planning and carrying out investigations [Andrews Peer Teaching Engage 10:00-18:00].

At the beginning of her Experience element, using an authoritative voice, Ms. Andrews reminded students of the predictions they had made earlier. She also provided students with a detailed explanation of how they should carry out the investigation, introducing the materials and assigning roles for students while collecting data. The explanation of the investigation was largely authoritative with Ms. Andrews pausing only to ask students if they understood the instructions. Midway through her monologue, Ms. Andrews directed students' attention to the representation they would be using to record their data and had two students practice reading the thermometers and record the temperatures [Andrews Peer Teaching Experience 8:00-12:00]. Ms. Andrews dismissed students to begin carrying out the investigation, allowing time for student pairs to talk through their instructions and gather the necessary materials [Andrews Peer Teaching Experience 18:00-22:00]. While students were gathering, Ms. Andrews stood at the group's table and did not question or monitor her students. Students were unable to collect any data because they had run out of time[12].

At the start of Ms. Andrews' Explain element, she was doing the majority of the talking and intellectual work for her students as indicated by her use of authoritative voice. For

[12] Ms. Andrews remedied this by working with other interns from other peer teaching groups to compile four complete sets of data to use for the Explain element.

example, she directed students' attention to a representation to help students see patterns in the data but then described all parts of the graph for the students [Andrews Peer Teaching Explain 0:00-4:00]. At this point, the teacher educator paused Ms. Andrews and prompted her to think of ways she could allow her students to do the intellectual work. Following this interaction, Ms. Andrews engaged all of her students in the discussion by asking open-ended questions, and rather than responding to students' answers, she moved on to the next student to get his or her thoughts about the topic or comment on what the previous student stated. Through her use of dialogic voice, students were able to talk to one another and listen and respond to others' comments [Andrews Peer Teaching Explain 4:00-8:00]. With her support, students were able to determine that all of the group's data were similar in that they all reached roughly the same ending temperature after ten minutes, and the cold water got warmer, and the hot water got colder. Ms. Andrews also fostered argumentation by asking her students periodically if they agreed or disagreed with others' statements [Andrews Peer Teaching Explain 10:00-16:00]. When one student argued that she thought they couldn't use one set of data because it did not look like the others, Ms. Andrews asked other students if they agreed:

> Student 1: I think that means we can't compare them at all.
>
> Ms. Andrews: That is an interesting idea. Does anyone disagree with [Student 1]?
> Student 2: Well earlier we talked about the idea that we could still probably use it. So even though the temperatures are different we could still probably use it.
>
> Student 3: I agree with [Student 2] I think that if you were to look at the graphs from afar they all have a similar shape and they touch in the middle. Even with this one if you ignore the dip in the middle it still has a similar shape so I think we can use it.
>
> Ms. Andrews: Ahh, so you are saying the trend is the same… the pattern.

Rather than immediately telling the student she was incorrect, Ms. Andrews used an open-ended question to engage her students in argumentation, pushing her students to do the intellectual work of determining what to do with the anomalous data. Following this conversation, Ms. Andrews's students began to work toward constructing an explanation to answer the investigation question. While supporting her students to construct their explanations based on evidence, she continuously referred students back to the representations of the data [Andrews Peer Teaching Explain 12:00-16:00]. Her use of a representation also seemed to focus students on key pieces of data and prompted them to use multiple pieces of evidence to support their claim.

Productive Teaching Practices: LiFE

Figure 7-3 provides evidence of the time points during which Ms. Andrews engaged in each of the productive teaching practices.

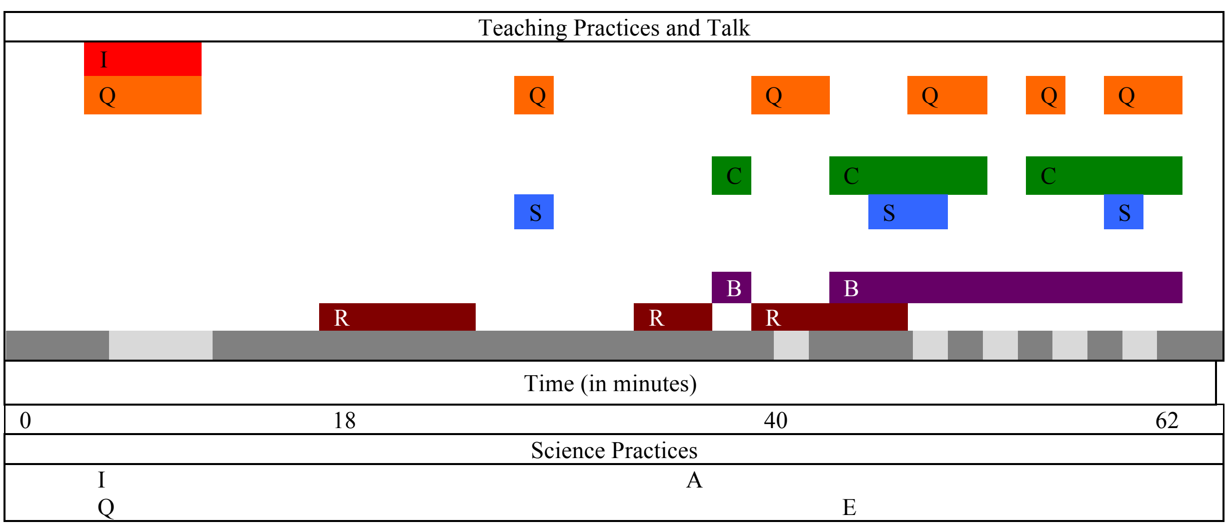

Figure 7-3: Ms. Andrews' LiFE Enactment

Toward the beginning of her lesson, Ms. Andrews posed the investigation question, "How does disease spread through a community?" [Andrews LiFE 4:00-6:00]. Similar to her peer teaching lesson, she elicited students' predictions allowing students to engage in the larger practice of planning and carrying out investigations. She provided time for students to discuss their ideas with one another and then share them in a whole class discussion. In her LiFE lesson, however, Ms. Andrews did not help students to connect their ideas but rather recorded all of the volunteered ideas on the board for students to visualize [Andrews LiFE 6:00-12:00]. Ms. Andrews then explained the investigation as a simulation of disease spreading through their classroom community, directing students to a representation to help them keep track of other students they traded "bodily fluids" with. Due to the nature of the activity, Ms. Andrews utilized authoritative voice as the students carried out the investigation, trading their milk solutions with others. Once students had completed their trades, Ms. Andrews tested their milk solutions for the presence of the disease [Andrews LiFE 24:00-30:00]. While testing students' solutions and making them aware of whether they were infected or not, one student told Ms. Andrews that he knew why the group that traded internally was free from the disease. Likely noticing the importance of this contribution, Ms. Andrews asked the student to repeat his comment loud enough for the entire class to hear [Andrews Life 28:00]. By selecting and drawing attention to the student's contribution, other students may have been prompted to begin thinking about why one of the student groups was completely unaffected by the spread of the disease.

After all students' milk solutions were tested for the presence of the disease, Ms. Andrews asked all infected students to come to the carpet and made a list of those students who were infected versus free of the disease [Andrews LiFE 32:00-36:00]. Then, Ms. Andrews asked all students who had traded with someone that still was free of the disease to return to their seats because they were not patient zero. Rather than asking the students to determine a reason why those students had not been infected at one point, Ms. Andrews explained the reasoning to them, missing an opportunity to ask the students to do the intellectual work. Without this opportunity students may not have understood that if they had traded with another student who remained uninfected at the end of the simulation, they too must have been uninfected at the time of that trade.

After students knew which student initially had been infected, Ms. Andrews utilized a representation that supported students to clearly view the patterns in the data. After creating the representation, several students commented that the number of infected individuals doubled after each round of the simulation and began to connect the claim back to the investigation question. As students were discussing the observations of patterns in the data, Ms. Andrews recorded student contributions on the board, stating that these trends or patterns were pieces of evidence students could use to support their explanations [Andrews LiFE 38:00-44:00].

During the whole-class discussion toward the end of the lesson, Ms. Andrews used dialogic voice, but it was often interspersed between segments that were largely I-R-E [Andrews LiFE 46:00-60:00]. For example, in the last few segments of the lesson, she used talk moves to question students' thinking, but many of the students' responses are followed with evaluative remarks. This was also the first time the students in this class were using the claim-evidence-reasoning framework to construct explanations and they seemed to need additional support to determine the parts of the explanation.

Missed Opportunities: Making Assumptions About Whole-Class Understanding

Although Ms. Andrews used several productive practices for capitalizing on student contributions throughout her LiFE lesson, such as selecting and highlighting student responses, use of a representation to help students clearly see patterns in the data, and use of open-ended questioning, her consistent use of authoritative voice throughout the lesson resulted in missed opportunities for students to do the intellectual work while engaging in argumentation and construction of evidence-based claims. In the peer teaching lesson, when reminded to press her students to do the intellectual work, Ms. Andrews was able to productively shift from authoritative voice to dialogic voice, summarizing important student contributions and using open-ended questioning to encourage her students to share their ideas and listen to each other. During the LiFE lesson, she was not given in the moment reminders. During the LiFE lesson, when Ms. Andrews posed open-ended questions, she often allowed only one student to respond and immediately evaluated the student's response. By only allowing a single student to contribute to the discussion, Ms. Andrews may have been unaware that several of her students were struggling to make an evidence-based claim to answer the investigation question (as evident by students' confusion at the end of the lesson). Ms. Andrews did not explicitly state the claim for students, but repeatedly called on two students to provide the scientifically accurate claim. The same two students also provided multiple pieces of evidence to support the claim.

Strengths and Successes: Accurate Science, Questioning, and Use of Representations

In both her peer teaching lesson and LiFE lesson enactments, Ms. Andrews drew on her accurate knowledge of the science content to help students construct explanations for the phenomena they observed. Additionally, Ms. Andrews consistently used open-ended questions to elicit students' initial ideas and extend and challenge student thinking. Finally, in both lessons, Ms. Andrews used a representation to help make patterns in the date more obvious for students. Because of her use of these representations, students were supported in analyzing their data and determining which pieces of evidence could be used to support their claims. Ms. Andrews's peer teaching lesson provided evidence that the use of open-ended questions to elicit and connect ideas along with her representation and use of dialogic voice provided multiple opportunities for students to engage in data analysis, argumentation, and explanation construction.

Ms. Lawrence

Ms. Lawrence engaged in all four of the synergistic productive teaching practices during her peer teaching lesson enactment but did not engage in all four practices in her LiFE lesson enactment. In both her peer teaching and LiFE enactments, Ms. Lawrence elicited students' initial ideas about the scientific phenomena. In her LiFE lesson, she returned to students' initial ideas at the end of the lesson, allowing students to compare their results to their predictions. Throughout her lessons, Ms. Lawrence consistently used open-ended questions to elicit, extend, or challenge student thinking and made connections between students' ideas and the bigger scientific ideas. In her peer teaching lesson, Ms. Lawrence also used a representation that supported students to see patterns in the data they had collected during the investigation. Finally, in her LiFE lesson, Ms. Lawrence monitored students' work as they were collecting data.

Productive Teaching Practice: Peer Teaching

Figure 7-4 provides evidence of the time points during which Ms. Lawrence engaged in each of the productive teaching practices.

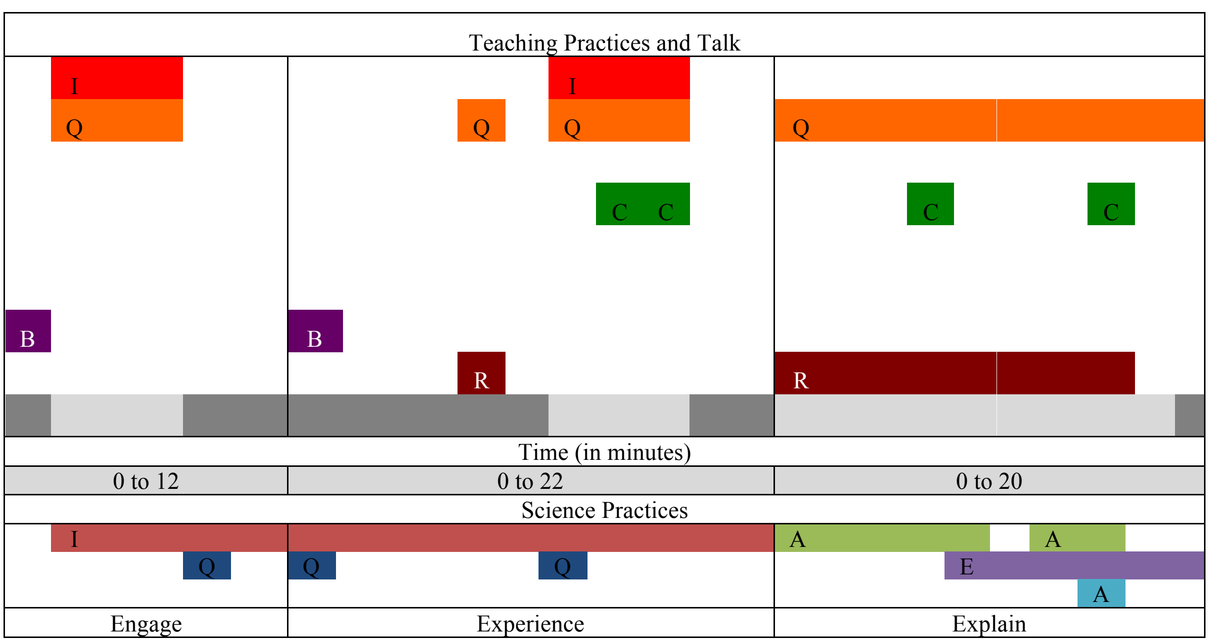

Figure 7-4: Ms. Lawrence's Peer Teaching Enactment

At the start of the lesson, Ms. Lawrence used questioning practices to elicit students' initial ideas after giving them reminders of some of the big ideas connected to the lesson (e.g., there are multiple forms of energy). Like Ms. Andrews and Ms. Chase, Ms. Lawrence also used the light bulb to elicit her students' initial ideas about heat transfer from one object to another. Unlike Ms. Andrews, Ms. Lawrence used the light bulb investigation to elicit all students' initial ideas about heat energy transfer, asking students to turn and talk with their neighbors about how the heat was able to move from the light bulb to a student's hand [Lawrence Peer Teaching Engage 0:2:00-8:00]. By using open-ended questions, she allowed her students to become engaged in the intellectual work of the investigation, developing initial predictions about how heat moves from one object to another. Following this experience, Ms. Lawrence briefly described the investigation question to her students [Lawrence Peer Teaching Engage 8:00-10:00]. In contrast to Ms. Andrews, Ms. Lawrence did not elicit students' initial predictions about the investigation question in her Engage element.

In the Experience element, Ms. Lawrence, using an authoritative voice, spent the first few minutes outlining the procedural steps of the investigation [Lawrence Peer Teaching Experience 0:00-10:00]. Ms. Lawrence then asked students for predictions directly related to the investigation question "What happens to a bag of warm water when it is placed in a container of cold water?". To elicit predictions, Ms. Lawrence used open-ended questions and connected students' predictions, drawing similarities between the predictions and highlighting nuanced differences, and recording predictions on the board [Lawrence Peer Teaching Experience 14:00-18:00]. She also encouraged students to provide reasoning for their predictions.

Ms. Lawrence:	What do you think is going to happen?
Student 1:	I think the hot water is going to get cold and the cold water is going to stay cold.

Ms. Lawrence: Who else has a prediction?

Student 2: I think they will become the same temperature, but I think it's going to take a long time.

Student 3: I think the hot water will stay the way it is, but the cold water is going to get warm.

Ms. Lawrence: So is that the same thing that [student 1] said?

Student 3: No… It's like the opposite.

Ms. Lawrence: Ah, so why do you think that?

Student 3: Sometimes when my mom makes me tea, she puts an ice cube in and it disappears. The tea is boiling hot but then when you put the ice cube in the tea it stays hot, and it only cools down a little bit and the ice cube disappears like it becomes part of the tea. It melts.

In her Explain element, Ms. Lawrence continuously referred back to the representation (a graph) she had created to support students to see patterns in the data. She asked students open-ended questions about what they were noticing and how each graph was different and similar to those next to it [Lawrence Peer Teaching Explain 0:00-10:00]. By doing this, all students were engaged in the intellectual work of analyzing the data and were able to construct an evidence-based claim [Lawrence Peer Teaching Explain 10:00-18:00]. Ms. Lawrence was not able to push students for the reasoning for their explanation, but that was likely due to running out of time. Her plan indicated she did have plans to press students for reasoning, but was unable to do so in the twenty minutes she was allotted.

Productive Teaching Practice: LiFE

Figure 7-5 provides evidence of the time points during which Ms. Lawrence engaged in each of the productive teaching practices.

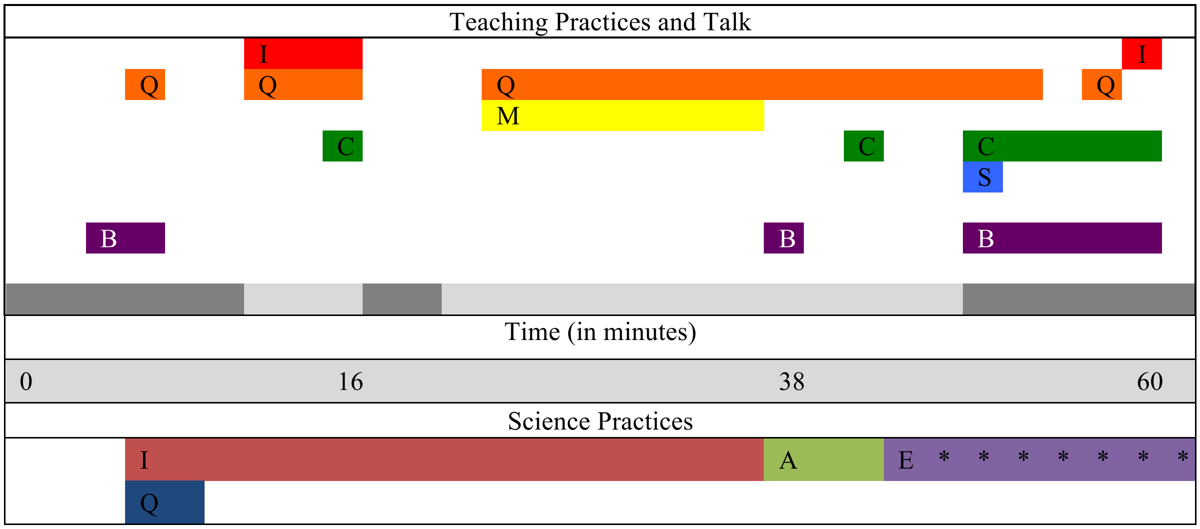

Figure 7-5: Ms. Lawrence's LiFE Enactment (* indicates segment in which Ms. Lawrence describes the science content in an inaccurate way)

In her LiFE lesson, Ms. Lawrence used the first segments of the lesson to review some concepts students had already covered (e.g., what happens to light when it hits an opaque object). In this part of the lesson, the discussion was largely I-R-E with Ms. Lawrence asking closed questions that had one right answer and evaluating students' responses [Lawrence LiFE 0:00-10:00]. Following these reminders of other concepts students should already know, Ms. Lawrence elicited students' predictions about what they thought would happen when they put the straw into the water bottles filled with oil and water. When eliciting predictions, Ms. Lawrence used open-ended questions and a dialogic voice, allowing multiple students to respond to the same question without evaluation [Lawrence LiFE 12:00-18:00]. She also made moves to help students to notice connections in their predictions. Similar to her peer teaching lesson, Ms. Lawrence's use of open-ended questions and teaching moves to connect students' ideas supported her students to actively engage in making scientific predictions, a key aspect of planning and carrying out investigations. Ms. Lawrence then briefly reminded students of procedural instructions [Lawrence Life 16:00-20:00], and broke students to groups to carry out the investigation.

While students were carrying out the investigation, Ms. Lawrence monitored their group work and used open-ended questions to gain better understanding of what students were noticing. She also guided them to be more systematic when looking at and writing about their observations of the bottle filled with water and the bottle filled with oil. Similar to her use of open-ended questions in her peer teaching lesson, her use of open-ended questions allowed her to shift into a dialogic voice, supporting multiple students to describe to her and each other what they were noticing as they were conducting the investigation [Lawrence LiFE 20:00-38:00].

She continued to use dialogic voice at the beginning of the investigation-based discussion, eliciting students' observations of both the straw in the bottle of water and the straw in the bottle of oil [Lawrence LiFE 38:00-44:00]. She recorded these observations on the board as students volunteered them. However, she did not use a representation to help students organize the observations and begin to notice similarities and differences across the observations of the straws in the two bottles.

Toward the end of the discussion, Ms. Lawrence used talk moves and open-ended questions to make connections between students' observations and scientific ideas of items being classified as opaque, transparent, or translucent. In doing so, however, she began to push students to focus on the straw being a transparent object rather than the water or oil. Even when one of her students brought the idea that the water and the oil were actually the transparent objects causing the straw to look bent, she failed to recognize this accurate idea and redirect the discussion toward the accurate explanation. During these segments, the discussion was also largely I-R-E, with Ms. Lawrence asking students questions, the students responding, and then Ms. Lawrence evaluating students' ideas, often incorrectly [Lawrence LiFE 46:00-60:00]. Because of the inaccurate explanation of the straw being a transparent object, students did not come away from the investigation with the understanding that the straw looked bent or fuzzy in the water and oil because the water and oil cause some of the light to bend as it passes through the liquids. At the end of the discussion, Ms. Lawrence returned to the students' initial predictions but continued to compare them to the inaccurate explanation [Lawrence LiFE 60:00-62:00].

Missed Opportunities: Inaccurate Science and Lack of Representation

Ms. Lawrence's struggles with the science content of focus in the LiFE lesson limited students' opportunities to come away from the lesson with an accurate understanding of what happens to light when it reaches a transparent object. Even when one of her students contributed the accurate scientific explanation, Ms. Lawrence failed to recognize her error and continued to describe the science content in an inaccurate way. Additionally, because Ms. Lawrence did not use a representation to help students organize their observations of the straw in the water and oil filled bottles, it was likely difficult for students to notice patterns in their data. This may have been why Ms. Lawrence used authoritative voice at the end of the lesson, seemingly unable to make productive shifts between providing students with information and allowing them to construct ideas together. She was unable to elicit important pieces of evidence for the explanation from her students and began to do much of the intellectual work for her students. She engaged in a teacher monologue to make connections between students' previously volunteered observations and the science content and comparing students' initial predictions with what they had observed.

Strengths and successes: Reminding Students of Initial Ideas and Questioning

In both her peer teaching lesson and her LiFE lesson, Ms. Lawrence used several productive practices for capitalizing on student contributions including three of the synergistic productive practices. She frequently asked students open-ended questions that allowed students to contribute ideas to the discussion. As a result, during her Engage and Explain elements of her peer teaching lesson and her Engage and Experience elements of her LiFE lessons student had opportunities to share their thinking with both Ms. Lawrence and other students. Similarly to Ms. Andrews, in her peer teaching lesson, Ms. Lawrence's use of a representation to help students analyze their data in combination with open-ended questions and dialogic voice allowed her to engage students in data analysis, argumentation and construction of an evidence-based claim.

Ms. Chase

Like Ms. Andrews and Ms. Lawrence, Ms. Chase engaged in three of the synergistic productive teaching practices in both her lessons (considering students initial ideas, questioning students to elicit, extend, and challenge ideas, and making connections across students' ideas and the disciplinary core idea). Like Ms. Lawrence, her use of a representation, however, was less consistent. In both her peer teaching and LiFE enactments, Ms. Chase elicited students' initial ideas about the scientific phenomena. In both lessons, she also returned to students' initial ideas at the end of the lesson, allowing students to compare their results to their predictions. Again, similar to Ms. Andrews and Ms. Lawrence, Ms. Chase frequently used open-ended questions to elicit, extend, or challenge student thinking. Ms. Chase monitored students as they collected data while carrying out the investigation. In her peer teaching lesson, Ms. Chase also used a representation that supported students to see patterns in the data they had collected during the investigation.

Productive Teaching Practice: Peer Teaching

Figure 7-6 provides evidence of the time points during which Ms. Chase engaged in each of the productive teaching practices.

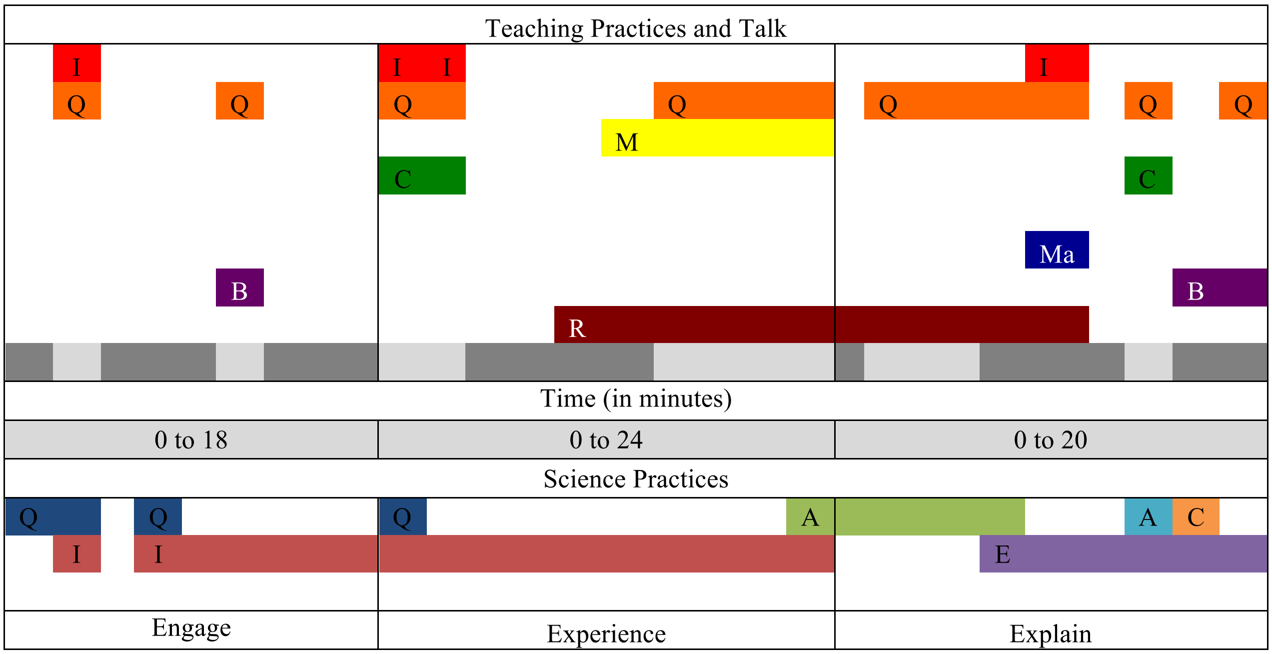

Figure 7-6: Ms. Chase's Peer Teaching Enactment

At the start of the lesson Ms. Chase posed the investigation question asking her students to consider how energy moves between a warm object and a cool object [Chase Peer Teaching Engage 0:00-4:00]. She allowed students to talk to a partner about their thoughts. After students had an opportunity to listen to each other's ideas, Ms. Lawrence asked students to share what they had discussed and recorded the ideas on the board. When one student shared that she thought the heat would disappear, Ms. Lawrence shifted into a teacher monologue, telling the student the heat wouldn't disappear [Lawrence Peer Teaching 8:00-12:00]. The teacher educator paused Ms. Lawrence, stressing that students likely would struggle with the concept because they are unable to see the energy actually being transferred between the objects. The teacher educator then encouraged Ms. Lawrence to allow the idea to persist rather than trying to explain how heat is transferred prior to students engaging in the investigation. Like Ms. Andrews and

Ms. Lawrence, Ms. Chase used the light bulb investigation to further elicit students' initial ideas about heat energy transfer. At the end of her Engage element, Ms. Chase described the investigation using an authoritative voice [Chase Peer Teaching Engage 12:00-18:00].

In her Experience element, Ms. Chase revised her investigation question, asking students to make a prediction about "what would happen to a bag of warm water when it was placed in a container of cold water?". She encouraged students to share their predictions with each other and then asked the pair groups to share their thoughts with the class. As students shared their predictions, Ms. Chase wrote the predictions on the board and helped students to see similarities and differences in ideas [Chase Peer Teaching Experience 0:00-6:00]. Much like the other focal interns teaching the energy lesson, Ms. Chase spent several minutes reviewing the investigation procedure with her students [Chase Peer Teaching Experience 8:00-16:00]. During this segment, Ms. Chase used authoritative voice and did not check for student understanding. Following the procedural reminders, she allowed students to gather the materials and begin carrying out the investigation. As students were collecting data, Ms. Chase monitored their work and asked probing questions about what students were noticing (e.g., asking them if they were noticing patterns and if so what that might mean). She also directed students' attention to the representation they were using to collect their data, encouraging them to make sure they were recording information in the correct columns [Chase Peer Teaching Experience 16:00-24:00]. Through monitoring and questioning, Ms. Chase was able to support her students to make systematic observations and collect accurate data.

Similar to Ms. Lawrence, in her Explain element, Ms. Chase continuously referred back to the representation (a graph) she had created to support students to see patterns in the data [Chase Peer Teaching Explain 0:00-12:00]. She asked students open-ended questions about what they were noticing and how each graph was different and similar to those next to it. She supported her students' analysis of the data and helped them to consider multiple explanations for anomalous data. As students noticed pieces of data that could be used as evidence for an explanation, she wrote the key pieces of data on the board and underlined specific phrases such as "met in the middle" [Chase Peer Teaching Explain 12:00-14:00]. This practice of marking key pieces of data likely supported her students to determine which pieces of data could be used as evidence in their claim-evidence-reasoning statement.

Although the first part of her Explain element was largely centered on student contributions, and she allowed the students to do the intellectual work, toward the end of the Explain element, the discussion shifted into an initiate-respond-evaluate pattern [Chase Peer Teaching 12:00-20:00]. When crafting the claim-evidence-reasoning statement, Ms. Chase asked her students open-ended questions but allowed only one student to respond and evaluated the response for accuracy. Shifting into a teacher monologue, Ms. Chase read sections of a scientific text to her students stating the text would provide the accurate scientific reasoning [Chase Peer Teaching 16:00-18:00]. The text provided students with information about the theory of conservation energy and explained how heat energy is transferred from a warm object to a cooler object until they reach a state of equilibrium. While use of the text likely supported students in understanding the phenomenon of heat energy transfer, Ms. Chased utilized the text prior to students trying to come up with their own reasoning first, leading to a missed opportunity for students to engage in the intellectual work of supporting an explanation with reasoning.

Productive Teaching Practice: LiFE

Figure 7-7 provides evidence of the time points during which Ms. Chase engaged in each of the productive teaching practices.

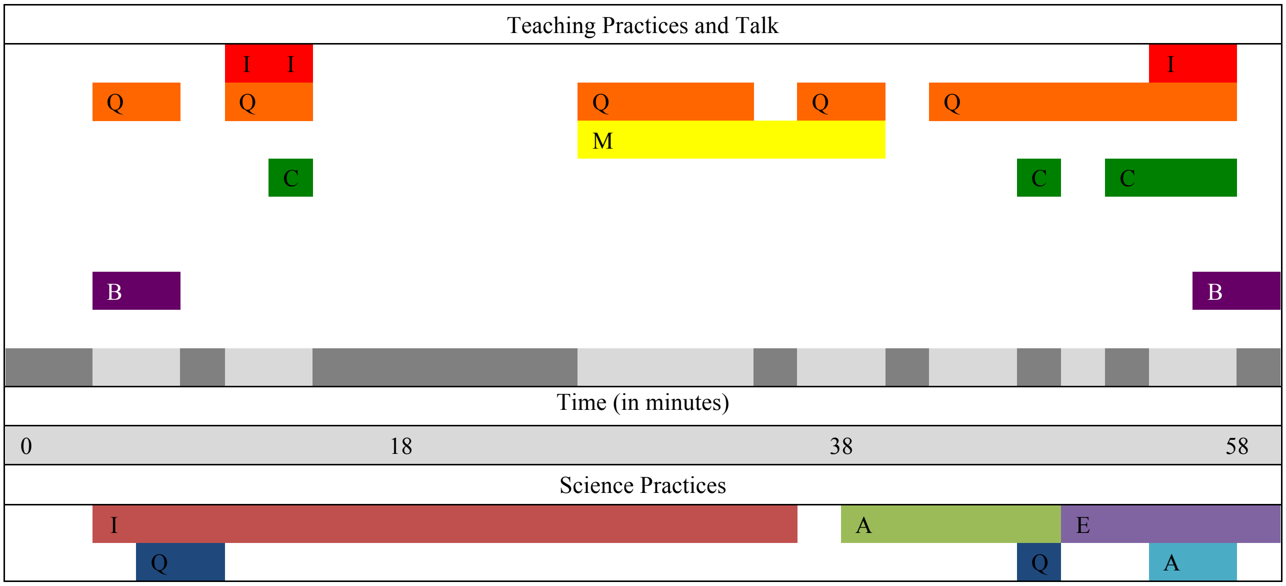

Figure 7-7: Ms. Chase's LiFE Enactment

At the beginning of her LiFE lesson, Ms. Chase reviewed the states of matter with her students and asked her students to begin thinking about how matter changes states from solid to liquid and liquid to gas, anchoring her lesson in the processes of condensation and evaporation [Chase LiFE 0:00-6:00]. Then, she posed the investigation question for her students, asking them to make a prediction answering the question "How and why do water droplets appear on cold surfaces?". She allowed time for her students to share their initial ideas with one another and then asked students to share ideas with the whole class [Chase LiFE 6:00-10:00]. While students shared their predictions, she recorded the ideas on the board, creating a visual record to return to later in the discussion. When several students described needing heat or sunlight for water to move from the inside of the container to the outside she connected students' ideas and underlined the words "heat" and "moved through the container". When students were sharing their initial ideas, Ms. Chase refrained from evaluating their responses and let alternative ideas persist, seeming to internalize the advice the teacher educator gave her during her peer teaching enactment.

Similar to her peer teaching lesson, Ms. Chase spent several minutes reviewing the investigation procedure with her students. Again, using an authoritative voice and teacher monologue, Ms. Chase did not check for student understanding of the investigation procedure. Following the procedural reminders, she allowed students to gather the materials and begin carrying out the investigation. Once all students had their materials, Ms. Chase began circulating around the room, monitoring students as they were carrying out the investigation [Chase LiFE 26:00-38:00]. While she circulated, she asked her students open-ended questions to get them to share their ideas about what they were noticing within their groups. She also asked them questions to get them to start thinking about why water droplets were forming on the outside of the cold water can and not on the outside of the room temperature can. By asking students questions as they collected data, she likely supported her students to be more systematic in their data collection and to be analyzing their data in their small groups.

After students had cleaned up their investigation materials, Ms. Chase invited students back to the carpet for the investigation-based discussion. She initiated the discussion by asking students to share their observations of what they noticed. Students began to share observations of all three cans (clear ice water, red ice water, and room temperature water) at the same time. During this segment, students seemed to have difficulty comparing observations and noticing important patterns in their data [Chase LiFE 40:00-42:00].

Perhaps noticing that students were sharing their observations in an unsystematic way, Ms. Chase paused the discussion and, using authoritative voice, briefly shifted into a teacher monologue to explain to her students the importance of being specific when describing their observations. At the end of the monologue Ms. Chase asked her students to share their observations of each can separately. This shift between authoritative and dialogic talk seemed to help Ms. Chase refocus the discussion by reminding her students to be more specific about their observations.

In contrast to her peer teaching enactment, Ms. Chase did not use a representation to help students organize their observations. She also did not write the observations on the board. After students shared observations, Ms. Chase asked students why all of the cold water cans had water droplets on the outside, focusing students' attention back to the investigation question [Chase LiFE 46:00]. When a student made the claim that the water came from inside the can, Ms. Chase pushed back, asking her about the color of the water on the outside of the can. A second student responded that the water was clear and the water on the outside couldn't have come from inside the can. Ms. Chase then asked students who agreed and disagreed with each claim facilitating students to engage in argumentation [Chase LiFE 54:00-58:00]. Most of the students became convinced that because the water was not red it was not coming through the can and had to be coming from the air instead. A student stated she still thought the water traveled through the can, and at the end of the lesson, Ms. Chase attempted to provide her with another example of water droplets forming on the outside of her sealed water bottle. For the majority of the investigation-based discussion, Ms. Chase used a dialogic voice and allowed her students' ideas to guide the discussion.

Missed Opportunities: Limiting Opportunities in Peer Teaching and Lack of Representation in Field

In her peer teaching lesson, Ms. Chase's use of a vague question in her Engage element likely led to students sharing initial ideas that were not directly focused on the phenomenon they would be observing. This likely led to having to use an authoritative voice during much of her Engage element to try to push the conversation in a productive direction. Once she revised her investigation question in the Experience element, she was able to elicit students' initial ideas on the concepts of heat energy transfer.

In her LiFE lesson, Ms. Chase's lack of use of a representation likely made it more difficult for students to see patterns in their data. Students may have been able to notice that the water droplets only formed on the outside of the cold water can and may have failed to notice that the water droplets were not red on the outside of the dyed water can. Had Ms. Chase recorded these observations on the board for students, marking key pieces of data, students may have been better supported to use those pieces of data as evidence for their claim that the water on the outside of the can must have been coming from the air. Students also may have been able to notice that droplets only formed when there was a difference in temperature between the water in the can and the temperature in the room.

Strengths and Successes: Allowing Alternative Ideas to Persist, Questioning

Similar to Ms. Andrews and Ms. Lawrence, Ms. Chase's frequent use of open-ended questions allowed her to elicit students' initial ideas and then challenge and extend those ideas throughout the lesson, providing students opportunities to express their understanding of the scientific phenomena they were observing. Like Ms. Andrews and Ms. Lawrence, Ms. Chase's use of a representation during her peer teaching lesson seemed to support her students to analyze their data and construct an evidence-based claim. In her LiFE lesson, Ms. Chase's continuous monitoring of student understanding throughout her lesson through eliciting and reminding students of their initial ideas, along checking in with each group of students while they were gathering data, seemed to allow her to press for justification of those ideas during the investigation-based discussion.

Similar to her peer teaching lesson, in her lesson in the field, she also posed a general question about how the states of matter changed, but then followed the general question with a question directly tied to the investigation students would be completing. This allowed students to make predictions about the investigation. By eliciting students' ideas about the phenomena, Ms. Chase became aware of students' alternative ideas of the process of condensation. Because she had a strong understanding of the alternative ideas for the lesson, Ms. Chase was able to allow those ideas to persist as they arose and come back to those ideas later, challenging the idea with evidence that contradicted the alternative idea and fostering argumentation.

Ms. Kramer

Ms. Kramer's engagement in the four synergistic productive teaching practices varied in her lesson enactments. Like Ms. Andrews, Ms. Lawrence, and Ms. Chase, Ms. Kramer used open-ended questioning throughout her lessons. However, the use of open-ended questions in her peer teaching lesson was more sporadic than in her LiFE lesson. In her peer teaching lesson, she also struggled to make connections between students' ideas and the disciplinary core idea. In her LiFE lesson, however, she used a representation to keep track of students' ideas throughout the investigation and a scientific text to help students make connections between student observations and the bigger scientific ideas.

Productive Teaching Practice: Peer Teaching

Figure 7-8 provides evidence of the time points during which Ms. Andrews engaged in each of the productive teaching practices.

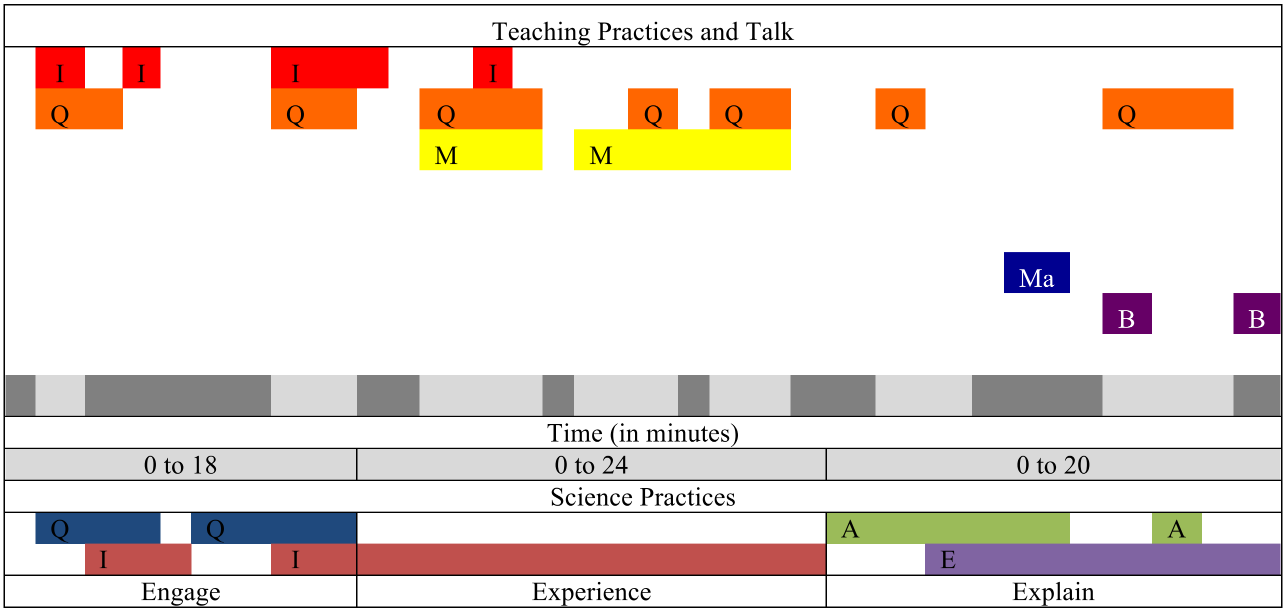

Figure 7-8: Ms. Kramer's Peer Teaching Enactment

For the majority of her Engage element Ms. Kramer used authoritative voice asking her students closed questions about the functions of the parts of the plant. The questions she posed had a single correct answer, and she often evaluated students' responses immediately after they were given. For example Ms. Kramer asked her students about the function of the roots. One student responded with, "They bring water into the plant". Ms. Kramer told the student she was correct and moved on to ask about other parts of the plant. Then, Ms. Kramer briefly allowed students to talk to each other about their initial ideas of the function of the stem before shifting into a description of what students would be doing with the celery [Kramer Peer Teaching Engage 2:00-14:00]. After she had explained to students they would be placing celery in clear and colored water and making observation over three days, she asked them to observe a piece of limp and stiff celery. Students passed the celery stems around the table commenting that the celery was mushy and floppy.

Similar to Ms. Zabel, Ms. Kramer then posed a series of questions that her students struggled to answer [14:00]. At that point, likely noticing the students' confusion and difficulty in answering Ms. Kramer's questions, the teacher educator paused Ms. Kramer and asked her to think about what her investigation question was. Ms. Kramer commented that she was unsure what the investigation question should be, and together they decided her investigation question was, "Why is this piece of celery limp and this piece of celery stiff?". Ms. Kramer then worked to elicit students' initial ideas about the investigation questions supporting them to make predictions about what was causing the differences in the celery.

At the beginning of the Experience element, Ms. Kramer told her peer teaching group that she had revised her investigation question, and it was now "What happens to limp celery when you place it in clear and colored water for three days?". She began her Experience element by reminding her students that they were using the red water only to be able to see what happened to the water over time [Kramer Peer Teaching Experience 0:00-4:00]. Then, supporting students to carry out the investigation, she prompted students to draw observations of the celery stems on the first day. As students were drawing their observations, Ms. Kramer walked around monitoring students' work and asking student pairs questions about their drawings [Kramer Peer Teaching Experience 4:00-10:00]. Like many of the other focal interns, use of the open-ended questioning while students were making observations supported the students to share their ideas and listen to one another. Ms. Kramer also encouraged her student to be more systematic and accurate when drawing their observations. Ms. Kramer used similar moves when supporting her students to draw their observations of both the whole celery and cross-sections on the third day [Kramer Peer Teaching Experience 12:00-22:00]. Throughout

Ms. Kramer's enactment of her Experience element students were able to engage in the scientific practice of carrying out an investigation.

Ms. Kramer initiated the investigation-based discussion in the Explain element by reminding students of what they had done in the Experience element. Rather than eliciting students' observations first, similar to Ms. Zabel, Ms. Kramer quickly asked students to begin evaluating the similarities and differences in their data [Kramer Peer Teaching Explain 2:00-6:00]. Students seemed to struggle to come up with the patterns that could serve as evidence supporting their answer to the investigation question. Ms. Kramer then began using authoritative voice to mark the key differences between how celery stems looked on day one and day three [Kramer Peer Teaching Explain 8:00-12:00]. Ms. Kramer described the celery as green and limp on day one and red and stiff on day three stating that was the claim that answered the investigation question.

After stating the claim Ms. Kramer directed students to look specifically at their observations of the cross section asking them what they noticed when they peeled the celery apart. One student exclaimed, "The tubes!" and continued to describe how the water moved up the tubes to the leaves making the celery leaves red. Several other students agreed and offered additional thoughts describing how the celery turned stiff and red [Kramer Peer Teaching Explain 12:00-18:00]. Again, by using the open-end questioning and a dialogic voice, Ms. Kramer was able to engage all of the students in the intellectual work of constructing an explanation.

Productive Teaching Practices: LiFE

Figure 7-9 provides evidence of the time points during which Ms. Kramer engaged in each of the productive teaching practices

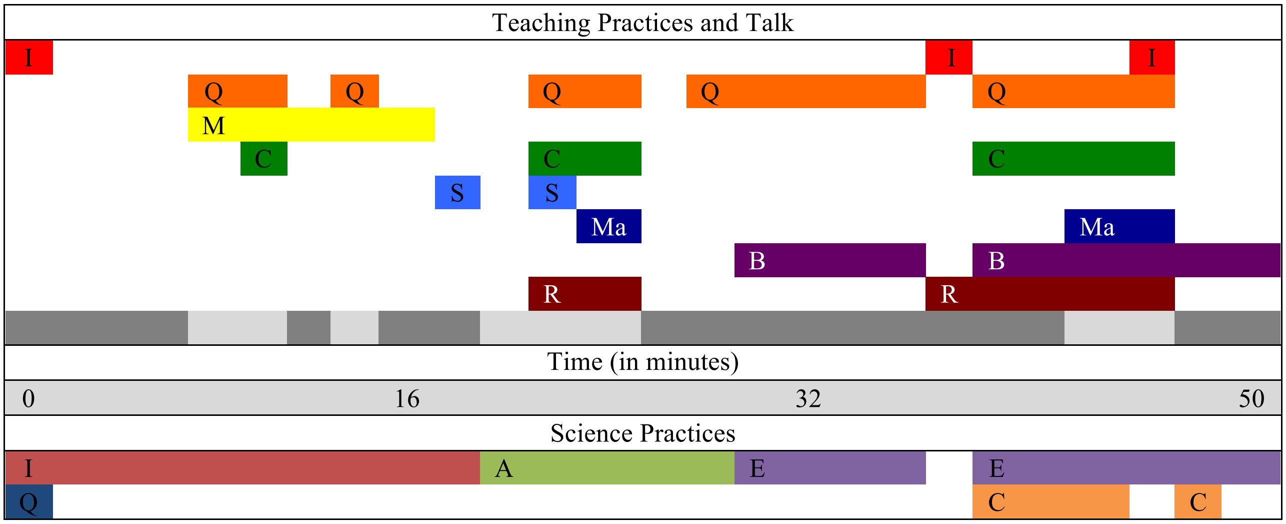

Figure 7-9: Ms. Kramer's LiFE Enactment

At the start of her LiFE lesson Ms. Kramer reminded her students of the initial ideas they had shared about how fish breathe and move[13]. Continuing to use authoritative voice, Ms. Kramer described what students would be doing during the investigation [Kramer LiFE 2:00-6:00]. Students moved to their group work tables and began making observations of the fish. Similar to her peer teaching enactment, while students were making their observations, Ms. Kramer circulated from table to table, asking students to describe what they were noticing and redirecting students to draw exactly what they were observing [Kramer LiFE 10:00-18:00]. By encouraging students to be more systematic and accurate when drawing their observations, Ms. Kramer supported students in carrying out the investigation. At several of the tables, Ms. Kramer allowed more than one student to respond to her questions encouraging students to share their ideas and listen to one another. However, with two tables of students the conversations followed an initiate-respond-evaluate pattern [Kramer LiFE 16:00-18:00]. In these

[13] Ms. Kramer had elicited students' initial ideas the day before, but researchers were unable to video record this part of the lesson.

conversations, Ms. Kramer shifted from asking students what they were observing to asking them how fish breathe, positively reinforcing students when they had an accurate understanding.

After the students had finished their observations of the fish, Ms. Kramer asked her students to gather on the carpet. Allowing a brief amount of time for students to discuss their observations, she asked each student to turn to a partner and share what he or she had observed. After students had a few moments to share, Ms. Kramer elicited observations from five students [Kramer LiFE 20:00-24:00]. Ms. Kramer recorded these observations on a representation that also had a record of students' initial ideas. One student described that she had observed the fish mouth open and the gills open shortly after. Perhaps noticing the importance of the student's idea, Ms. Kramer hushed the class and asked the student to repeat her contribution very loudly so all students could hear her. Ms. Kramer then revoiced the contribution and underlined the word "gills" on the representation [Kramer LiFE 22:00]. Rather than helping students to see patterns in their data, Ms. Kramer's representation seemed to support students to compare their claims with their initial predictions. This short exchange at the end of the first day of the lesson was the only time students were asked about their observations.

The following day, Ms. Kramer continued to facilitate her investigation-based discussion. During the first part of the discussion, Ms. Kramer used authoritative voice to support students to label their observational drawings of the fish [Kramer LiFE 30:00-36:00]. Ms. Kramer used closed questions that had a single correct answer until all parts of the fish were labeled. For example, Ms. Kramer pointed to the gills on the diagram and asked students to name the part. One student responded with "That is one of the gills". Ms. Kramer responded the student was correct and labeled the diagram. After the parts of the fish were labeled, Ms. Kramer asked her students to explain the function of each part of the fish. Despite her use of open-ended questions, this discussion followed the initiate-respond- evaluate pattern. Ms. Kramer often called on a single student to respond to her question and then evaluated the student's response before moving on to the next part of the fish.

Moving the students back to the carpet, Ms. Kramer explained they were going to read a book about fish to determine if the way her students were thinking about the parts of the fish matched how scientists talk about the parts of the fish [Kramer LiFE 36:00-38:00]. Although the students had yet to construct an evidence-based claim in response to the investigation question, "how do fish move and breathe?" comparing their thoughts to a scientific text provided students with an opportunity to obtain scientific information. As she was reading the text, Ms. Kramer asked students to compare the text to the class's initial ideas about how fish move and breathe and the observations they had recorded the day before. When reading the section of the text that pertained to how fish breathe [Kramer LiFE 42:00-46:00], Ms. Kramer used the representation to explicitly point the students back to their initial ideas and observations connecting to how fish breathe.

Ms. Kramer: So this next page says how do fish breathe. I want you to take a look at our list here. We said that fish need water to breathe oxygen. They breathe water in through their gills and blow bubbles out of their mouth. And fish need to come out of the water for air. Do we still agree with all three things here? What about this? Fish need water to breathe. Do we agree?

Student 1: Yeah.

Ms. Kramer: They breathe water in through their gills and blow bubbles out of their mouth. Do we still agree with that? How about fish need to come out of the water to breathe.

Student 2: No.

Student 3: Some fish need to do that.

Ms. Kramer: So we have no and some fish. I'm going to circle this one, and we're going to see if the scientists observed the same things we observed.

(Ms. Kramer reads section of the book that explains fish get their oxygen from the water)

Ms. Kramer: So do fish get their oxygen from the water or from the air out of the water?

Students: From the water.

Several students then commented on how they thought the fish used their mouths and gills to get oxygen from the water. Although Ms. Kramer used authoritative voice for the majority of the investigation-based discussion, this exchange provided students an opportunity to work together to construct a claim about how fish breathe. Ms. Kramer, however, did not prompt students to use evidence from their observations to support their claims, rather students used evidence from the scientific text.

Missed Opportunities: Limited Analysis and Discussion Largely I-R-E

In her peer teaching lesson, Ms. Kramer used open-ended questions inconsistently. Additionally, several of the questions she posed were confusing and difficult for her students to answer. When her students struggled to answer her questions, Ms. Kramer shifted into authoritative voice providing students with the claim to answer the investigation question.

Though her use of open-ended questions was more consistent in her LiFE lesson, Ms. Kramer made several pedagogical moves that limited students' opportunities to engage in the intellectual work of analyzing data and constructing evidence-based claims. First, Ms. Kramer spent little class time eliciting students' observations of the fish. This was either due to Ms. Kramer running out of time on the first day or Ms. Kramer making assumptions that all students had noticed the fish mouth opening slightly before the gills. Although she did draw attention to the student who contributed the observation of the gills, she did not explicitly remind students of that observation before labeling the fish on the second day. Then, instead of allowing students time to discuss how they thought fish moved and breathed, Ms. Kramer used an initiate-respond-evaluate pattern asking single students to describe how fish used their body parts. She then moved quickly to reading the scientific text. This was a missed opportunity for Ms. Kramer to allow her students to construct a claim based on their observational data.

Strengths and successes: Questioning while Monitoring, Use of a Representation

Despite her struggles toward the end of her lessons to use clear questions and dialogic voice to allow students to contribute to the investigation-based discussion, Ms. Kramer's use of open-ended questions while students carried out the investigation provided students opportunities to share their ideas about the phenomena. In both her lessons, while monitoring, Ms. Kramer also encouraged her students to be more systematic and accurate when drawing their observations, supporting her students to carry out their investigation of the phenomena.

Additionally during her LiFE lesson enactment, Ms. Kramer's use of a representation to record students' ideas likely helped students to construct a scientific claim. Although the representation did not seem to help students analyze their data, it likely helped to remind students of their initial ideas about how fish move and breathe. By recording students' initial ideas and then asking them to re-evaluate those ideas while listening to the scientific text, students may have been able to evaluate how their claim had changed based on their observations and the information in the text.

Ms. Zabel

Like Ms. Kramer, Ms. Zabel's engagement in the four synergistic productive teaching practices varied across her lesson enactments, and in comparison to other focal interns, her engagement in the four practices was the most infrequent. Like the other focal interns, Ms. Zabel elicited students' initial ideas about the scientific phenomenon during both of her lesson enactments. She also used open-ended questions to extend and challenge her students' thinking. However, her use of open-ended questions was much sparser than all of the other focal interns, and often her questions were confusing. Ms. Zabel also did not use a representation in either of her lesson enactments, and did not frequently connect students' ideas.

Productive Teaching Practice: Peer Teaching

Figure 7-10 provides evidence of the time points during which Ms. Zabel engaged in each of the productive teaching practices.

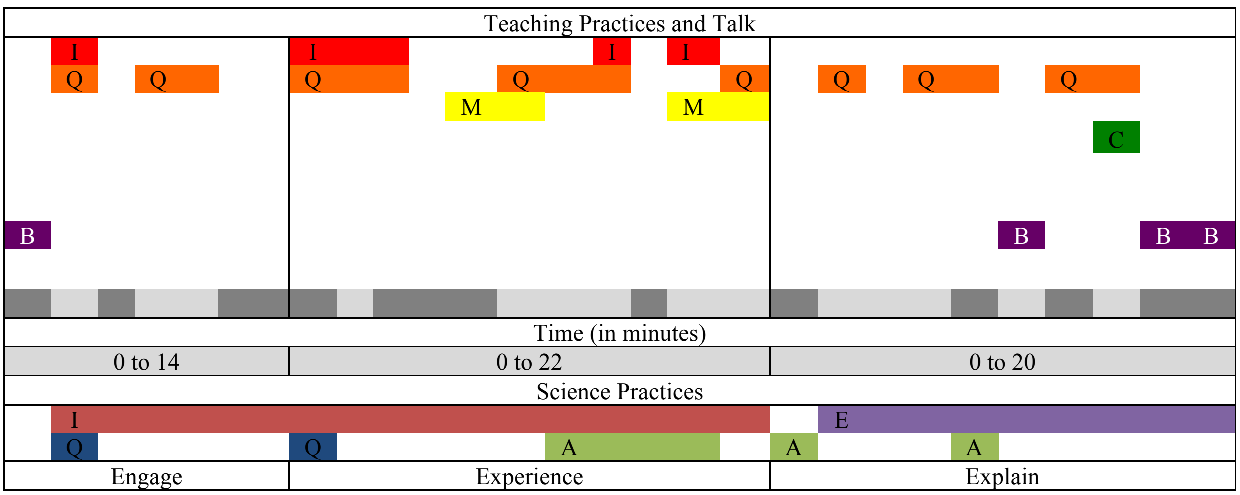

Figure 7-10: Ms. Zabel's Peer Teaching Enactment

Much like the other interns teaching the stems lesson, Ms. Zabel began her peer teaching lesson by asking her students questions about part of the plant they had already knew. Following this interaction, she asked her students to consider the function of the stem. To do so, she used several open-ended questions and elicited responses from all of the students within the peer-teaching group. When one student offered that she thought the wilted celery looked sad, Ms. Zabel took the opportunity to shift back to authoritative voice to help students not to anthropomorphize the celery by assigning it human emotions [Zabel Peer Teaching Engage 4:00-6:00]. Students were given the opportunity to observe both the firm and wilted celery while Ms.

Zabel questioned them about what they were noticing and how the stems were alike and different. Toward the end of her Engage element, Ms. Zabel began to explain to the students that they would be placing celery into water, one of which was dyed with red food coloring [Zabel Peer Teaching Engage 10:00-14:00]. During this explanation she shifted back into authoritative voice and became confused about the purpose of using the water without food coloring.

During her Experience element of the peer teaching lesson, Ms. Zabel used open-ended questions to elicit students' predictions about what would happen to the celery when placed in water and water with red food coloring using open-ended questions. She continued to ask students questions but did not allow any time for the students to respond before allowing them to begin to draw their observations of the celery on the first day (Zabel Peer Teaching Experience 6:00-8:00]. While students were drawing she monitored their work and then began to ask them questions about what they were noticing, providing students opportunities to articulate their ideas and listen to each other while carrying out the investigation [Zabel Peer Teaching Experience 10:00-14:00]. After students made their observations of the celery on the third day, Ms. Zabel encouraged students to compare whether or not their predictions "came true." During the time when students were checking their predictions, a student asked Ms. Zabel about the red water, and Ms. Zabel again became confused about the purpose of the red water versus the regular water[14] [Zabel Peer Teaching Experience 18:00]. Visually still seeming confused, Ms. Zabel then prompted her students to draw the cross sections of the celery.

At the start of her Explain element, rather than allowing her students time to compare and contrast their observations, Ms. Zabel immediately asked her students why they thought the

[14] As a reminder, the clear water without food coloring served as a control for the investigation, helping the students to see that it was the water that was making the celery firmer rather than the food coloring.

leaves of the celery in the red water were red. Ms. Zabel also did not use a representation to help the students begin to see patterns in their observational data.   When beginning to elicit students' initial explanations about why the celery turned red, Ms. Zabel stumbled over how to explain to the students that the red food coloring was there to allow the students to see the water (Zabel Peer Teaching Explain 6:00-8:00].   For the remainder of the lesson, Ms. Zabel asked her students open-ended questions but often did not allow the students time to answer the questions or the questions seemed unclear. This lack of wait time between questions and decreased clarity made it difficult for her to fully engage all of her students in the investigation-based discussion. At the end of the lesson, Ms. Zabel made connections between what students were seeing in the celery and the functions of the stem. However, she did so using only authoritative voice, explicitly stating the explanation for her students rather than allowing the students to construct it based on evidence from their observations [Zabel Peer Teaching Explain 16:00-20:00].

Productive Teaching Practice: LiFE

Figure 7-11 provides evidence of the time points during which Ms. Zabel engaged in each of the productive teaching practices.

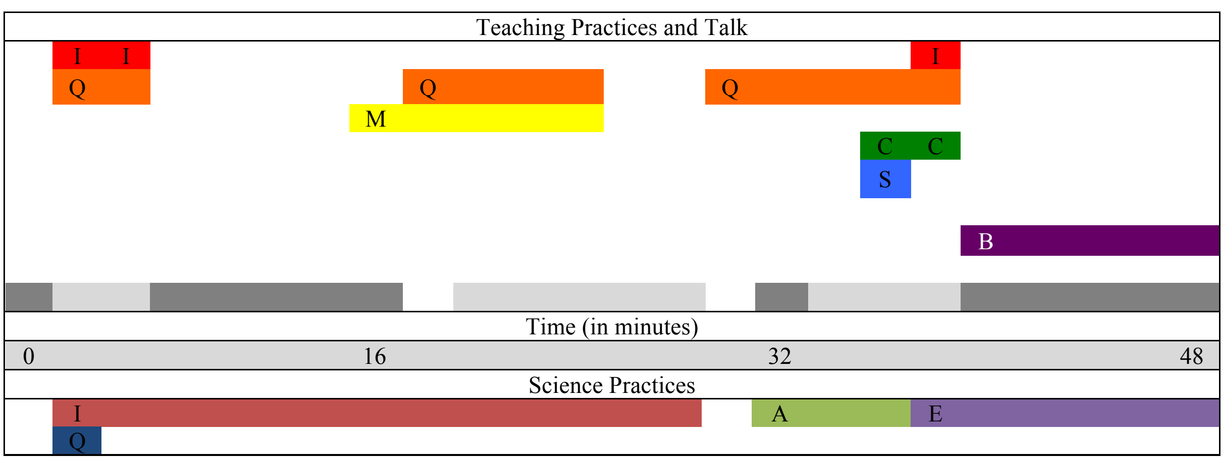

Figure 7-11: Ms. Zabel's LiFE Enactment

For her LiFE lesson, Ms. Zabel again used open-ended questioning to elicit students' ideas about what would happen to the black line and paper when they placed it into a cup of water [Zabel LiFE 2:00-6:00]. In doing so, she was able to get several students engaged in the whole-class discussion at the beginning of the lesson. Rather than evaluating their predictions, she acknowledged the contributions and allowed other students to volunteer ideas. Following eliciting predictions, Ms. Zabel, using authoritative voice, explained the investigation procedure to her students [Zabel Life 6:00-14:00]. Following this explanation of the investigation procedure, Ms. Zabel paired the students together and distributed materials.

While students were carrying out the investigation, Ms. Zabel walked around the classroom from table to table asking students what they were noticing and prompting students to draw exactly what they saw [Zabel LiFE 16:00-24:00]. At several of the tables of students working together, Ms. Zabel asked the same sets of open-ended questions including "What are you noticing?" and "Where do you think the black line went?" to get students to begin thinking about their explanation for the phenomena they were observing. In doing so, she was able to redirect students back to the purpose of the investigation (determining that black is a mixture of all colors).

After directing the students to clean up their materials and return to the carpet, she allowed students to turn and talk to a partner. Students took almost two minutes to share the observations they made when carrying out the investigation. This allowed students to share their ideas with others and compare and contrast the similarities and differences in their observations. After this paired discussion, rather than asking students to share their observations and help students to see patterns in what they saw, Ms. Zabel asked students to comment on what they thought happened to the black line. Students seemed to struggle to answer the question Ms.

Zabel had posed. Perhaps noticing this confusion, Ms. Zabel called on a student she had spoken to while monitoring the small group work during the investigation. Ms. Zabel selected this student to share her idea that the black line turned into all the colors because black is actually a mixture of colors. Once the student shared her idea, Ms. Zabel asked other students what they thought about black being a mixture of all the colors and if they thought the black line had disappeared. Allowing little time for her students to respond, Ms. Zabel confirmed that the black ink was a mixture of other colors of ink, and when placed in the water, the black ink separated into different colored bands on the paper. Then, in a teacher monologue, Ms. Zabel provided additional examples of mixtures that look different from their starting ingredients (e.g. brownies and cookies).

Missed Opportunities: Question Clarity, Limited Analysis, and Lack of Representation

In both her lessons, Ms. Zabel did not frequently engage in the four synergistic productive teaching practices for facilitating investigation-based discussions. Similar to her peer teaching lesson, at the start of the investigation-based discussion Ms. Zabel asked open-ended questions. The questions, however, were often confusing, and students had difficulty answering them. Students also were not provided a representation to organize and compare their data and were given limited time to analyze their data before having to volunteer claims. Use of a representation may have reminded Ms. Zabel to allow time for students to analyze the data they collected. By using a representation to highlight similarities and differences in their observations, students would likely have better supported to find patterns in their observations and noticed what changed over the course of the investigation. Further, Ms. Zabel may have been able to draw students' attention to the black line being present in the before drawings and the colored bands being present in the after drawings. Then with the focused attention on the changes, student may have drawn the conclusion that black was a mixture of the colors themselves. When she was unable to move the discussion forward, she selected a student who she knew had the scientifically accurate understanding of the phenomena being observed. Then, without providing space for students to agree or disagree with the claim, Ms. Zabel immediately confirmed that black was a mixture of all the colors and provided students with similar examples of the phenomena.

Strengths and Successes: Questioning while Monitoring

Like Ms. Kramer, despite Ms. Zabel's struggles to use clear questions and dialogic voice to allow students to contribute to the investigation-based discussion, Ms. Zabel's use of open-ended questions while students carried out the investigation provided students opportunities to share their ideas about the phenomena. Similar to Ms. Kramer, Ms. Zabel encouraged her students to be more systematic and accurate when drawing their observations, supporting her students to carry out their investigation of the phenomena, and probing their understanding of the phenomena while they were collecting data.

Ms. Sawyer

Like Ms. Andrews, Ms. Sawyer engaged in all four synergistic productive practices for facilitating investigation-based discussions during both lesson enactments. Like all other focal interns, Ms. Sawyer elicited students' initial ideas during both her peer teaching and LiFE lesson enactments. She also frequently used open-ended questions to probe, extend, and challenge students' thinking throughout the lesson enactments. She also made connections among students' ideas and the disciplinary core ideas in both lessons, but engaged in this practice less frequently in her LiFE lesson. In both her lesson enactments, Ms. Sawyer used a representation to help students organize their observations supporting them to notice common patterns. In addition to the four synergistic practices, in her peer teaching lesson, Ms. Sawyer engaged in sophisticated monitoring practices, using a *monitoring tool* to remind her to probe students' thinking and record students' ideas while they were collecting data.

Productive Teaching Practice: Peer Teaching

Figure 7-12 provides evidence of the time points during which Ms. Sawyer engaged in each of the productive teaching practices.

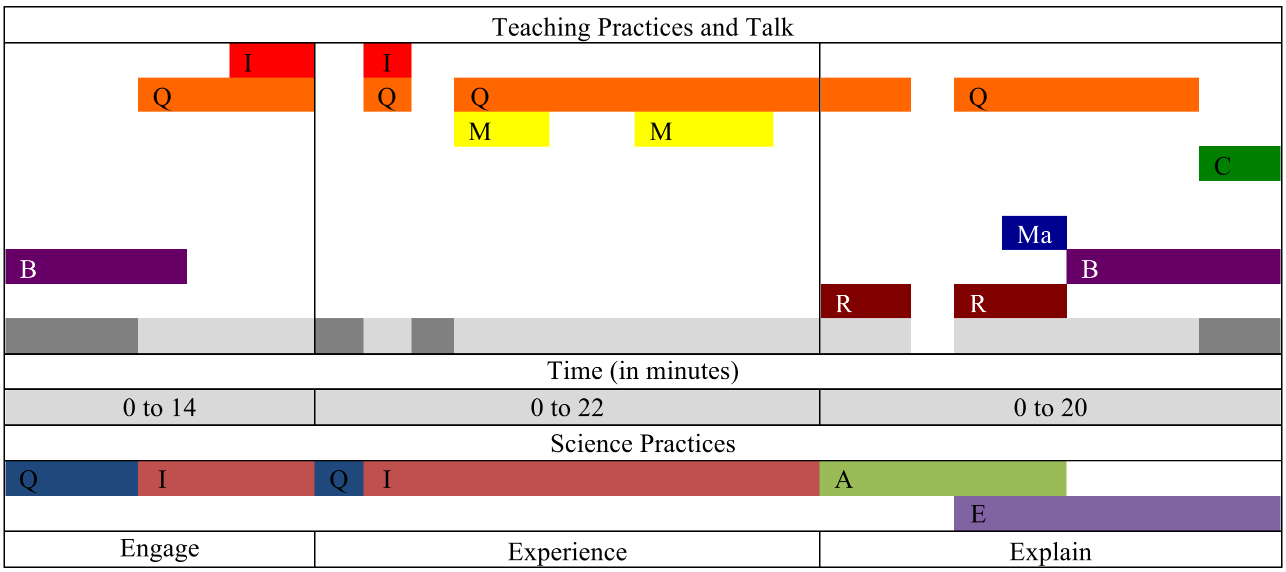

Figure 7-12: Ms. Sawyer's Peer Teaching Enactment

Like Ms. Zabel and Ms. Kramer, Ms. Sawyer started her peer-teaching lesson by reminding students of parts of the plants with which they were already familiar with [Sawyer Peer Teaching Engage 0:00-6:00]. She also asked the students to consider how and why apples were wet inside to get the students to start thinking about the importance of moving water throughout a plant's parts. Ms. Sawyer transitioned her students to focus on the celery investigation by posing the question "What do you think stems do for a plant?" [Sawyer Peer Teaching Engage 6:00].

After posing this question for her students, Ms. Sawyer elicited students' initial ideas about the function of a stem [Sawyer Peer Teaching Engage 8:00-14:00]. Each student in the peer teaching group volunteered her ideas, and Ms. Sawyer pressed each student to provide reasoning for her ideas. Like several other focal interns, this allowed Ms. Sawyer's students to engage in making scientific predictions. However, these initial ideas were not focused explicitly on the investigation question for the lesson because Ms. Sawyer did not provide her students an opportunity to observe the limp and still celery in her Engage element.

In her Experience element, Ms. Sawyer focused her students' attention on the investigation by explicitly posing the investigation question "What will happen to celery placed in clear and colored water over three days?" Using open-ended questions she asked students to make predictions about what they thought would happen to the celery [Sawyer Peer Teaching Experience 2:00-4:00]. Similar to her use of teaching moves in the Engage element, Ms. Sawyer pressed her students to provide justification for their predictions.

Then, using authoritative voice, Ms. Sawyer gave students a brief explanation of why they would be using red food coloring to help them see what happened to the water, and then she allowed students to take their time making observations of the celery stems on day one of the experiment [Sawyer Peer Teaching Experience 4:00-.10:00]. While students were making observations, Ms. Sawyer circulated to all students, monitoring their work and making notes to herself about their observation drawings on her *monitoring tool*. While circulating, she posed open-ended questions to her students prompting them to talk with each other about what they were seeing and encouraging her students to make clear, accurate, and labeled observation drawings. Her questioning seemed to support her students to engage in carrying out their investigation of the celery. In addition, several of her questions supported students to begin to think about what had changed in the celery over three days setting her students up to analyze their data in the Explain element. For example, she asked each of her students "What is different in this drawing compared to the one you did before?" prompting students to notice that the celery had become firmer and the leaves of the celery in the red water had become red.

In her Explain element, Ms. Sawyer was the only focal intern teaching the stems lesson to utilize a representation to support her students to notice patterns in their observational data. The representation helped to organize students' data by asking them to comment on a single piece of celery at a time (e.g., celery in the red water on day 1 versus celery in the clear water on day 1).

At the start of the Explain element, Ms. Sawyer used the representation in combination with open-ended questions to elicit students' observations of the celery on the first day of the investigation [Sawyer Peer Teaching Explain 0:00-4:00]. Once students volunteered their observations of the celery on the first day, Ms. Sawyer elicited students' observations of the celery after three days in the clear and colored water. After students provided observations of the whole celery stalks, Ms. Sawyer pressed her students to describe what they had noticed in the cross sections. By systematically asking for students to describe one set of observations at a time and recording those observations in a representation on the board, Ms. Sawyer better supported students to begin analyzing the data.

Once all the observations were recorded, Ms. Sawyer directed her students' attention back to the investigation question, asking her students to consider what happened to the celery over three days [Sawyer Peer Teaching 6:00-10:00]. When her students began to list characteristics of the clear and colored water celery that were the same on day three, Ms. Sawyer commented that her students were noticing patterns in their data, and told students that she was going to circle things they noticed that were the same in the clear and colored water celery stems [Sawyer Peer Teaching Explain 8:00-10:00]. By circling similarities students were noticing, Ms. Sawyer effectively marked important pieces of data for her students. Students described both celery stems as being firm and wet. When one student volunteered the idea that she thought the water was what was causing the celery to become firm and wet, Ms. Sawyer used open-ended question to press the student to explain what evidence she could use to support her scientific claim. The other two students in the group also volunteered evidence to support the first student's claim stating the celery became firm and wet in both type of water. Through the use of her questions, Ms. Sawyer pushed her students to do the intellectual work of constructing an explanation. At the end of the Explain element, Ms. Sawyer asked her students to apply what they had learned about the function of the stem by reposing her initial question about how and why an apple is wet inside [Sawyer Peer Teaching Explain 16:00-20:00].

Productive Teaching Practice: LiFE

Figure 7-13 provides evidence of the time points during which Ms. Sawyer engaged in each of the productive teaching practices.

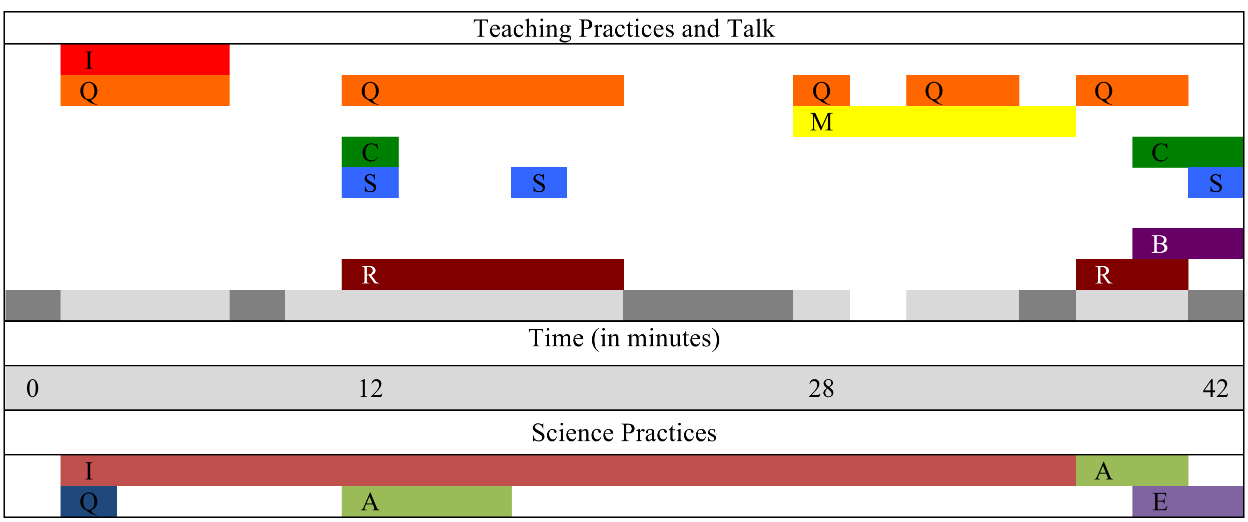

Figure 7-13: Ms. Sawyer's LiFE Enactment

Similar to her peer teaching lesson, Ms. Sawyer frequently used open-ended questioning, dialogic voice, and made use of a representation to organize students' data during her LiFE lesson. At the start of her lesson, she used open-ended questions to elicit students' ideas to the investigation question "What makes sound?" [Sawyer LiFE 2:00-4:00]. This question seemed to be too general for students because students volunteered ideas of objects (e.g., cars) that make sounds rather than describing how the sound itself was made. Ms. Sawyer struggled to rephrase her question so she could elicit initial ideas of how sounds were made.

Ms. Sawyer briefly described the investigation to students and explained they would be investigating how three of the objects made sound together as a whole group [Sawyer LiFE 8:00-10:00]. Starting with the ruler, Ms. Sawyer demonstrated how to safely use the ruler to make sound. Then, she elicited students' observations of the ruler as it was making sound. Multiple students in the class described their observations of the ruler and Ms. Sawyer recorded those observations in the representation on the board. A similar discussion ensued as students made observations of their lips and throats making sound. After observing these three objects, Ms. Sawyer pressed students to consider how the sound was being made supporting the students to begin to analyze their data before carrying out the rest of the investigation on their own [Sawyer LiFE 12:00-16:00]. During this discussion, one student expressed the idea that sounds were made when something hits something else or when something is moving very quickly [Sawyer LiFE 12:00]. Perhaps noticing the importance of that contribution, Ms. Sawyer rephrased the student's idea saying "Oh, so something was vibrating?". The student agreed, and Ms. Sawyer asked another student to explain the meaning of the word vibrating.

After Ms. Sawyer gave some additional safety reminders, she allowed the students to conduct the rest of the investigation on their own. While students were carrying out the investigation, she circulated around to students' work tables monitoring their work and encouraging students to think about what they were observing [Sawyer LiFE 28:00-36:00]. Like her peer teaching lesson, by using open-ended questions while monitoring, she encouraged students to talk and listen to one another's ideas about what was making the sounds.

After the students completed their investigation, Ms. Sawyer asked them to return to the carpet [Sawyer LiFE 36:00]. She asked students to describe their observations of the additional objects they had investigated and recorded their observations in the representation. She also asked students to describe the item that was vibrating when the sound was made. Despite her use of the representation to organize students' observations, Ms. Sawyer never asked students what was similar in all of their observations. Asking students to notice the similarities may have prompted students to notice the patterns in the data. The pattern of sound only being produced when something was vibrating was implicit, and Ms. Sawyer did not connect the students' observations to the idea one of her students raised earlier in the lesson (noticing the sounds were being made when something was moving). Students also struggled to understand how sound was being made when they couldn't physically see something vibrating (e.g., blowing air across the top of a soda bottle). Because she needed to finish the lesson to move on to social studies, Ms. Sawyer was allowed little time to support students to begin to make sense of their observations and use those observations as evidence for an explanation of how sounds were made.

Missed Opportunities: Broad Investigation Question and Eliciting an Explanation

In her LiFE lesson enactment, Ms. Sawyer's initial question was broad, and she struggled to support students to notice important details in their observations of the objects making sounds. Her use of a representation helped to organize students' contributions, but she struggled to support students to see patterns in the data and make connections to the disciplinary core idea. Because of this, the investigation-based discussion became stalled after students shared their observations, and students were unable to describe that sounds were only being made when something was vibrating. She seemed unable to support students to notice the similarity in all their observations (that the sound was only heard when and object was moving). Ms. Sawyer also left little time to support students to construct an evidence-based claim.

Strengths and Successes: Monitoring, Questioning, and Use of a Representation

Ms. Sawyer's enactment of her peer teaching lesson showed use of productive practices for capitalizing on student contributions beyond what was expected for a novice teacher. For the majority of her lesson, she used dialogic voice and encouraged her students to describe their ideas and listen to one another's contributions. Her careful monitoring of students' ideas during the Experience element likely helped her structure the investigation-based discussion. In the discussion, her use of a representation to organize students' qualitative data helped students to see patterns in their data and use that data as evidence to construct a scientific explanation.

Similarities and Differences Within the Enactments

Focal interns used the productive practices and engage students in science practices in similar ways in both their peer teaching and LiFE lesson enactments. All of the interns' enactments showed strengths of teaching practice. However, missed opportunities persisted despite the use of several of the productive teaching practices for capitalizing on student contributions. Table 7-2 provides a summary of each intern's missed opportunities as well as strengths in the enactments.

Table 7-2: Summary of focal interns' missed opportunities and strengths within lesson enactments

Focal Intern	Missed Opportunities	Strengths and Successes
Andrews	Making assumptions about whole-class understanding in LiFE lesson	Accurate science and questioning throughout both lessons Use of representation in both lessons
Lawrence	Inaccurate science and lack of representation in LiFE lesson	Use of a representation in peer teaching Reminding of initial ideas and use of questioning throughout both lessons
Chase	I-R-E discussions in peer teaching Lack of representation in LiFE lesson	Use of a representation in peer teaching Allowing alternative ideas to persist in both lessons Accurate knowledge of students' likely alternative ideas in LiFE lesson Questioning throughout both lessons
Kramer	Limited time for analysis in LiFE lesson I-R-E discussions in both lessons	Use of a representation in LiFE lesson Questioning while monitoring in both lessons
Zabel	Questions lacked clarity, limited time for analysis, and lack of a representation in both lessons	Questioning while monitoring in both lessons
Sawyer	Broad investigation question, difficulty eliciting explanation, and limited time in LiFE lesson	Sophisticated monitoring during peer teaching Questioning throughout both lessons Use of a representation in both lessons

Interns' engagement in four synergistic productive practices for facilitating investigation-based discussions (considering students' initial ideas, questioning students to elicit, extend, or challenge ideas, making connections across students' ideas and the disciplinary core idea, and using a representation to organize and highlight students' ideas) led to increased opportunities for students to share their ideas and engage in data analysis, argumentation, and explanation construction. Intern engagement in the four practices, however, varied. All six focal interns elicited students' initial ideas about the scientific phenomena and used open-ended questions to probe, extend, and challenge student thinking. However, interns differed in how often they engaged in the practice of questioning. Ms. Andrews, Ms. Lawrence, Ms. Chase, and Ms. Sawyer used open-ended questions throughout both lessons, and use of these open-ended questions frequently led to increased use of dialogic voice and student engagement in data analysis, argumentation, and explanation construction. In addition, in their peer teaching lessons, Ms. Andrews, Ms. Lawrence, Ms. Chase, and Ms. Sawyer also frequently made connections across students' ideas and the disciplinary core idea of the lesson during the investigation-based discussion.

Alternatively, in both lessons, Ms. Kramer and Ms. Zabel often only used open-ended questioning and dialogic voice while monitoring students as they were carrying out the investigation. While use of open-ended questions and dialogic voice offered students opportunities to share their ideas with one another while making observations, limited use of open-ended questioning and dialogic voice in the Explain element of both their lessons limited students' opportunities to analyze data, argue, and construct explanations.

In addition, several interns used representations that supported students to determine patterns or trends in their data and then use those trends as evidence to support their scientific claims. In the peer teaching lesson, Ms. Andrews's, Ms. Lawrence's, Ms. Chase's, and Ms. Sawyer's use of a representation to organize student data supported students to analyze patterns in that data. Similarly, Ms. Andrews's use of a representation in her LiFE enactment served a similar purpose. Although the nature of Ms. Kramer's representation for her LiFE was different (i.e., not intended to support students to analyze their data), it likely helped to remind students of their initial predictions and scientific claims, drawing attention to how ideas may have changed over the course of the investigation.

When considering elements of the enactments beyond the four synergistic teaching practices, Ms. Andrews's and Ms. Chase's knowledge of the scientific content and alternative ideas seemed to allow them to recognize when students contributed both alternative ideas and accurate understanding of scientific phenomenon. Once students had shared their ideas, both Ms. Andrews and Ms. Chase were able to use those contributions in productive ways (i.e., to work toward an accurate explanation, or to foster argumentation), making connections between students' ideas and the disciplinary core idea. In contrast, Ms. Lawrence's inaccurate understandings of the science content in her LiFE lesson seemed to limit students' opportunities to come away from the investigation with an accurate understanding of the phenomenon.

Few of the interns used the teaching practice of selecting specific students to contribute to the investigation-based discussion and few marked key ideas as they arose during the discussions. For the interns that did select specific students to contribute and marked key ideas, the intern engagement in these two teaching practices was very limited (i.e., use of the practice a single time during a 60-minute enactment). Therefore it is difficult to determine how the use or absence of these two teaching practices in the enactments led to strengths in the enactments or missed opportunities or problems of practice.

Conclusion

This chapter described focal interns' use of productive teaching practices for capitalizing on student contributions, intern voice, and opportunities for student engagement in scientific practices in lesson enactments for both the peer teaching and LiFE lesson. The chapter describes both the strengths and successes found in each intern's lesson enactments as well as the problems of practice that persisted despite these strengths. In addition to describing the strengths and problems of practice, the chapter describes the similarities and differences that existed across interns including intern engagement in four synergistic teaching practice that appear to be important for facilitating investigation-based discussions. In the next chapter, I explore how characteristics of each focal intern (e.g., their knowledge and beliefs about science teaching, science content, and science practice) related to tool use and the characteristics of their plans and lesson enactments. Chapter 8 utilizes both the lesson enactment figures for tool use and engagement in teaching practice to provide evidence of tool use, teaching practice, talk, and student engagement in science practice co-occurrence as well as Remillard's participatory relationship framework to depict these relationships.

CHAPTER 8

RELATIONSHIPS AMONG KNOWLEDGE AND BELIEFS, TOOL USE, AND TEACHING PRACTICE

In this chapter, I discuss how interns' knowledge and beliefs about science content and practices and use of tools relate to one another and to characteristics of interns' plans and enactments of investigation-based discussions, addressing Research Question 3. Based on my analysis of focal interns' card sorting activities, beginning of course survey, interviews, lesson plans and enactments, I make the following assertions:

a) The use of tools was related to intern engagement in productive teaching practices for capitalizing on student contributions.

b) Intern characteristics (e.g., content knowledge, beliefs about science teaching, etc.) related to the types of tools interns used to plan and enact their lessons (participatory relationships).

c) For some interns, use of dialogic voice and student engagement in data analysis, argumentation, and explanation construction occurred more frequently when interns used talk moves from the *talk moves tool* and representations to support data analysis. These same interns had at or above threshold knowledge of science content specific to their lesson and threshold knowledge of fostering argumentation.

In this chapter, I adapt and use aspects of Remillard's (2005) participatory relationship framework describing the interaction between teachers and curriculum materials (a specific type of tool) to highlight relationships among each focal intern's characteristics (including her knowledge and beliefs of science content and science practice) and her use of tools and other resources, and intern's plans and enactments of investigation-based discussions. Remillard (2005) argues that teachers' participation with curriculum materials is shaped by the teachers' own resources (e.g., their knowledge and beliefs) and the resources in the curriculum materials (e.g., the materials' characteristics), and that this participation shapes the planned and then – in turn – the enacted curriculum. In this chapter, I apply this theoretical frame to consider interns' characteristics related to tool use (the participatory relationship), and how the participatory relationship shaped planned and enacted lessons. First, I describe interns' beliefs about science teaching and knowledge of how to foster argumentation. Then, looking closely at the lesson enactments, I explore the co-occurrence of each focal intern's use of tools, engagement in teaching practices for investigation-based discussions, use of authoritative versus dialogic voice, and student engagement in science practices. To do so, I combine figures presented in Chapters 5 and 7 for each focal intern's peer teaching and LiFE enactments. Finally, I discuss the similarities and differences across the focal interns.

Beliefs about Science Teaching and Knowledge of Argumentation

Figure 8-1 provides summary statistics of all participants' scores on the beliefs about science teaching survey and Table 8-1 provides a summary of focal interns' scores on both the beliefs about science teaching survey (TBEST[15]) (Smith, Smith, & Banilower, 2014) as well as

[15] The TBEST survey measures beliefs along three factors: learning-theory aligned science instruction, confirmatory science instruction, or all-hands-on all the time science instruction. Learning theory science instruction reflects a constructivist approach. A high score here is preferable. Confirmatory science instruction reflects on an emphasis on students completing investigations to confirm ideas they have been taught. A low score here is preferable.

the questionnaire about the practice of argumentation developed by McNeill and colleagues (2015). Figure 8-1 shows, on average, interns' beliefs about science teaching aligned with current theories on learning, and aligned less with a confirmatory science and all hands-on all the time approach to science teaching. Table 8-1 shows that Ms. Andrews's beliefs about science teaching were strongly aligned with learning theory (i.e., they were more sophisticated compared to the cohort average), whereas Ms. Kramer's and Ms. Zabel's belief about science teaching were less aligned with current learning theories (i.e., they were less sophisticated). Ms. Chase strongly believed science instruction should not follow a confirmatory approach (i.e., her beliefs were more sophisticated than those of her colleagues). Ms. Sawyer held beliefs aligned with the all hands-on all the time approach (a less sophisticated belief), whereas Ms. Lawrence held beliefs that science teaching should not be all hands-on all the time (a more sophisticated belief). Ms. Andrews, Ms. Lawrence, Ms. Kramer, and Ms. Sawyer all had knowledge of how to facilitate argumentation that was similar to the cohort average. Ms. Chase's argumentation questionnaire showed that she had knowledge for facilitating argumentation that was higher than the cohort average; whereas Ms. Zabel's knowledge of how to facilitate argumentation was slightly lower than the cohort average. Overall, then, the focal interns varied in their beliefs and knowledge related to science teaching.

All-hands-on all the time represents an activity-focused stance, without sensemaking. A low score here is preferable.

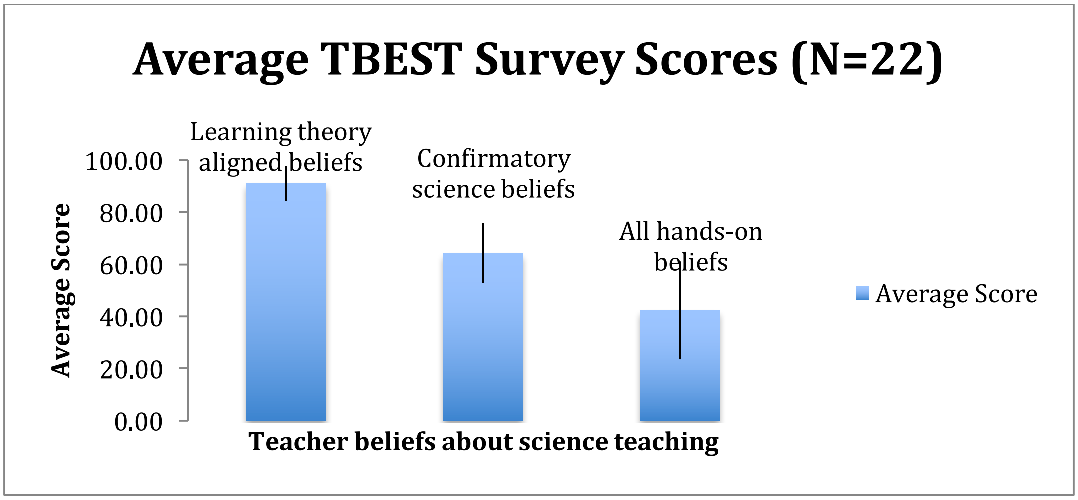

Figure 8-1: Intern Scores on TBEST Survey

Table 8-1: Focal Intern Scores on TBEST Survey and Argumentation Questionnaire

Focal Intern	Learning Theory (Max 100)	Confirmatory Science (Max 100)	All Hands-On (Max 100)	Argumentation Questionnaire (Max 12)
Andrews	100.00 +	59.52	27.78	7
Lawrence	95.45	71.43	22.22 +	5
Chase	89.39	38.10 +	33.33	8 +
Kramer	80.30 -	61.90	38.89	7
Zabel	81.82 -	73.81	44.44	4 -
Sawyer	87.88	71.43	72.22 -	7

+ Signals more positive difference compared to preferable (i.e., a more sophisticated belief);
- signals a negative difference compared to preferable (i.e., a less sophisticated belief).

Ms. Andrews

Figure 8-2 provides an overview of the relationships among Ms. Andrews' characteristics (knowledge and beliefs about science teaching, science content, and science practice), tool use, lesson plans, and lesson enactments. The next sections provide additional detail about each of these relationships.

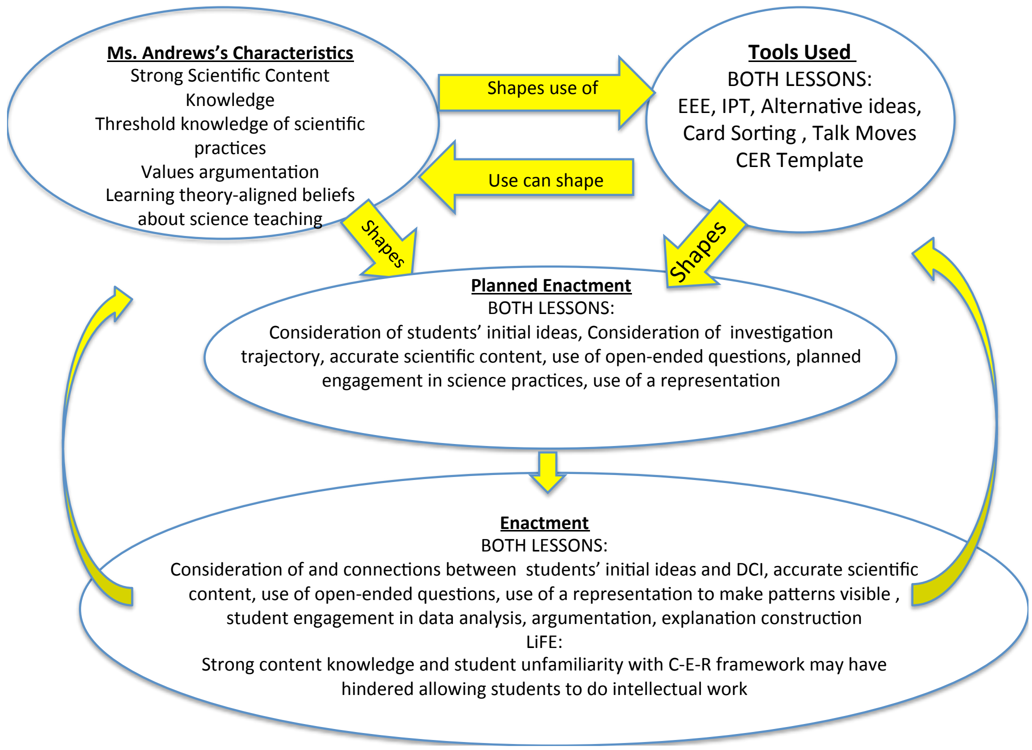

Figure 8-2: Ms. Andrews's participatory relationship

Ms. Andrews's Characteristics

In the survey designed to measure interns' beliefs about science teaching (Smith, Smith, & Banilower, 2014), Ms. Andrews had beliefs aligned with current theories on learning (See Table 8-1), showing sophistication and alignment with the student-centered focus of the science methods course. According to her argumentation questionnaire, Ms. Andrews had moderate understanding of how to foster argumentation among students. Despite her moderate understanding according to the survey, Ms. Andrews seemed to value argumentation in the science classroom. When commenting on how she used the *Argumentation Checklist* to plan her peer teaching lesson she stated, "Arguing is important. I really want to get my kids to think and talk to each other, but I am not really good at that yet… so that was really helpful" [Andrews, Interview 2].

Ms. Andrews also described the methods course as being an influence on how she thought about science teaching. Placing value on student-contributed ideas, she stated, "The methods course was a huge influence. I know it is important to teach kids to reason, talk to each other, make claims, and use the evidence that *they* found to learn something" [Andrews, Interview 1]. Although Ms. Andrews's beliefs about science teaching were aligned with constructivist learning theories prior to the start of the methods course (See Table 8-1), the methods course and associated tools may have further supported development of student-centered constructivist beliefs about science teaching and learning.

Finally, Ms. Andrews's card sorting activity and lesson plans provided evidence of her accurate content knowledge. For example, in her card sort, Ms. Andrews was able to make multiple accurate connections among the ideas of heat energy transfer, energy equilibrium, and the first law of thermodynamics. For both of her lessons she reported using resources (e.g., Khan Academy) to refresh her understanding of the science content and complete her card sorting activity. In both of her lesson plans, there was high evidence of consideration of how the investigation students would be completing connected with the bigger scientific concepts. For example, in her LiFE lesson, Ms. Andrews connected the investigation students would be doing to simulate the spread of disease to the rate of disease spreading being dependent on the virulence of the microbe and the concept of immunity[16]. Strong content knowledge and ability to connect the concepts to bigger scientific ideas likely enabled Ms. Andrews to recognize when a student contributed both accurate scientific ideas as well as alternative ideas.

[16] Ms. Andrews stated she did not introduce these concepts to students, but rather listed them for herself so she could have an idea of how the simulation connected to big picture ideas.

Tool Use and Planned Enactment

Because of her beliefs about science teaching, Ms. Andrews may have been more likely to use tools aligned with those beliefs. For example, she consistently drew upon the *talk moves tool* to plan both her peer teaching and LiFE lessons. By including the open-ended questions from the *talk moves tool* in her *instructional planning template*, Ms. Andrews planned to elicit students' initial ideas and then extend and challenge those ideas throughout the investigation. Using these questions allowed Ms. Andrews to prepare opportunities to engage students in data analysis, argumentation, and explanation construction – three scientific practices that privilege student contributions and press students to do the intellectual work of developing evidence-based claims, a characteristic of science teaching Ms. Andrews said she valued.

Ms. Andrews also used the *claim-evidence-reasoning template* in both of her lesson plans. By using the *C-E-R template* Ms. Andrews may have been better supported to engage her students in explanation construction. By planning to use the *C-E-R template*, Ms. Andrews likely recognized that students would enter into the investigation with prior knowledge of the phenomena. The *C-E-R template* may have helped Ms. Andrews plan to remind her students of the investigation question, support students to construct an explanation, press students to provide multiple pieces of evidence for their explanations, and connect their explanations to reasoning.

Within the Enactments

Like her plans, in both of her lesson enactments, Ms. Andrews used talk moves from the *talk moves tool* and the *claim-evidence reasoning template*. Use of the talk moves from the *talk moves tool* often occurred when she engaged in questioning her students to elicit, extend, or challenge their thinking, and when making connections among multiple students' ideas and the bigger scientific idea of focus. Additionally, Ms. Andrews's use of representations in both enactments seemed to allow her students to analyze data collected during the investigation helping to support students to see patterns in their data. Then, in both enactments, she referred students to the *claim-evidence-reasoning template* to press students to use those patterns as pieces of evidence in their claim-evidence-reasoning statements. Figures 8-3 and 8-4 provide evidence of segments where Ms. Andrews's tool use and engagement in productive teaching practices co-occurred with her use of dialogic or authoritative voice and student engagement in science practices. As a reminder, the legend for these figures is included in Chapter 7 and the colors are referenced in the text that follows.

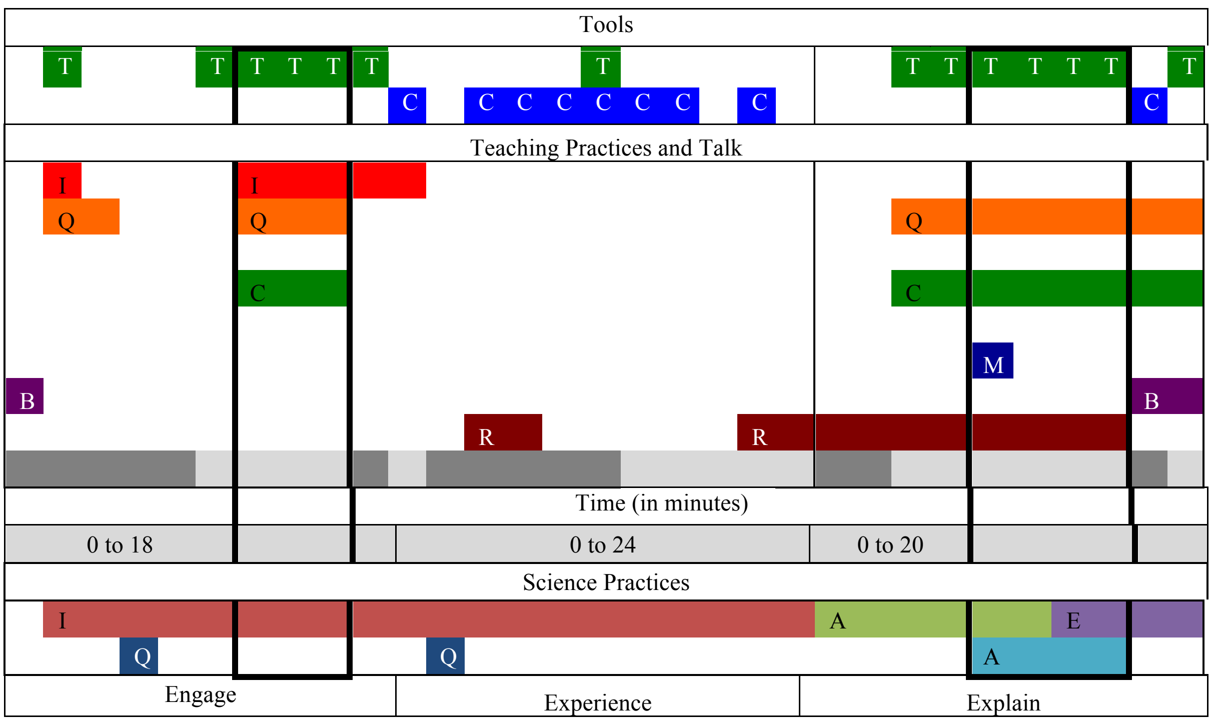

Figure 8-3: Ms. Andrews's peer teaching enactment

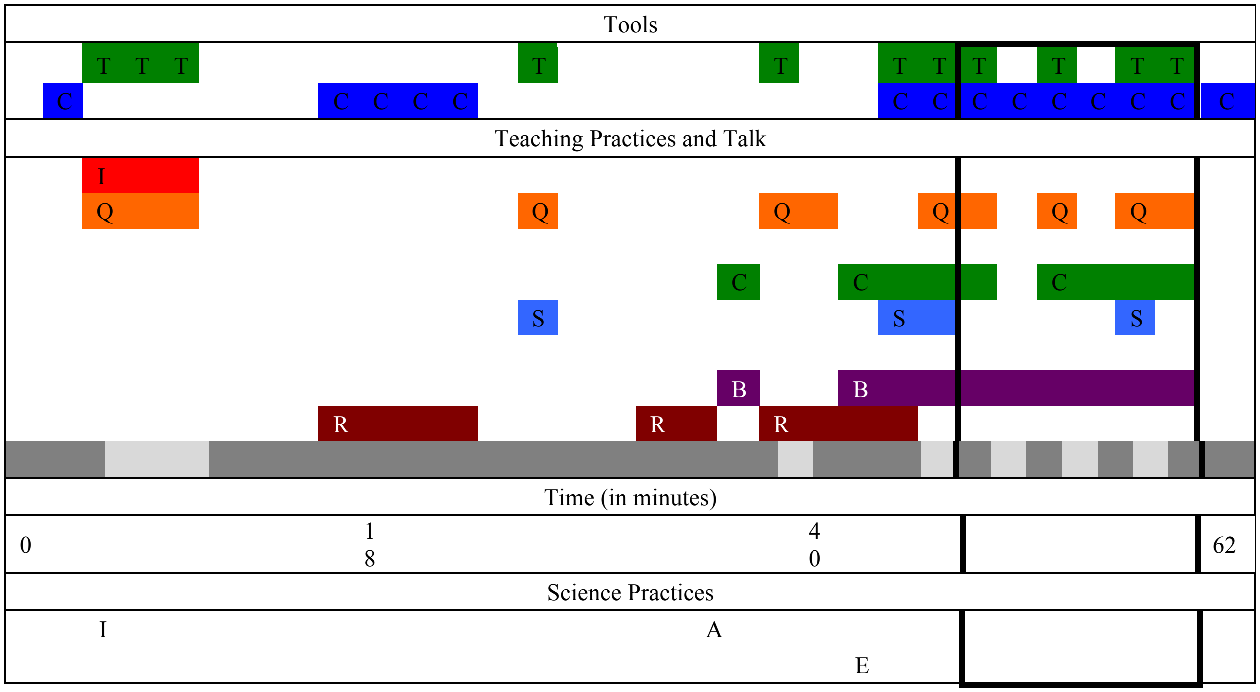

Figure 8-4: Ms. Andrews's LiFE enactment

Talk moves, questioning and connections. In both Ms. Andrews's peer teaching enactment and her LiFE enactment, she frequently used open ended-questions as indicated by the orange questioning rows in Figures 8-3 and 8-4. The open-ended questions were often those included on the *talk moves tool* (as indicated by the green talk moves row in Figures 8-3 and 8-4) provided to all interns in the science methods course. At the start of her lessons, use of the talk moves often resulted in Ms. Andrews being able to elicit students' initial ideas about the scientific phenomenon and making predictions about the investigation question as indicated by the pink investigation row at the bottom of both figures. Additionally, during her engage element of both lessons, use of the *talk moves tool* and the open-ended questions included on the tool likely helped Ms. Andrews to use a dialogic voice (as indicated in light gray), inviting multiple students into the whole-class discussion, and making connections among students' ideas (as indicated in green) [Andrews Peer Teaching Engage 14:00-18:00 outlined in Figure 8-3].

Similarly, toward the end of both lesson enactments, Ms. Andrews frequently used talk moves from the *talk moves tool* to ask her students open-ended questions about the investigation. In the peer teaching lesson, this seemed to allow Ms. Andrews to use a dialogic voice, supporting her students to do the majority of the intellectual work during the investigation-based discussion. Ms. Andrews was able to make connections among students' ideas and utilize student contributions to support students to make a claim backed by evidence and reasoning (as indicated in purple at the bottom of both figures). Additionally, use of the talk moves helped Ms. Andrews to foster argumentation (as indicated in light blue) during the discussion in the peer teaching [Andrews Peer Teaching Explain 10:00-16:00 outlined in Figure 8-3].

In contrast, Ms. Andrews's use of talk moves from the talk moves tool did not seem to support her to consistently use dialogic voice during her investigation-based discussion during her LiFE lesson enactment, nor did use of the talk moves from the *talk moves tool* help Ms. Andrews foster argumentation in her mentor teacher's classroom. Ms. Andrews frequently shifted into authoritative voice (as indicated in dark gray) during the investigation-based discussion, either asking a single student to respond to an open-ended question or engaged in a teacher monologue after posing a question [Andrews LiFE 50:00-60:00 outlined in Figure 8-4]. During this time, however, she was able to make connections among student contributions (as indicated in green) and the bigger scientific ideas (as indicated in purple) detailing how disease spreads within a community. Ms. Andrews's frequent use of authoritative voice in her LiFE lesson may have been related to her relatively strong knowledge of the scientific content (Carlsen, 1991). Alternatively, Ms. Andrews's frequent use of authoritative voice may have been due to students being unfamiliar with the claim-evidence reasoning framework. Because of this unfamiliarity Ms. Andrews may have determined a need for additional support for her students to construct the scientific claim.

Additionally, use of a *monitoring tool* during her LiFE lesson might have allowed Ms. Andrews to keep better track of students' ideas as they arose. Knowing how students were thinking prior to the discussion might have allowed Ms. Andrews to call on specific students to contribute both accurate and alternative ideas that would push the discussion forward in a productive way, potentially increasing opportunities for argumentation and explanation construction.

Representations and claim-evidence-reasoning exemplar. In both her peer teaching and LiFE lesson enactments, Ms. Andrews utilized scientific representations (as indicated by maroon in both figures) to help support students to see patterns in the data they collected during the investigation. During her use of representations, the students were actively involved in analysis of data (as indicated by light green at the bottom of both figures). By using representations, such as graphs, students were supported in their analysis of whole class data. Ms. Andrews used the representations to support students to notice patterns and trends in the data that could be used as evidence to support a scientific claim. Use of the representations also may have supported Ms. Andrews to use dialogic voice (as indicated in light gray). By asking open-ended questions specifically about the representations Ms. Andrews was able to press students to do the intellectual work of analyzing the data.

In her LiFE lesson, Ms. Andrews also facilitated data analysis by using a representation; however in her LiFE lesson Ms. Andrews shifted into authoritative voice more frequently (as indicated in dark gray). This was a missed opportunity to use dialogic voice and open-ended questioning in combination with the representation to support students to analyze their data [Andrews' LiFE 34:00-44:00].

Finally, Ms. Andrews's use of the *claim-evidence-reasoning template* (as indicated in blue at the top of each figure) likely supported her students to make claims supported by multiple pieces of evidence. The *C-E-R template* likely served as a scaffold for both Ms. Andrews and her students, reminding Ms. Andrews to press students to use evidence to support their claims and setting the expectation for students that claims must be supported by multiple pieces of evidence. Use of the *C-E-R template* provided students in both the peer teaching lesson and LiFE lesson opportunities to construct explanations [Andrews Peer Teaching Explain 14:00-20:00; Andrews Life 46:00-62:00].

Ms. Andrews: Summary of Relationships

Ms. Andrews's lesson plans and card sorting activities provided evidence of her strong knowledge of the science content. Ms. Andrews's content knowledge may have allowed her to consider the big ideas throughout her lesson plans and lesson enactments and connect student contributions to those big ideas. Additionally, Ms. Andrews's beliefs about science teaching were aligned to the goals of the science methods course and likely allowed her to make use of tools aligned with those beliefs (e.g., *talk moves tool* and *C-E-R template*). Use of these tools allowed Ms. Andrews to engage in productive practices for capitalizing on student contributions. Her use of open-ended questions from the *talk moves tool* and use of the *C-E-R template* in combination with representations to support students to analyze data related to higher use of dialogic voice and student engagement in data analysis, argumentation, and explanation construction during her peer teaching lesson enactment. However, her strong content knowledge or her students' unfamiliarity with the C-E-R framework might have hindered her from allowing students to do the majority of the intellectual work during her LiFE investigation-based discussion despite her learning theory centered beliefs about science teaching.

Ms. Lawrence

Figure 8-5 provides an overview of the relationships among Ms. Lawrence's characteristics, tool use, lesson plans, and lesson enactments. The following sections provide additional detail about each of these relationships.

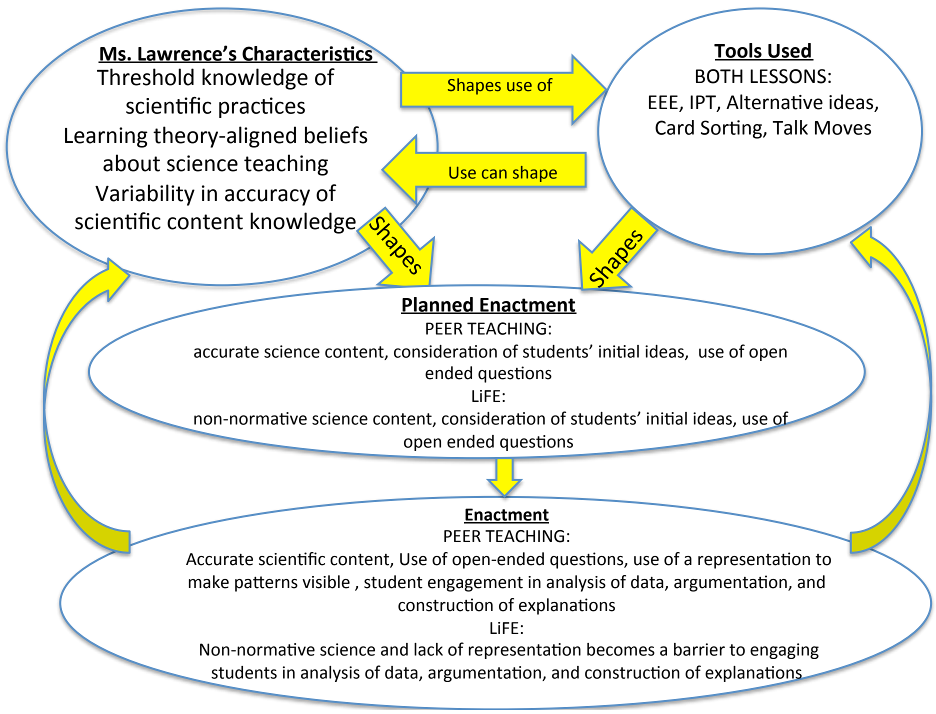

Figure 8-5: Ms. Lawrence's participatory relationship

Ms. Lawrence's Characteristics

Like Ms. Andrews, in the survey designed to measure interns' beliefs about science teaching (Smith, Smith, & Banilower, 2014), Ms. Lawrence had beliefs aligned with current theories on learning and alignment with the student-centered focus of the science methods course (See Table 8-1). She also believed that science instruction should not be all hands-on all the time indicating she valued sensemaking in addition to hands-on investigations (See Table 8-1). In her interview, she described the importance of sensemaking stating, "I feel like it is important for students to make observations, but that the really important part is analyzing and understanding the data and what it means from a science perspective" [Lawrence, Interview 1]. Additionally, according to her argumentation questionnaire, Ms. Lawrence's knowledge of how to foster argumentation among students did not differ from the intern average. Ms. Lawrence also stated she had not observed her mentor teacher teaching science at all during her time in her field placement, and that her students had limited time during their class day to learn science.

Ms. Lawrence's card sorting activity showed evidence of her accurate science content knowledge for the Energy peer teaching lesson. Like Ms. Andrews, Ms. Lawrence was able to make multiple accurate connections among the ideas of heat energy transfer, the laws of thermodynamics, and the concepts of heat and temperature. Ms. Lawrence's accurate understanding of heat energy transfer was also reflected in her lesson plan. She was able to list key pieces of evidence that students could use to support their claims, and made multiple connections between the investigation and the disciplinary core ideas.

However, her card sort for her LiFE lesson was much more focused on defining scientific vocabulary than making connections among ideas. Ms. Lawrence provided the accurate descriptions of what happens to light when it reaches opaque, transparent, and translucent objects, but was not able to list typical objects that had these characteristics. When I asked Ms. Lawrence about her process to make the card sort, she commented that she relied heavily on the curriculum materials her mentor teacher had provided her. Ms. Lawrence explained that she used the teachers' manual and highlighted key terms she thought students should be able to define after the investigation. Her card sort reflected this focus on defining scientific terms.

Additionally, in her interview after the course, Ms. Lawrence commented that she didn't really understand why students were looking at a straw in a bottle of water and oil, stating that she felt that she "missed the point of the lesson" and that she had "difficulty when one of [the] students kept focusing on what the water and oil were doing to the straw" [Lawrence, Interview 2]. Ms. Lawrence's struggles with the scientific content were also apparent in her lesson plan for her LiFE lesson, providing few connections between the investigation and the disciplinary core ideas. Ms. Lawrence's difficulties understanding the science content likely made it challenging for her to recognize that several of her students were contributing accurate understandings of the scientific phenomenon, and harder to guide students toward a scientifically accurate claim based on evidence and reasoning.

Tool Use and Planned Enactment

Like Ms. Andrews, Ms. Lawrence's student-centered and sensemaking focused beliefs about science teaching may have made her more likely to use tools aligned with those beliefs. Ms. Lawrence described her use of open-ended questions from the *talk moves tool* in her interview stating, "The [talk moves] really aligned with what we have been talking about throughout this program. I feel like using them gives students an opportunity to describe what they are thinking, allowing me to be more of a guide" [Lawrence, Interview 2]. She consistently included open-ended questions from the *talk moves tool* in her lesson plans for both her peer teaching and LiFE lessons. Use of the questions allowed Ms. Lawrence to prepare opportunities to engage students in data analysis, and explanation construction.

Although it wasn't included in the LiFE lesson plan she submitted, in her interview, Ms. Lawrence commented that she had created a *monitoring tool* for her LiFE lesson. Ms. Lawrence described the *monitoring tool* as, "having a lot of value, and although I didn't use it like I had planned to in the LiFE lesson, I can see myself using that tool moving forward" [Lawrence, Interview 2]. Use of the *monitoring tool* in her LiFE lesson may have allowed Ms. Lawrence to formatively assess students' understanding of the science phenomenon as they were collecting data.

Within the Enactments

Ms. Lawrence used talk moves from the *talk moves tool* in both her lesson enactments. Like Ms. Andrews, use of the talk moves often occurred when Ms. Lawrence was eliciting, extending, or challenging students' ideas. Additionally, Ms. Lawrence's use of a representation in her peer teaching provided students opportunities to make sense their data, analyzing the graphical representations to find patterns and trends, engaging in argumentation, and constructing an explanation about heat energy transfer. In contrast, Ms. Lawrence's struggles with the science content seemed to hinder Ms. Lawrence's engagement in other productive teaching practices for capitalizing on students' contributions. Figures 8-6 and 8-7 provide evidence of segments where Ms. Lawrence's tool use and engagement in productive teaching practices co-occurred with her use of dialogic or authoritative voice and student engagement in science practices.

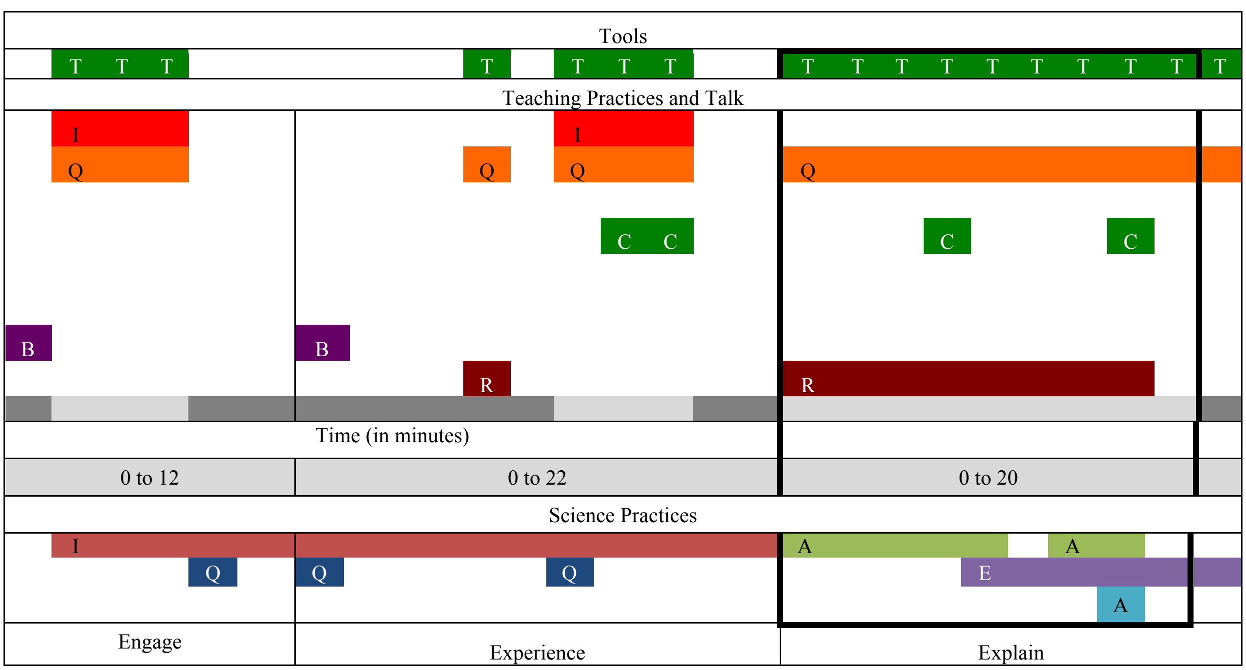

Figure 8-6: Ms. Lawrence's peer teaching enactment

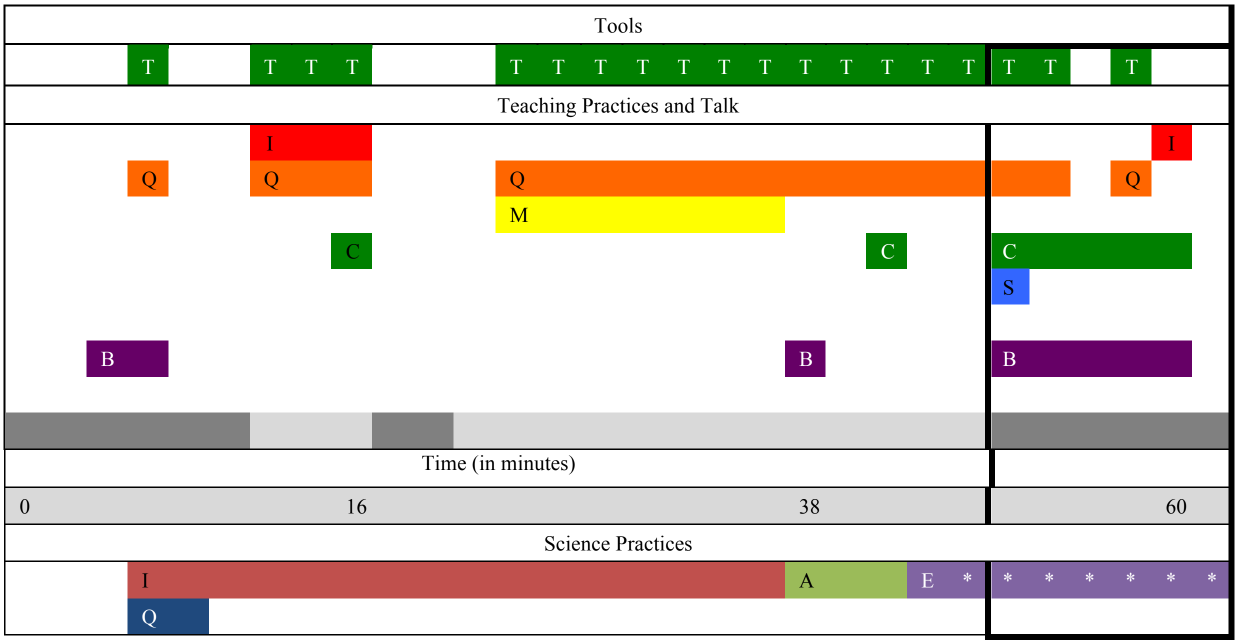

Figure 8-7: Ms. Lawrence's LiFE enactment

Talk moves, questioning, and use of a representation. In both Ms. Lawrence's peer teaching lesson and LiFE lesson, she frequently used open-ended questions from the *talk moves tool* to elicit, extend, and challenge students' ideas as indicated in Figures 8-6 and 8-7 by the green talk moves row and orange questioning row. Like Ms. Andrews, Ms. Lawrence's use of the talk moves at the beginning of the lessons provided opportunities for students to make and discuss predictions as indicated by the pink investigation row at the bottom of both figures. In both her lessons, Ms. Lawrence reminded students of their initial ideas as indicated in red. In her LiFE lesson, Ms. Lawrence also used talk moves (indicated in green) to question students' ideas (indicated in orange) as they were carrying out the investigation (indicated in pink at the bottom of Figure 8-7).

Similarly, Ms. Lawrence used talk moves at the end of the lesson as students were engaged in data analysis and explanation construction as indicated by the green analysis row and purple explanation row at the bottom of the figures. In her peer teaching lesson, use of the talk moves (green talk moves row) to question students' ideas (orange questioning row) and use of a representation to organize student data (maroon representation row), related to higher use of dialogic voice indicated in light gray. By using dialogic voice, Ms. Lawrence was able to include all of her students in the investigation-based discussion, and pressed each student to justify his or her ideas [Lawrence Peer Teaching Explain 0:00-18:00 outlined in Figure 8-6]. Additionally, use of the graphical representations of the temperature data supported students to find patterns in the data, which, in turn, could be used as evidence for their scientific claim.

Student unfamiliarity and non-normative science. Like Ms. Andrews, Ms. Lawrence's use of talk moves did not support her to consistently use dialogic voice during the explain element of her LiFE lesson. Ms. Lawrence's use of talk moves seemed to allow her students to contribute their observations to the investigation-based discussion and engage in initial analysis of those observations as indicated by the light green analysis row at the bottom of Figure 8-7. However, when Ms. Lawrence began to press students to construct a claim to answer the investigation question, students seemed to struggle, and Ms. Lawrence shifted into authoritative voice as indicated in dark gray [Lawrence, LiFE 48:00-60:00 outlined in Figure 8-7].

The change in voice could have been due to Ms. Lawrence recognizing students needed additional support. When asked about her enactment of her explain element, Ms. Lawrence described her LiFE lesson as being "the first time students were asked to do science this way, where they had to really think, and it was their first time seeing the [claim-evidence-reasoning] framework" [Lawrence, Interview 2]. Additionally, she commented that she thought her students did a good job of listing their observations. She described that students struggled to construct a claim, and because of their struggles, she felt the need to step in and "scaffold the process and lead them a lot more" [Lawrence, Interview 2]. Development and use of *a claim-evidence-reasoning template* might have better supported students in becoming familiar with the C-E-R framework. Additionally, had Ms. Lawrence used the *monitoring tool* she had created for her LiFE lesson, she may have been better able to keep track of students' ideas, and provide additional structure to the discussion by calling on students' who had ideas that would move the discussion forward in productive ways.

Another plausible explanation for Ms. Lawrence's shift in voice was due to her non-normative understanding of the scientific phenomenon (as indicated by asterisks in Figure 8-7). Ms. Lawrence commented in her final interview that when one of her students described the oil and water as transparent objects, she was not sure how to refocus the students toward the accurate understanding, not realizing her student had already contributed an accurate scientific claim and reasoning to the discussion. It is likely that her non-normative understanding of the phenomenon impeded her ability to continue to use dialogic voice and the other teaching practices in a way that would support students to understand what happens to light when it reaches a transparent object (Windschitl, et al., 2012). Instead, she shifted into initiate-respond-evaluate exchanges and teacher monologues (as indicated in dark gray) to connect students' observations to an inaccurate understanding of the phenomenon.

Lawrence: Summary of Relationships

Ms. Lawrence's use of the talk moves from the *talk moves tool* in both her lesson plans and lesson enactments was aligned with her student-centered and sensemaking focused beliefs about science teaching. Use of the talk moves allowed Ms. Lawrence to elicit students' ideas and press for justification during her peer teaching enactment. Specifically during her peer teaching lesson, use of the talk moves in combination with use of a representation seemed to allow Ms. Lawrence to support students to analyze data, and engage in argumentation and explanation construction. However, in her LiFE lesson, either her students' unfamiliarity with the C-E-R framework or Ms. Lawrence's non-normative understanding of the science content seemed to impede her ability to foster similar student engagement in the investigation-based discussion.

Ms. Chase

Figure 8-8 provides an overview of the relationships among Ms. Chase's characteristics, tool use, lesson plans, and lesson enactments. The next sections provide additional detail about each of these relationships.

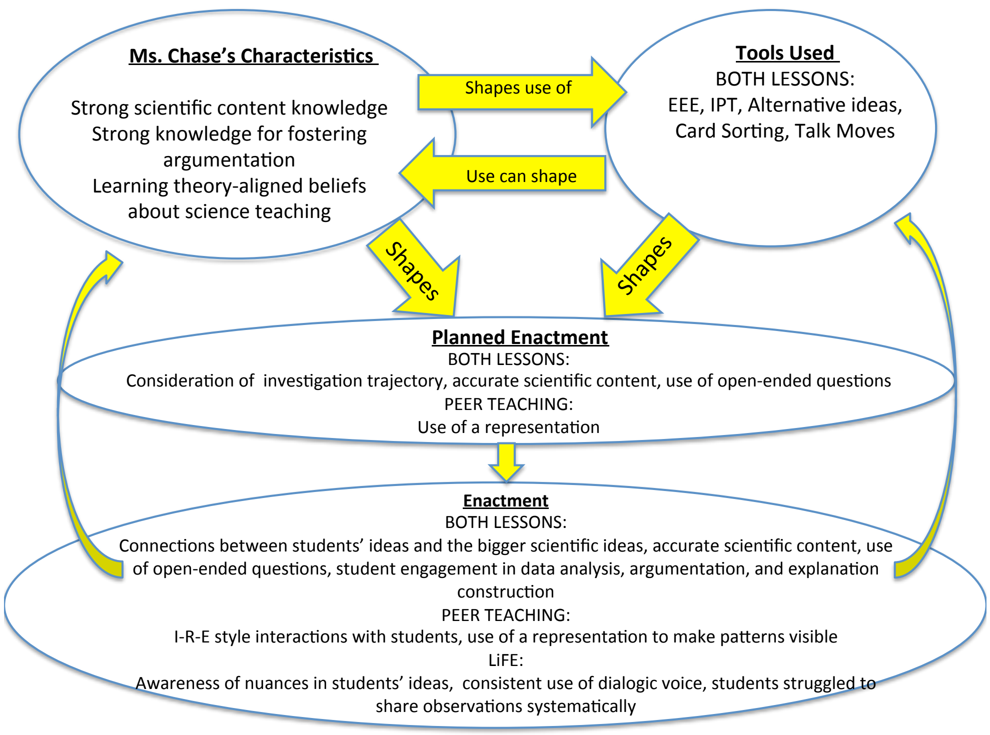

Figure 8-8: Ms. Chase's participatory relationship

Ms. Chase's Characteristics

In the survey designed to measure interns' beliefs about science teaching (Smith, et al., 2014), Ms. Chase had beliefs aligned with current theories on learning (See Table 8-). Ms.

Chase also strongly believed science teaching should not be confirmatory (See Table 8-1), aligning instead with the vision of the science methods class that students should draw conclusions from data they collected rather than doing investigations to confirm what the teacher has already explained. Additionally, of the focal interns, Ms. Chase's knowledge for fostering argumentation in the science classroom was the strongest (See Table 8-1). Like Ms. Lawrence, Ms. Chase also reported that she had never seen science being taught in her field placement classroom.

Similar to Ms. Andrews, Ms. Chase described the methods course being an influence on how she thought about science teaching. Placing value on student sensemaking and making her lesson more than just hands-on activities, Ms. Chase explained, "Now I think I am more careful to give my lessons scientific purpose. I have to think about how the investigation advances and helps them understand the concept I am trying to teach them" [Chase, Interview 1].

Deep thinking about the scientific purpose was evident in Ms. Chase's card sort and both Ms. Chase's peer teaching and LiFE lesson plans. For example, in her card sort for her LiFE lesson on condensation, Ms. Chase accurately described multiple aspects of the water cycle and made connections to the phase changes happening during each of the processes (e.g., evaporation, condensation, etc.). Ms. Chase included connections to the big ideas in her lesson plans drawing parallels between what students would be doing during the investigation and bigger science ideas. When asked about how she refreshed her own understanding of the scientific content Ms. Chase stated she "spent a lot of time on the internet trying to figure these things out" and described the content-focused conversations with the methods instructor and her colleagues as helpful. Like Ms. Andrews, strong content knowledge and ability to connect the concepts to bigger scientific ideas likely enabled Ms. Chase to recognize when a student contributed both accurate scientific ideas as well as productive alternative ideas during the investigation-based discussion.

Tool Use and Planned Enactment

Perhaps because of her beliefs about science teaching, Ms. Chase was more likely to use tools that would support students to do the intellectual work of the investigation. For example, Ms. Chase consistently planned to use talk moves from the *talk moves tool* in her *instructional planning template*. Like Ms. Andrews and Ms. Lawrence, using the talk moves allowed Ms. Chase to plan to engage students in data analysis, argumentation, and explanation construction – all of which allow students to make sense of their data and draw their own conclusions rather than having the teacher tell students what they should be finding – aligning with Ms. Chase's non-confirmatory views on science teaching.

Within the Enactments

Similar to her plans, and like Ms. Andrews and Ms. Lawrence, Ms. Chase used the talk moves from the *talk moves tool.* When using the talk moves, Ms. Chase was often able to elicit her students' ideas about the scientific phenomenon and then press students for justification of those ideas. Additionally, she was often able to make connections among students' ideas and the bigger scientific ideas. Additionally, Ms. Chase's use of a representation to organize students' data in her peer teaching enactment supported students to analyze their data. Lack of use of a representation was a missed opportunity in her LiFE lesson.

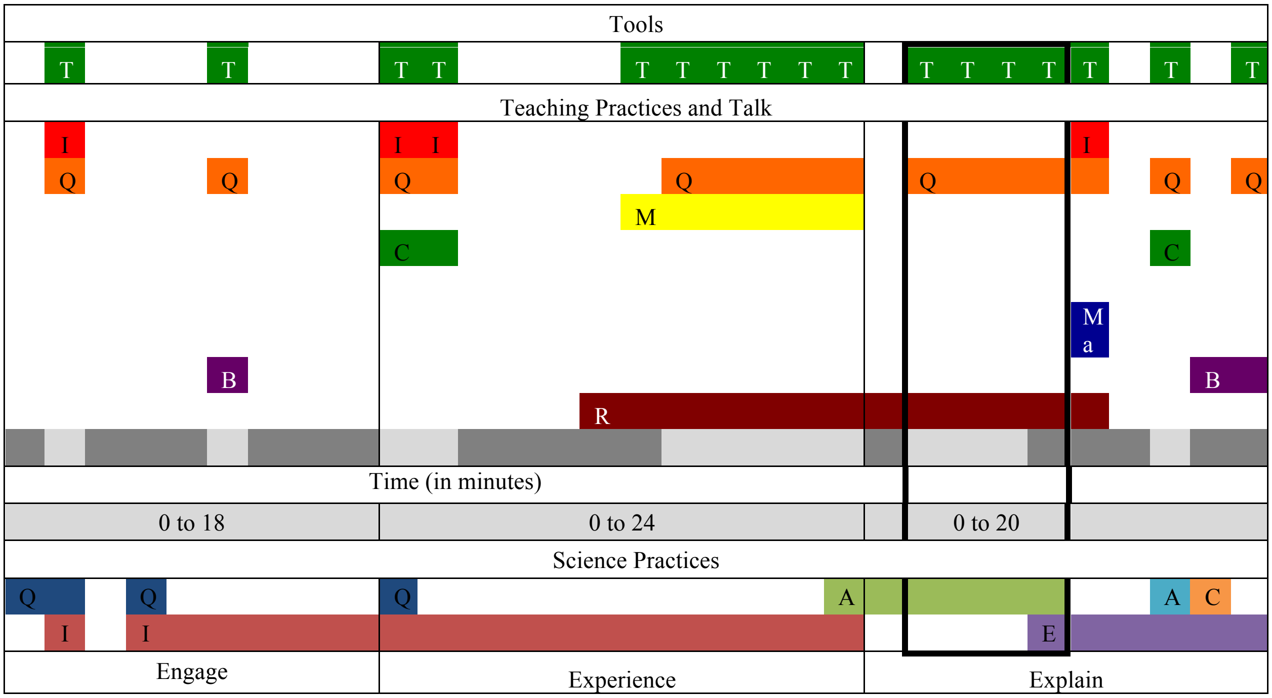

Figure 8-9: Ms. Chase's Peer Teaching Enactment

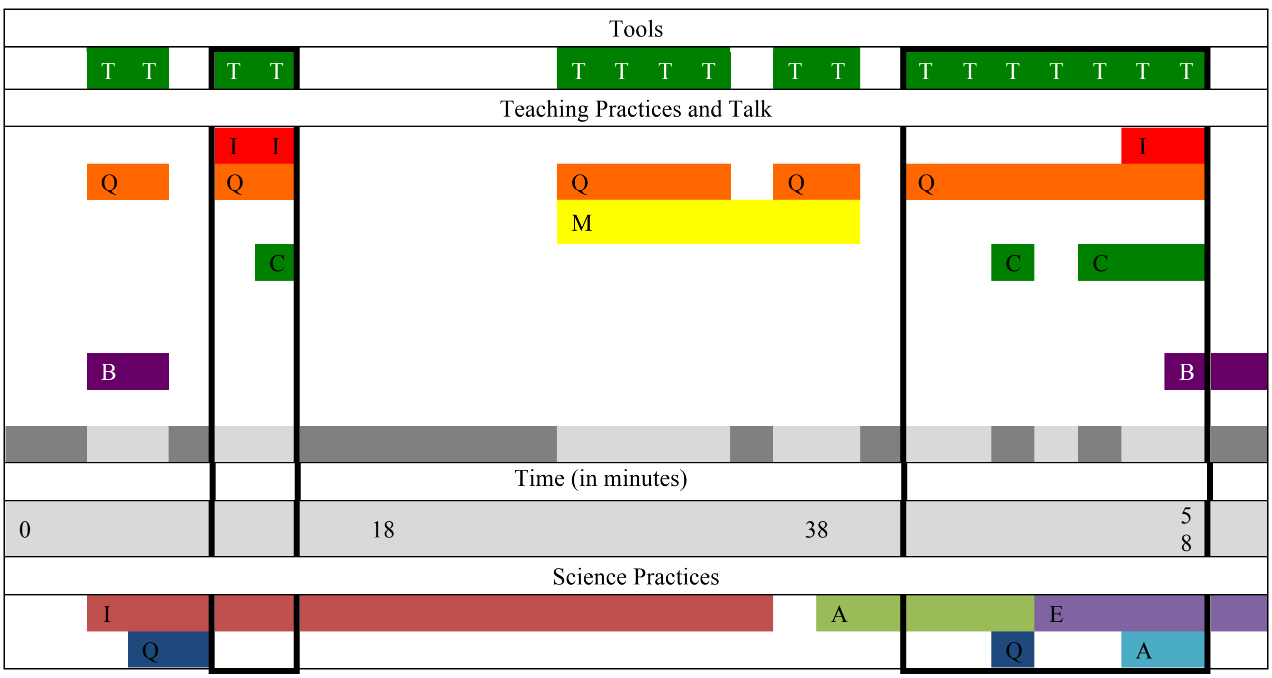

Figure 8-10: Ms. Chase's LiFE Enactment

Talk moves, questioning, and connections. Throughout both her peer teaching lesson and her LiFE lesson enactments, Ms. Chase used talk moves from the *talk moves tool* indicated by the green talk moves row in Figures 8-9 and 8-10. Use of open-ended questions from the *talk* *moves tool* allowed Ms. Chase to question (as indicated in orange) students about their initial ideas of the scientific phenomenon, making predictions that would answer the investigation question as indicated in pink at the bottom of both figures. Use of the talk moves for questioning also allowed Ms. Chase to check in with students about their evolving ideas as she monitored (indicated in yellow) students carrying out the investigation. Finally, use of the talk moves prompted students to share their ideas while analyzing data (indicated in light green), engaging in argumentation (indicated in light blue) and explanation construction (indicated in purple) during the investigation-based discussion. In all three elements of both lessons, use of the talk moves also likely supported Ms. Chase to use dialogic voice more frequently as indicated in light gray, offering additional opportunities for more students to become engaged in the whole-class discussions (e.g., Chase Peer Teaching Explain 2:00-10:00 outlined in Figure 8-9).

Ms. Chase was the only focal intern whose use of talk moves in her LiFE lesson may have allowed her to consistently use dialogic voice and engage her students in data analysis, argumentation, and explanation construction [Chase Life 42:00-58:00 outlined in Figure 8-10]. Ms. Chase's ability to continue to use dialogic voice as indicated in light gray could have been due to her knowledge of how to foster argumentation in the science classroom. Additionally or alternatively, it may have been due to Ms. Chase's strong content knowledge and understanding of nuances in students' ideas. In her lesson plan, Ms. Chase listed multiple common alternative ideas students may hold about the concept of condensation. In her LiFE plan she made connections among several of the alternative ideas (e.g., students thinking the water on the outside of the cold soda cans somehow traveled through the can and collected on the outside) and pieces of data that students would collect during the investigation that would contradict those alternative ideas (e.g., clear water on outside of the can containing red ice water). Several of these alternative ideas arose at the beginning of Ms. Chase's LiFE enactment [Chase Life 12:00-14:00 outlined in Figure 8-10].

Rather than addressing those ideas at the start of the lesson so the investigation could confirm the accurate idea, Ms. Chase allowed those ideas to persist and returned to the ideas at the end of the lesson asking questions to prompt student to think about how their evidence contradicted the alternative claims. Ms. Chase's use of questioning (indicated in orange in Figure 8-10) and dialogic voice (indicated in light gray) at the end of the lesson likely allowed her to engage students in data analysis (indicated in light green), helped her to foster argumentation (indicated in light blue), and supported students to construct accurate understandings of the phenomenon (indicated in light purple).

Use of a representation. Similar to Ms. Andrews and Ms. Lawrence, Ms. Chase used graphical representations of the temperature data (as indicated in maroon in Figure 8-9) in her peer teaching lesson enactment to support students to analyze their data and construct evidence-based claims (as indicated by light green and light purple). Use of the representations seemed to support Ms. Chase to use dialogic voice (as indicated in light gray).

In contrast, in her LiFE lesson, Ms. Chase did not use a representation to support students to organize their data and find patterns. When asking students to share their observations at the beginning of the investigation-based discussion, students shared observations of all three soda cans. Perhaps noticing that students were having difficultly sharing their observations in a systematic way, Ms. Chase shifted into authoritative voice as indicated in dark gray [Chase LiFE 40:00]. Use of a representation to help students organize their data likely would have helped students to share their observations and make patterns in the data more visible.

Ms. Chase: Summary of Relationships

Ms. Chase's strong content knowledge and knowledge of how to foster argumentation in the science classroom seemed to have allowed Ms. Chase to connect the investigation to bigger scientific concepts. Additionally, this knowledge seemed to allow Ms. Chase to classify students' ideas as accurate or non-normative while teaching. Noticing the nuances in her students' ideas, Ms. Chase was able to foster argumentation among students despite not having seen any science instruction in her mentor teacher's classroom prior to teaching her LiFE lesson. Finally, Ms. Chase's use of a representation in her peer teaching enactment supported students' data analysis and explanation construction. Lack of use of a representation in her LiFE lesson seemed to cause students to struggle to share observations in a systematic way, perhaps making the trends in the data less visible for some students.

Ms. Kramer

Figure 8-11 provides and overview of the relationships among Ms. Kramer's characteristics, tool use, lesson plans, and lesson enactments. The next sections provide additional detail about each of these relationships.

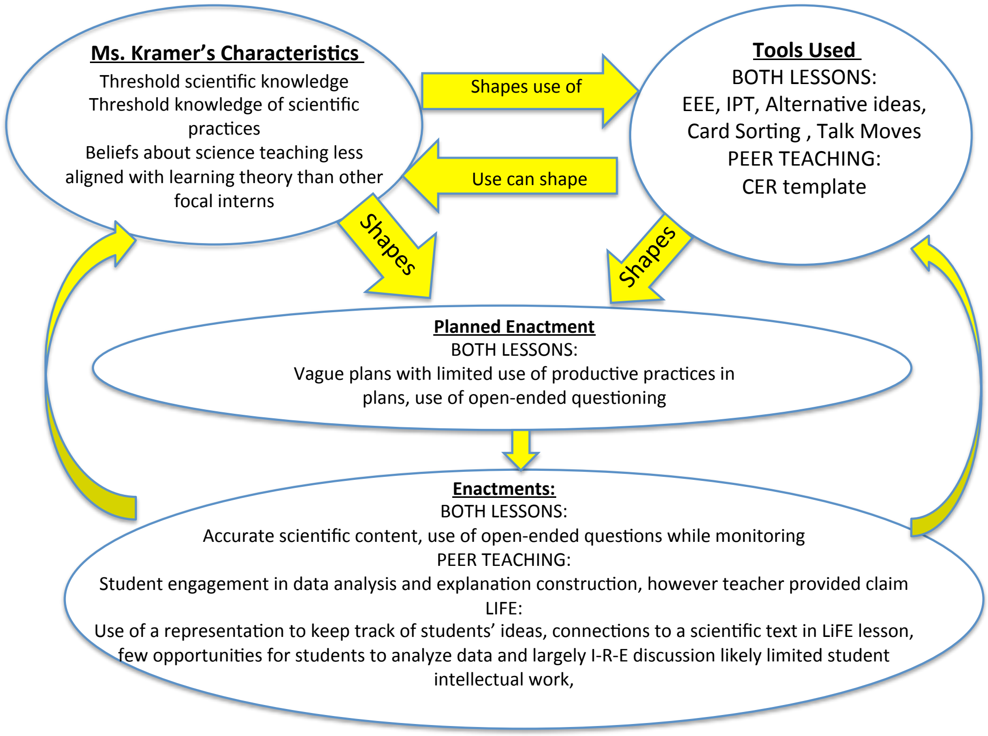

Figure 8-11: Ms. Kramer's participatory relationship

Ms. Kramer's Characteristics

In the survey designed to measure interns' beliefs about science teaching, Ms. Kramer had beliefs less aligned with current learning theories (See Table 8-1) than the interns enrolled in the science methods course. Because her beliefs about science teaching were less aligned with the methods course goals, Ms. Kramer may have found it difficult to plan for and teach lessons aligned with the goals of the course. In addition, according to her argumentation questionnaire, Ms. Kramer had moderate understanding of how to foster argumentation among students.

Despite having beliefs about science teaching less aligned with the goals of the methods course at the start of the course, in her end of course interview, Ms. Kramer described the value of teaching with sensemaking in mind. When commenting on her use of the *EEE framework* to plan and enact her lessons she stated,

> Without the *EEE framework* I would have had to work through it on my own, and I would have missed important things. It would have been really easy to teach a science lesson and tell them everything rather than letting them do it on their own.
> I am learning where the line is with that, and without [the *EEE framework* and the methods course] I might be doing all the telling. But now I am seeing they get so much more out of it when they are the ones wondering and discovering it for themselves rather than us just telling them.
> [Kramer, Interview 2]

This interview excerpt provides evidence that Ms. Kramer's beliefs about science teaching may have been shifting toward alignment with current learning theories and the goals of the methods course by the end of the course, placing value on student sensemaking and student-contributed ideas. Unlike Ms. Lawrence and Ms. Chase, Ms. Kramer had observed her mentor teacher teaching science in her field placement classroom.

Ms. Kramer's card sorting activities provided evidence that she had a moderate understanding of the scientific content for both her peer teaching lesson and her LiFE lesson. For example, she was able to provide connections between each part of the plant and its function for the Stems lesson, and was able to describe how fish move and breathe and compared those ideas to how humans move and breathe for her LiFE lesson. However, in her LiFE lesson plan her claim-evidence-reasoning statement she expected students to make after the investigation was vague and contained inaccurate reasoning. As described in Chapter 6, Ms. Kramer's inclusion of inaccurate reasoning in her plan may have prevented her from recognizing accurate student contributions in the investigation-based discussions.

Tool Use and Planned Enactment

Like all other focal interns, Ms. Kramer frequently used talk moves from the *talk moves tool* in both her peer teaching and LiFE *instructional planning templates*. Ms. Kramer planned to use the talk moves to elicit students' initial ideas about the phenomenon, and then challenge and extend those ideas in her experience and explain elements. Additionally, for her peer teaching lesson, Ms. Kramer planned to use the *claim-evidence-reasoning exemplar* to support her students to construct a scientific claim based on multiple pieces of evidence. Finally, Ms. Kramer created a *monitoring tool* for her peer teaching lesson; however, she did not use the tool during her enactment.

Of all the focal interns, Ms. Kramer's plans were the most vague, providing little detail about how she would engage students in the intellectual work of carrying out the investigation, analyzing data, and constructing explanations. In her end of course interview, Ms. Kramer commented that she did a lot of editing of her plans after turning them in explaining,

> I fill out the instructional planning template as a 'I have to do this now because it is due tomorrow' and it is a good place to start because it has everything outlined for you that you need to be thinking about. But then, after I turn it in I really think about what is actually going to happen. I usually end up making changes up to the minute before I teach and write myself sticky note reminders of the important things I want to be sure to touch on.
>
> [Kramer, Interview 2]

Ms. Kramer's description of her last-minute changes to her plan provide evidence as to why Ms. Kramer's plans were vague, and explains why she included things in her enactments that were not explicitly listed in her plans. The last minute changes to the plans may also explain why Ms. Kramer seemed to struggle with the clarity of her questions during the peer teaching lesson.

Within the Enactments

Like her plans, and similar to the other focal interns, in both of her lesson plans, Ms. Kramer used talk moves from the *talk moves tool*. Additionally, in her peer teaching lesson, Ms. Kramer used the *claim-evidence reasoning template*. Use of the talk moves often occurred when Ms. Kramer was eliciting students' ideas and pressing students to justify their ideas. She also used talk moves while monitoring students as they carried out the investigation. Finally, in her LiFE lesson, Ms. Kramer's use of a representation helped her to keep track of students' initial ideas and likely supported students to consider how their ideas may have changed over the course of the lesson. Figures 8-12 and 8-13 provide evidence of segments where Ms. Kramer's tool use and engagement in productive teaching practices co-occurred with her use of dialogic or authoritative voice and student engagement in science practices.

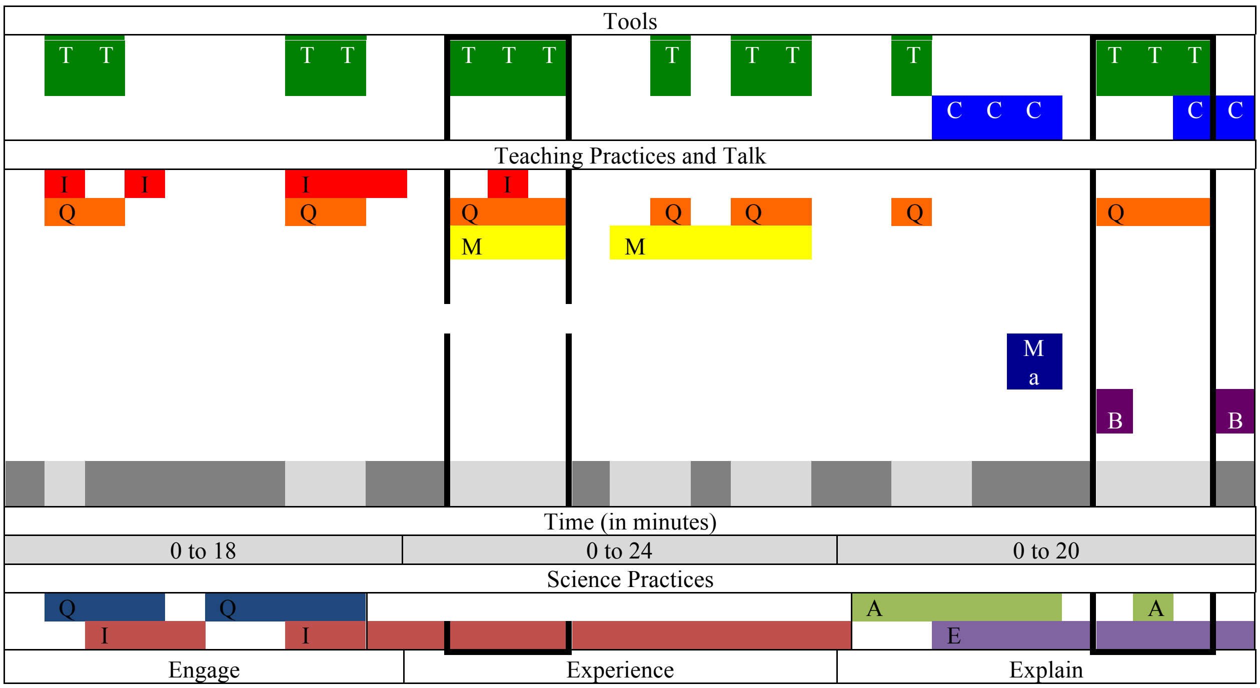

Figure 8-12: Ms. Kramer's peer teaching enactment

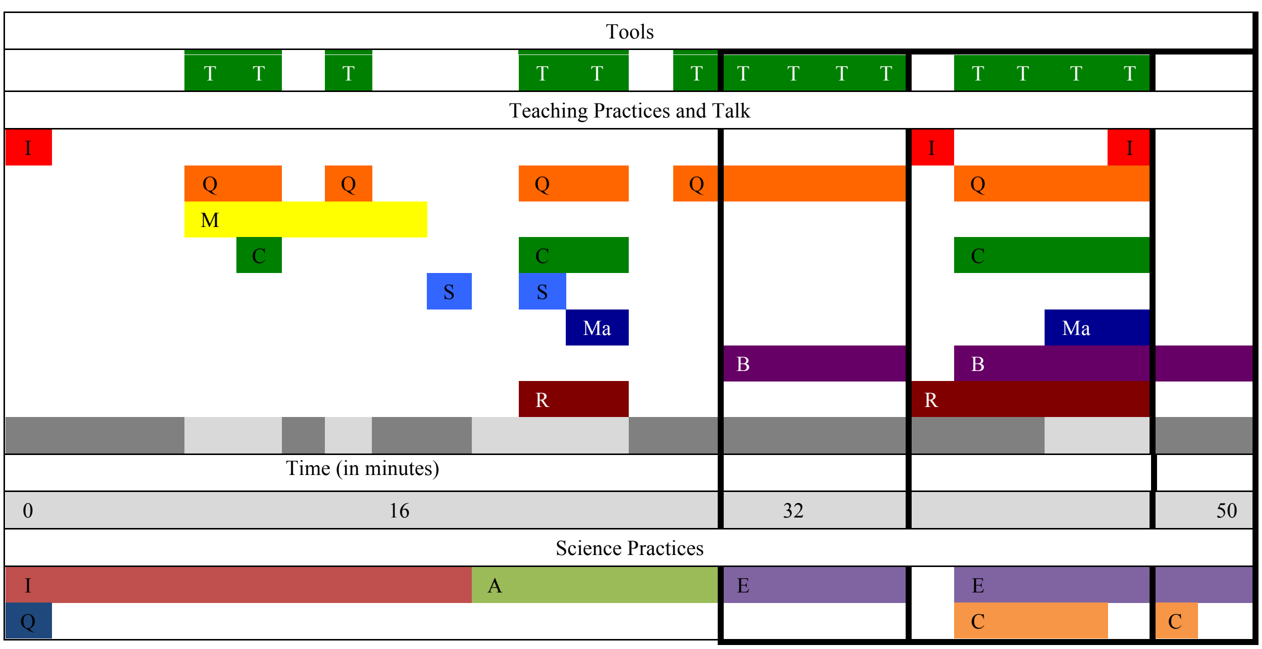

Figure 8-13: Ms. Kramer's LiFE enactment

Talk moves, questioning, and monitoring. In both Ms. Kramer's lesson enactments, she frequently used talk moves from the *talk moves tool* (as indicated by the green talk moves row) to question students about their ideas (as indicated by the orange questioning row). Use of the talk moves allowed Ms. Kramer to gain insight into how students were thinking about the phenomena. Additionally, Ms. Kramer used talk moves while monitoring (indicated in yellow) to question students as they were carrying out the investigation (indicated by the pink rows at the bottom of the figures). Ms. Kramer's use of the talk moves while monitoring likely supported Ms. Kramer's use of dialogic voice (indicated in light gray) while she pushed students to be more systematic when collecting their data [e.g., Kramer Peer Teaching Experience 2:00-8:00 outlined in Figure 8-12].

Similar to Ms. Andrews and Ms. Lawrence, Ms. Kramer also used the talk moves toward the end of her lessons to help support students to construct evidence-based claims. Use of these moves in the peer teaching lesson seemed to allow Ms. Kramer to support her students to analyze their data (indicated in light green) and construct explanations (indicated in purple). Through her use of the talk moves and dialogic voice, Ms. Kramer was able to include more students in the investigation-based discussion [e.g., Kramer Peer Teaching Explain 12:00-18:00 outlined in Figure 8-12]. In addition, Ms. Kramer's use of the *claim-evidence-reasoning template* in her peer teaching lesson (indicated in blue at the top of Figure 8-12) likely reminded Ms. Kramer to ask her students to provide multiple pieces of evidence to support their claims.

In contrast to her peer teaching lesson, and again similar to both Ms. Andrews and Ms. Lawrence (but different from Ms. Chase), Ms. Kramer's use of talk moves toward the end of her LiFE lesson did not result in the use of dialogic voice [Kramer LiFE 30:00-50:00 outlined in Figure 8-13]. As described in Chapter 7, Ms. Kramer progressed from supporting students to label their drawings of the fish to reading them the scientific text (indicated in light orange) about how fish move and breathe, and did not ask students to construct a claim based on their observations first. Shifting into consistent use of authoritative voice as indicated in dark gray toward the end of her LiFE lesson may have been a reflection of Ms. Kramer's shifting beliefs about teaching. While she began to see the value of teaching science in a way aligned with the goals of the methods course, she commented in her interview that she was still struggling to "find the line" between telling students about the phenomena and allowing them to explore it and explain it themselves. Additionally or alternatively, Ms. Kramer's last minute changes to her plan may explain why she struggled to support students in constructing their own evidence-based claims. Finally, had Ms. Kramer used a *claim-evidence-reasoning template* in her LiFE enactment, she could have been reminded to allow students to make an evidence-based claim prior to reading the scientific text. By allowing students to construct their own claim first, students would have had the opportunity to compare their thinking to that of scientists.

Use of a representation to keep track of student ideas. In her LiFE lesson, Ms. Kramer used a representation (indicated in maroon) to keep track of students' initial ideas and final ideas. Use of the representation likely provided Ms. Kramer's students an opportunity to see how their thinking changed or remained the same over the course of the investigation [Kramer LiFE 38:00-46:00]. Use of the representation also likely allowed Ms. Kramer's students to make connections (as indicated in green) between their own thinking and the scientific ideas included in the scientific text. She did not use a representation in her peer teaching lesson.

Ms. Kramer: Summary of Relationships

Ms. Kramer's use of the talk moves throughout her enactments allowed Ms. Kramer to question student thinking and prompted her students to be more systematic while collecting data. Additionally, her use of the *C-E-R template* during her peer teaching lesson allowed Ms. Kramer to support students to construct claims based on multiple pieces of evidence. However, Ms. Kramer's vague lesson plans and beliefs about science teaching may have led to missed opportunities in her enactments. Last minute changes to her plans may have resulted in instruction that lacked coherence or was confusing for students, causing higher use of authoritative voice to drive the lesson toward a scientific explanation. Finally, because Ms. Kramer's beliefs about science teaching were less aligned with the goals of the methods course, she may have struggled to enact lessons that prioritized student contributions, limiting students' opportunities to engage in the intellectual work.

Ms. Zabel

Figure 8-14 provides and overview of the relationships among Ms. Zabel's characteristics, tool use, lesson plans, and lesson enactments. The next sections provide additional details about each of these relationships.

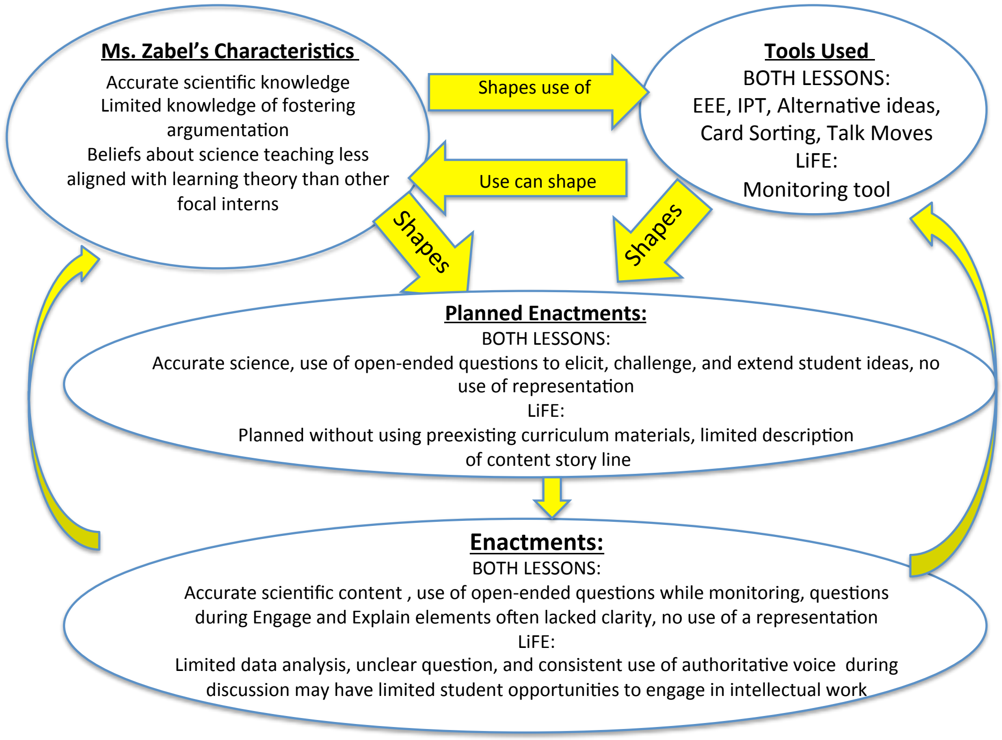

Figure 8-14: Ms. Zabel's participatory relationship

Ms. Zabel's Characteristics

Like Ms. Kramer**,** in the survey designed to measure interns' beliefs about science, Ms. Zabel had beliefs less aligned with current learning theories (See Table 8-1). Similar to Ms. Kramer, Ms. Zabel may have found it difficult to plan for and teach lessons aligned with the goals of the science methods course. According to her argumentation questionnaire, Ms. Zabel also had below threshold knowledge of how to foster argumentation in her classroom, again potentially making it difficult to plan lessons that engage students in argumentation.

Ms. Zabel did comment, however, that the methods course had an influence on how she thought about science teaching. She described the *EEE framework* as being a scaffold for her to learn how to teach science, helping her to adapt the lesson to make it "so the students could get excited about science, and then actually learn something by talking about it" [Ms. Zabel, Interview 2]. Like Ms. Kramer, by the end of the course Ms. Zabel's beliefs about science teaching may have been shifting toward alignment with current learning theories and the goals of the methods course. Like Ms. Kramer, Ms. Zabel also had observed her mentor teacher teaching science in her field placement classroom. All the lessons Ms. Zabel had observed however used a scientific text to explain science content rather than allowing students to experience the phenomena by engaging in an investigation.

Tool Use and Planned Enactment

Similar to the other focal interns, Ms. Zabel planned to use talk moves from the *talk moves tool* in both her peer teaching and LiFE lessons. Planned use of the talk moves likely provided students' additional opportunities to share their ideas with each other and allowed Ms. Zabel to press students for justification of those ideas. Additionally, Ms. Zabel was the only focal intern who was not provided existing curriculum materials as a starting point for her LiFE lesson. Ms. Zabel constructed her lesson plan from materials she had found on the Internet, using the "*EEE framework* as a guide for how the lesson should be structured" [Zabel, Interview 1].

Within the Enactments

Similar to what she had planned, Ms. Zabel used talk moves from the *talk moves tool* to elicit her students' ideas about the phenomena. Ms. Zabel also used the talk moves while monitoring her students as they were collecting data. Figures 8-15 and 8-16 provide evidence of segments where Ms. Zabel's tool use and engagement in productive teaching practices co-occurred with her use of dialogic or authoritative voice and student engagement in science practices.

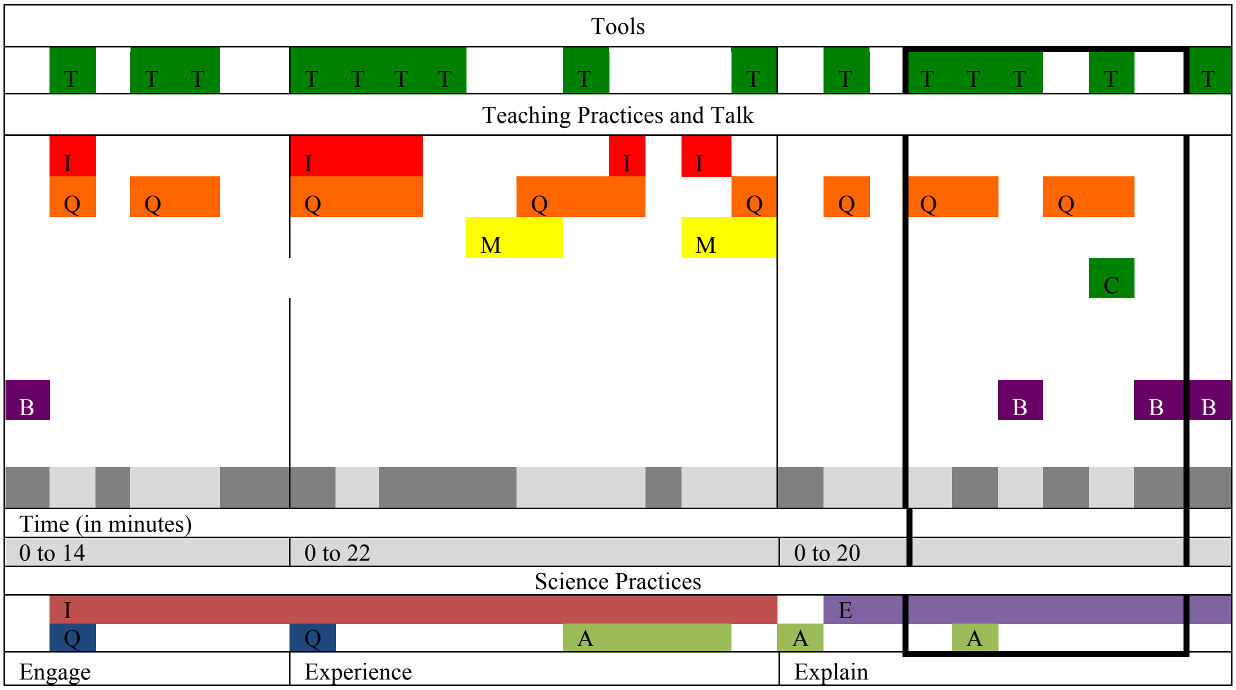

Figure 8-15: Ms. Zabel's peer teaching enactment

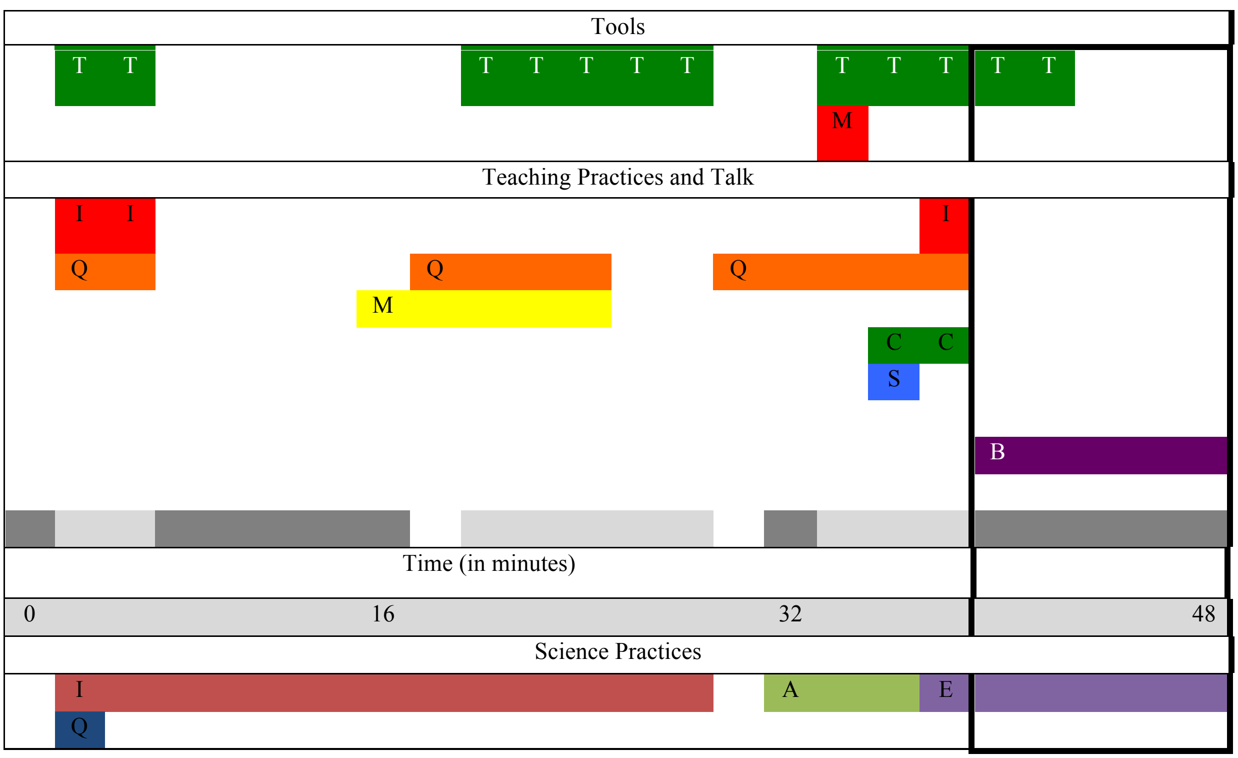

Figure 8-16: Ms. Zabel's LiFE enactment

Talk Moves, Questioning, and Monitoring. Like the other focal interns, in both Ms. Zabel's lesson enactments she used talk moves from the *talk moves tool* (as indicated by the green talk moves row in both Figures 8-15 and 8-16). Using the talk moves, Ms. Zabel was able to question her students about their ideas (as indicated in orange) and then extend and challenge those ideas as she was monitoring students (as indicated in yellow) while they collected data (as indicated in pink at the bottom of both figures). However often Ms. Zabel's questions lacked clarity and she had to shift into authoritative voice (indicated in dark gray) to reword her question or answer the question herself [e.g., Zabel Peer Teaching Explain 6:00-18:00 outlined in Figure 8-15]. Having to use authoritative voice more frequently throughout the lesson likely limited students' opportunities to contribute to the investigation-based discussion. In her interview, Ms. Zabel described that asking clear and concise questions was a goal she and her field instructor had agreed upon during the methods course, indicating that questioning may have been a practice Ms. Zabel struggled with in past courses [Ms. Zabel, Interview 1].

Enacting a lesson using limited resources. Some of the missed opportunities in Ms. Zabel's LiFE lesson may have been due to needing to construct her LiFE lesson using limited resources. Because she was not able to adapt the lesson from pre-existing materials, Ms. Zabel likely had to spend more time determining how to plan her lesson with the EEE framework in mind. The cognitive demand required to create the lesson may have limited Ms. Zabel's ability to plan to use multiple teaching practices that capitalize on student contributions. For example, Ms. Zabel did not use a representation to help students organize their observational data of the lines on the filter paper. The lack of representation, combined with unclear questions likely contributed to students' difficulty crafting a scientific claim backed by evidence. Noticing that students were struggling to develop a claim at the end of her lesson, Ms. Zabel again shifted into a teacher monologue using authoritative voice as indicated in dark gray [Zabel LiFE 40:00-48:00

outlined in Figure 8-16]. Additionally, use of a *claim-evidence-reasoning template* could have allowed Ms. Zabel to better support her students to make an evidence-based claim.

Ms. Zabel: Summary of Relationships.

Ms. Zabel's use of talk moves from the *talk moves tool* in her enactments allowed Ms. Zabel to question students about their initial ideas, and then extend and challenge those ideas as she monitored students collecting data. However, despite Ms. Zabel's accurate knowledge of the science content, the questions in her investigation-based discussion at the end of her lessons often lacked clarity and students struggled to answer the questions. Missed opportunities to support students to engage in the investigation-based discussion may have resulted from Ms. Zabel's struggles asking clear and concise questions, having to craft her LiFE lesson using limited resources, or lack of use of tools and teaching practices that capitalize on student contributions.

Ms. Sawyer

Figure 8-17 provides an overview of the relationships among Ms. Sawyer's characteristics (knowledge and beliefs about science teaching, science content, and science practice), tool use, lesson plans, and lesson enactments. The next sections provide additional detail about each of these relationships.

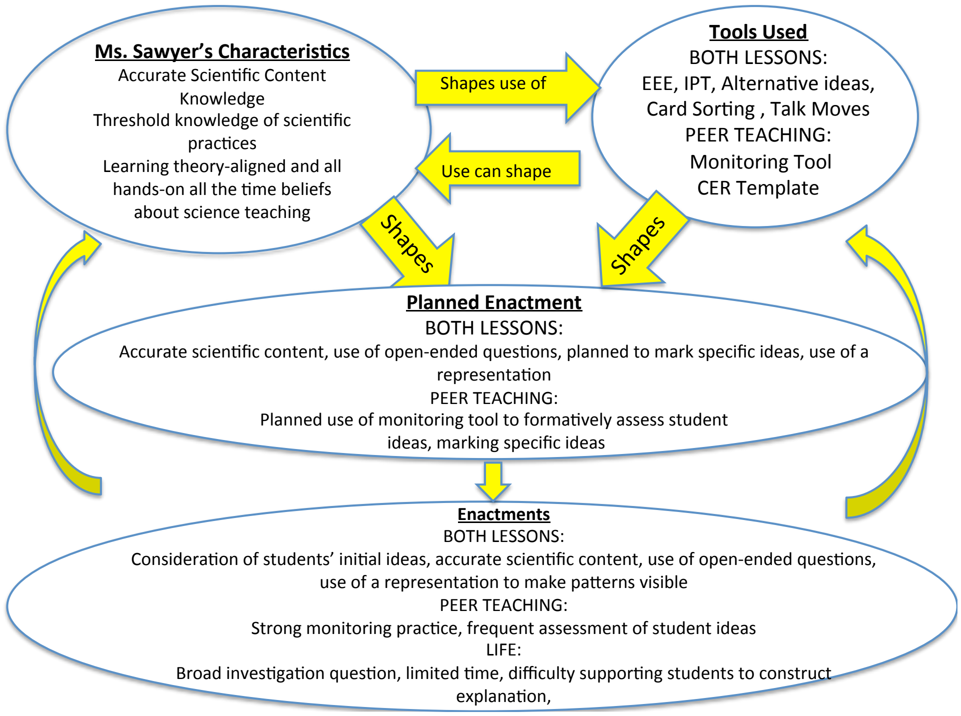

Figure 8-17: Ms. Sawyer's participatory relationship

Ms. Sawyer's Characteristics

In the survey designed to measure interns' beliefs about science teaching, Ms. Sawyer had beliefs aligned with current theories on learning (See Table 8-1). However, Ms. Sawyer also believed science instruction should be all hands-on all the time, deemphasizing student sensemaking. Despite having all hands-on all the time beliefs about science teaching at the start of the course, the science methods course seemed to have influenced Ms. Sawyer's beliefs about teaching. When commenting on how the course influenced how she planned and enacted her lessons, Ms. Sawyer stated,

> I feel like [before the course] I would have taught more activities, never really getting into the deeper question of why things were happening and the science behind it. I feel like I would have just taught a bunch of hands-on activities, probably making the teaching misconception of never really going back to the Explain element. I never realized how important that is for science… now that I have taught the [LiFE] lesson I realized I can't just say 'oh you did the experiment so now you should understand the science'. There is more to it than that. The kids need more support to make sense of it.
> [Sawyer, Interview 2]

Ms. Sawyer also had moderate understanding of how to foster argumentation among students and accurate content knowledge. For example, in her LiFE lesson plan she listed accurate connections between how sounds are made and the frequency and volume of the sound. She also listed three pieces of evidence from the investigation that students would be able to use to support their scientific claims for both her peer teaching and LiFE lessons. By listing multiple pieces of evidence in her plans and making connections to bigger scientific ideas in her card sorting activity, Ms. Sawyer was likely better able to recognize when her students contributed accurate scientific ideas during the investigation-based discussions.

Tool Use and Planned Enactment

Perhaps realizing the importance of student sensemaking during the methods course, Ms. Sawyer likely drew upon tools that would support her to scaffold student discussion during the Explain element. For example, in both her peer teaching lesson plan and her LiFE lesson plan, Ms. Sawyer planned to use open-ended questions from the *talk moves tool* to elicit, extend, and challenge students' ideas. In her peer teaching lesson plan, Ms. Sawyer also planned to make use of a *monitoring tool* and a *claim-evidence reasoning template.* Similar to Ms. Andrews, the *C-E-R template* likely allowed Ms. Sawyer to support her students to engage in explanation construction. The *C-E-R template* may have reminded Ms. Sawyer to press students for multiple pieces of evidence to support their scientific claims. Additionally, Ms. Sawyer planned to use the *monitoring tool* to formatively assess students' ideas throughout the investigation. As previously described in Chapter 6, Ms. Sawyer's *monitoring tool* included anticipated alternative ideas students may have about both the science content and the science practices as well as open-ended questions to ask students as she was circulating. Use of the *talk moves tool, C-E-R template*, and *monitoring tool* likely allowed Ms. Sawyer to plan a lesson that aimed to capitalize on student contributions and prioritize sensemaking – two characteristics Ms. Sawyer stated she valued in her end of course interview.

Within the Enactments

Like all other focal interns, Ms. Sawyer used talk moves from the *talk moves tool* in both her lessons. Use of the talk moves often occurred when she was eliciting students' initial ideas or prompting students to provide justification for those ideas. In both her peer teaching lesson and LiFE lesson enactments, Ms. Sawyer used representations to support her students to find patterns in data. Finally, in her peer teaching lesson Ms. Sawyer used the *C-E-R template* and *monitoring tool* to support her student to construct claims based on evidence and reasoning, and assess student understanding throughout the lesson enactment. Figures 8-18 and 8-19 provide evidence of segments where Ms. Sawyer's tool use and engagement in productive teaching practices co-occurred with her use of dialogic or authoritative voice and student engagement in science practices.

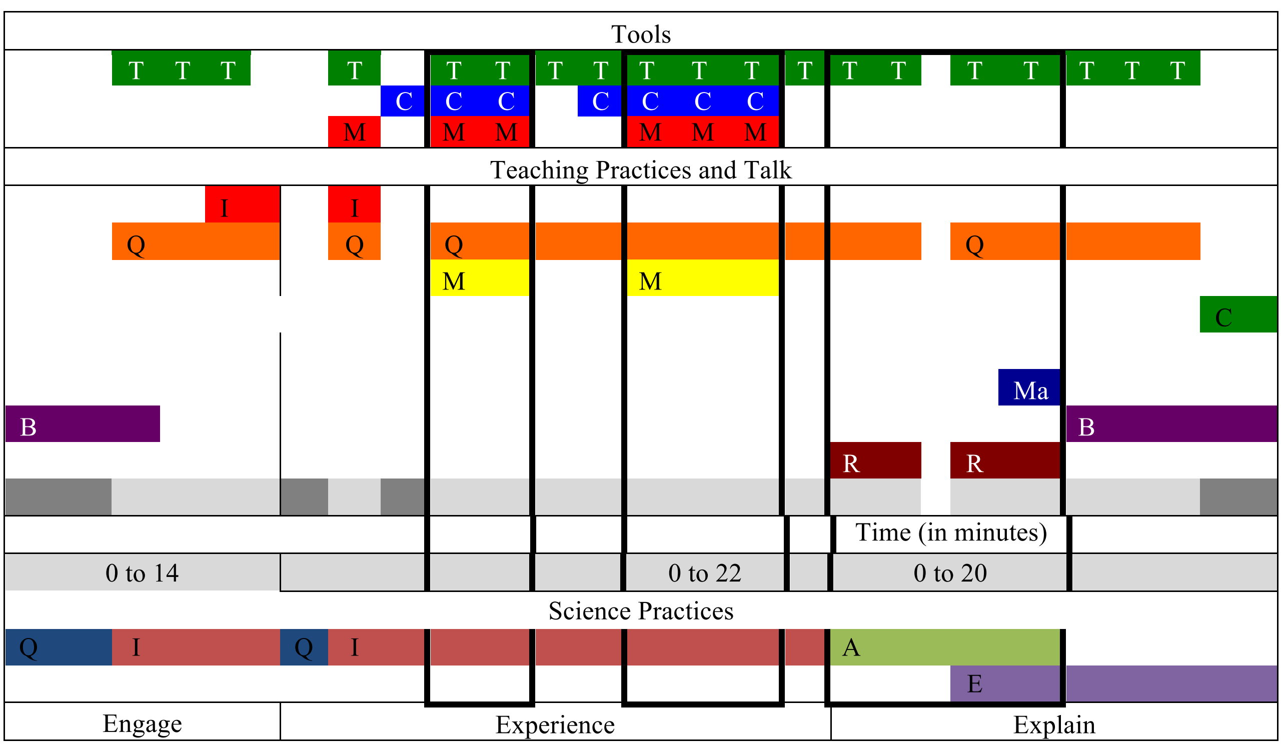

Figure 8-18: Ms. Sawyer's peer teaching enactment

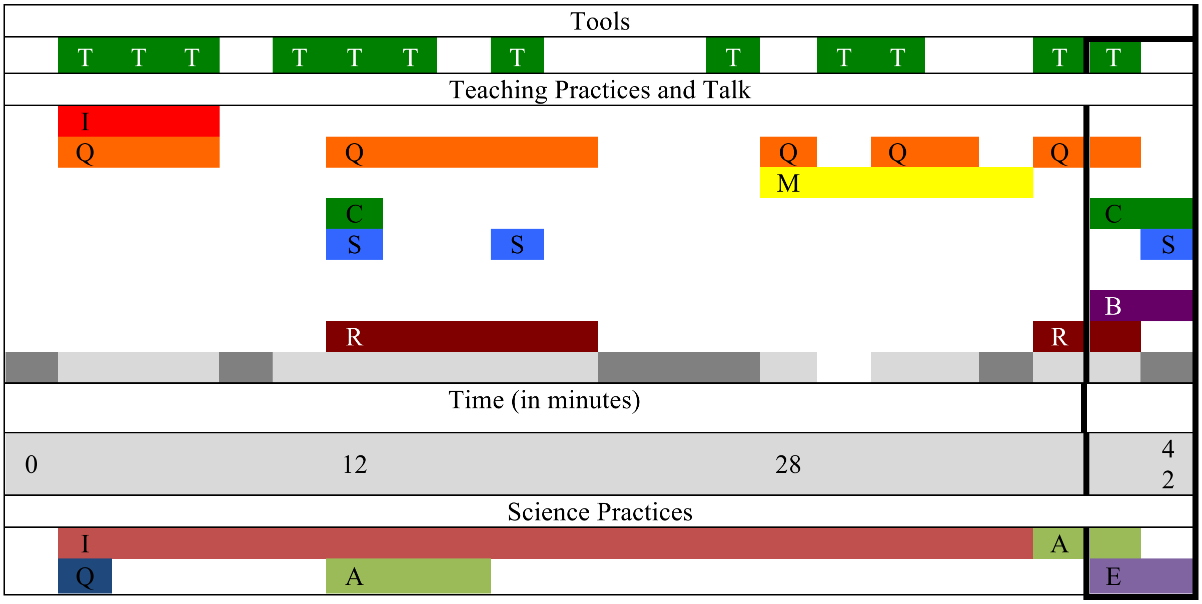

Figure 8-19: Ms. Sawyer's LiFE enactment

Talk moves, questioning, sophisticated monitoring, and representation. In both Ms. Sawyer's peer teaching and LiFE lesson enactments, she frequently used talk moves from the *talk moves tool* to elicit students' initial ideas (indicated by the red row), extend, or challenge her students' ideas (indicated by the orange row). Similar to Ms. Andrews, Ms. Lawrence, and Ms. Chase, Ms. Sawyer's use of the talk moves seemed to allow her to use dialogic voice (indicated in light gray), inviting more students to participate in the investigation-based discussion.

Ms. Sawyer's monitoring practices in her peer teaching enactment were more sophisticated than the other focal interns. Ms. Sawyer used the *monitoring tool* during the experience element of her peer teaching lesson [Sawyer Peer Teaching Experience 6:00-10:00; 14:00-18:00 outlined in Figure 8-18] to assess students' ideas as they were collecting data. Use of the *monitoring tool* in combination with the open-ended questions from the *talk moves tool* likely allowed Ms. Sawyer to notice nuances in students' ideas about their observations and the functions of a stem. Additionally, by using open-ended questions and the *monitoring tool*, Ms. Sawyer was able to pose questions to her students and then invite students into the conversation using dialogic voice (as indicated in grey) rather than explaining to students what they should be observing. In her LiFE lesson enactment, Ms. Sawyer did not use a *monitoring tool* to formatively assess students' ideas. Less aware of students' ideas during the lesson enactment, Ms. Sawyer may have had difficulty facilitating the investigation-based discussion, struggling to know which students may be able to contribute scientifically accurate understandings or productive alternative ideas to help students consider alternate claims.

Finally, in both her peer teaching lesson and her LiFE lesson, Ms. Sawyer used representations to support students to organize their observational data (indicated by the maroon representation row). The representation used during the investigation-based discussion was the same representation Ms. Sawyer provided her students on the *C-E-R template* during the experience element. By using the same representation on the *C-E-R template* and during the whole class discussion, Ms. Sawyer made patterns in the data more visible for her students. Use of the representation in combination with open-ended questions (indicated in orange) from the *talk moves tool* (indicated in green) allowed Ms. Sawyer to provide opportunities for her students to analyze their data and construct evidence-based claims [Sawyer Peer Teaching Explain 0:00-10:00 outlined in Figure 8-18]. The representation Ms. Sawyer used during her investigation-based discussion during her LiFE enactment helped organize students' contributions, but it did not seem to help make patterns in the data more visible, and students struggled to construct an evidence-based claim.

Time management and decreased use of tools. Ms. Sawyer struggled to elicit an explanation of what makes sound during the investigation-based discussion of her LiFE lesson [Sawyer LiFE 38:00-42:00 outlined in Figure 8-19]. This may have been due to having limited time to complete the science lesson or due to Ms. Sawyer's decreased tool use. During her peer teaching lesson, Ms. Sawyer could be seen checking her notes on her monitoring tool during the discussion. In doing so, Ms. Sawyer seemed to be able to support students to construct an evidence-based claim by asking students to contribute ideas she had heard them discuss while they were collecting data. In her LiFE lesson, Ms. Sawyer struggled to elicit ideas needed to support the students to progress to an accurate understanding of the phenomenon. Additionally, in her end of course interview as she watched her enactment, Ms. Sawyer described realizing that her students needed more support than she anticipated to construct the investigation-based claim stating, "I felt like I got them to share their observations, and then I got stuck. I didn't know who to call on to help me, and I had totally forgotten what they had said.... It felt chaotic" [Sawyer, Interview 2]. From this excerpt, it seemed Ms. Sawyer was aware of her difficulties in supporting her students to construct an evidence-based claim, Additionally, if Ms. Sawyer had had a systematic method of monitoring, it likely would have helped her structure the discussion.

Ms. Sawyer: Summary of Relationships

The combined use of the *talk moves tool*, *monitoring tool*, and *C-E-R template* during her peer-teaching enactment likely allowed Ms. Sawyer to have a sophisticated understanding of her students' ideas during each element of the peer teaching lesson; thus enabling her to facilitate an investigation-based discussion that was centered largely on student contributions. Given Ms. Sawyer's initial beliefs that science teaching should be all hands-on all the time, she may have been able to shift those beliefs, building knowledge for science teaching that was more aligned with current learning theories. In her LiFE enactment, with removal of the tools for support, Ms. Sawyer had difficulties supporting her students to construct evidence-based claims.

Summary of the Relationships

For all six of the focal interns, use of the tools was related with engagement in productive practices for capitalizing on student contributions. For example, use of talk moves from the *talk moves tool* allowed the interns to question students, eliciting initial ideas and then challenging and extending those ideas throughout the investigation-based lessons. Additionally, use of the *claim-evidence-reasoning template* seemed to allow the interns who used it to better support students to construct accurate scientific claims backed by multiple pieces of evidence. Use of the *monitoring tool* seemed to support interns who used it to formatively assess students' ideas throughout the lesson enactments, and then use those ideas to support students to develop an accurate understanding of the scientific phenomenon.

Interns also seemed to use tools that aligned with their beliefs about science teaching. Although some of the interns had beliefs about science teaching less aligned with current learning theories at the start of the course, all interns seemed to value sensemaking and tools that would support student sensemaking by the end of the methods course. Finally, accurate knowledge of the scientific content and threshold knowledge of fostering argumentation combined with the use of the *talk moves tool* and representations to support students to analyze data related to higher use of dialogic voice and student engagement in data analysis, argumentation, and explanation construction during lesson enactments.

Conclusion

This chapter considered each of the focal intern's characteristics, specifically their knowledge and beliefs about science content and science practices and beliefs about science teaching, in relation to their use of tools, engagement in productive teaching practices, voice, and student engagement in science practices. In Chapter 9, I discuss findings from this chapter as well as the findings from Chapters 5, 6, and 7 in connection to prior research.

CHAPTER 9

DISCUSSION AND IMPLICATIONS

Current reform efforts in science education prioritize science learning through the integration of science content and science practices, including student engagement in productive talk about scientific phenomena (National Research Council 2012; NGSS Lead States, 2013). Research has described the rich learning opportunities provided to students when teachers are able to plan and enact instruction that integrates science content and practice (Lehrer & Schauble, 2006; McNeill, 2009; Songer & Gotwals, 2012); however, planning and enacting this type of instruction is challenging and does not happen often in U.S. classrooms (Banilower et al., 2013; Pasley, Weiss, Shimkus, & Smith, 2004). Teaching science in this way requires a vision for science instruction that today's teachers may not have (Abell, 2007; Davis, Petish, & Smithey, 2006), and teachers learning to teach in this way require support (Abell, 2007; Appleton, 2007; Windschitl et al., 2012). Considering how a practice-based teacher education program might support interns to learn the knowledge and engage in the practices necessary to enact this kind of teaching, this dissertation looks at how interns within a science methods course use a suite of teacher-educator provided tools to engage in such teaching practices that capitalize on student contributions. Findings from this study contribute to the work on how practice-based teacher education programs and teacher-educator provided tools can foster beginning teachers' learning to plan and enact ambitious science instruction (Thompson et al., 2013; Windschitl et al., 2012).

This chapter begins with a discussion of the findings from the study and I situate the findings in the literature. I describe interns' use of the suite of tools designed to develop knowledge for science teaching, specifically knowledge for facilitating investigation-based discussions, and discuss intern justification of tool use. Additionally, I describe intern engagement in productive practices for capitalizing on student contributions, and looking closely at six focal interns, discuss possible relationships that existed among intern characteristics, tool use, teaching practice, voice, and student engagement in science practices. I conclude this chapter by describing implications for teacher education programs and science teacher educators.

Supporting Beginning Teacher Planning and Enactment of Investigation-Based Discussions

Interns showed similarities in the types of tools they used to plan and enact investigation-based discussions. Additionally, similarities and differences existed among intern engagement in productive practices for capitalizing on student contributions during investigation-based science lessons. In this section, I begin by considering similarities in interns' use of tools to plan and enact two investigation-based science lessons and summarize intern justifications for the use of those tools. Then, I consider how all participants planned to engage in productive practices for capitalizing on student contributions. Finally, I consider the similarities and differences among the individual focal interns' characteristics (specifically their knowledge and beliefs about science content and practice and knowledge and beliefs about science teaching) and how those characteristics relate to interns' use of tools (the participatory relationship) and planned and enacted investigation-based science lessons. First, I provide a summary of assertions made in each findings chapter of this dissertation in Table 9-1.

Table 9-1: Summary of Assertions

Dissertation Chapter	Assertion
Chapter 5	Interns used a range of different tools when planning investigation-based lessons.
Chapter 5	Interns used similar tools to plan both the peer teaching lesson and the LiFE lesson and use of specific tools supported interns to use additional productive teaching practices.
Chapter 5	Focal interns used similar tools in their enactments for both the peer teaching lesson and the LiFE lesson and use of specific tools supported focal interns to use additional productive teaching practices.
Chapter 5	Interns justified their use of tools in similar ways and justifications of tool use included but were not limited to (1) tools helped to keep the goals of science teaching in mind, (2) tools were coherent with the goals of the methods course and the teacher education program, and (3) tools helped to attend to learners' ideas and needs.
Chapter 6	Interns used a range of teaching practices that are productive for capitalizing on student contributions.
Chapter 6	Interns used productive teaching practices for capitalizing on student contributions more frequently and with more sophistication in their peer teaching lesson plans versus their LiFE lesson plans.
Chapter 7	Focal interns used the productive practices and engaged students in science practices in similar ways in both their peer teaching and LiFE lesson enactments.
Chapter 7	Focal interns differed both in their frequency of use and types of practices used during their lesson enactments.
Chapter 7	Focal interns' lesson enactments showed evidence of success and strength as well as missed opportunities and problems of practice.
Chapter 7	Combined use of teaching practices throughout lesson enactments seemed to lead to increased opportunities for students to share their ideas and engage in data analysis, argumentation, and explanation construction. These synergistic productive practices included: (1) considering students' initial ideas, (2) questioning students to elicit, extend, and challenge ideas, (3) making connections across students' ideas and the disciplinary core idea, (4) using a representation to organize and highlight students' ideas
Chapter 8	The use of tools was related to intern engagement in productive teaching practices for capitalizing on student contributions.
Chapter 8	Intern characteristics (e.g., content knowledge, beliefs about science teaching, etc.) related to the types of tools interns used to plan and enact their lessons.
Chapter 8	During lesson enactments, for some focal interns, use of dialogic voice and student engagement in data analysis, argumentation, and explanation construction occurred more frequently when interns used talk moves from the *talk moves tool* and representations to support data analysis. These same interns had at or above threshold knowledge of science content specific to their lesson and threshold knowledge of fostering argumentation.

Tool Use to Support Teacher Knowledge and Productive Teaching Practice

Similar to Windschitl and colleagues (2012), within lesson plans, I observed evidence of interns' interactions with a variety of tools. Interns used these tools to plan their investigation-based science lessons, organizing the lessons to support students to participate in construction of knowledge of scientific content by engaging in science practices. Although the use of the *EEE framework* and *lesson planning template* were requirements for the course, interns described heavily drawing on the *EEE framework* and *lesson planning template* to organize their lessons and keep the goals of science teaching in mind. Additionally, the use of the *EEE framework* seemed to help interns get a sense of the purposes of an investigation-based science discussion, pressing interns to assign importance to the Explain element during which students would be afforded opportunities to construct explanations (Davis, in press; Arias, 2015). Use of the core tool in combination with several of the priming tools/planning tools seemed to provide not only a framework for investigation-based discussions by planning to engage "students in talk that was productive in terms of developing science ideas and equitable in terms of opportunities for participation by all students" (Windschitl, et al., 2012, p. 886), but also scaffolding to allow interns to integrate productive moves for science teaching within their lesson plans. For example, use of the *EEE framework* to plan the Explain element of the lesson helped to focus interns' planning to support student construction of evidence-based claims.

Use of the *talk moves tool* helped interns to craft questions that would elicit both evidence and reasoning providing additional opportunities for student-to-student discussion. For example, all interns included science-teaching specific talk moves in their peer teaching plans such as, "What claim can you make based on the data you have so far?" or "Is there another claim that explains the data better?". Planning to use the talk moves from the *talk moves tool* allowed interns to have a set of questions to ask students to foster engagement in scientific discourse while engaging in science practices (e.g. data analysis, argumentation, and explanation construction) (Michaels et al., 2008; Sassi et al., 2013).

Also use of the teacher-educator provided tools might have supported interns to construct knowledge for science teaching and to use that knowledge in the teaching practice of planning for investigation-based science lessons. Use of the *alternative ideas tool* may have supported construction of knowledge of content and students (Ball et al., 2008). Almost all interns included researched-based alternative ideas in both of their lesson plans prompting several interns to consider both accurate and non-normative ideas about scientific phenomena as potential responses to open-ended questions throughout the plans. By including the alternative ideas in their plans, interns were likely more aware of the differences and nuances in students' ideas. This may have helped interns to avoid characterizing student ideas as simply "right" or "wrong" (Gotwals & Birmingham, 2015).

Use of the *monitoring tool* in combination with the *alternative ideas tool* may have facilitated the development of specialized content knowledge for science teaching supporting interns to become aware of knowledge needed only for fostering student understanding of scientific phenomena (Ball et al., 2008). Creation of a lesson-specific *monitoring tool* prompted interns to consider how they might respond to particular alternative ideas raised during instruction, and--in the moment--plan and enact instruction that might be responsive to helping students move from the alterative ideas toward a more accurate understanding the science phenomenon (Cartier et al., 2013; Ross, 2014). For example, Ms. Sawyer's use of the *monitoring tool* in her peer-teaching plan seemed to help her plan to assess her students' understanding of the function of a stem, and prompted her to support her students to be more systematic in their data collection.

Use of the *card sort tool* likely fostered intern common content knowledge development and horizon content knowledge development (Ball et al, 2008). Through the *card sort*, interns were provided opportunities to refresh their understanding of the big ideas targeted by their lessons and the larger science unit, gaining a better understanding of how science content ideas are connected. This allowed many interns to move past identifying and defining key terminology, allowing students to focus on substantive mechanistic explanations of scientific phenomena (Windschitl, et al., 2012). Analyses of interns' lesson plans showed the majority of interns were able to anticipate accurate student ideas about the scientific phenomenon, and provide some evidence of consideration of connections between the lesson and bigger scientific ideas, potentially due to completing the *card sort.*

Finally, use of the *Claim-Evidence-Reasoning template* may have supported interns' development of common content knowledge of both the scientific content and science practices. Several interns described the *Claim-Evidence-Reasoning template* as being helpful for supporting their own understanding of science content. Additionally, interns who used the *C-E-R template* planned to press students for more than one piece of evidence to support their claims, illustrating interns may have understood that scientific claims are often backed by multiple pieces of evidence (McNeill, 2009; National Research Council, 2012; NGSS Lead States, 2013; Songer & Gotwals, 2012). Interns also reported that the *C-E-R template* held them accountable for the sensemaking discussion that should occur after students analyze data from the investigation. By using the *C-E-R template* with students, interns planned to go beyond having students share their observations moving toward constructing scientific explanations (Zangori &

Forbes, 2013), and planned to engage in the teaching practices that have been connected to student learning (Berland & McNeill, 2010; McNeill & Krajcik, 2009; Songer & Gotwals, 2012). For example, many interns' *C-E-R templates* used a logical structure (e.g. Toulmin's (1958) framework for argumentation) for constructing claims; in some cases, representations to scaffold student data analysis; and sentence starters prompting students to list multiple pieces of evidence to support their claims.

Like interns' plans, similarities existed across the types of tools the focal interns used in their enactments for the peer teaching and LiFE lessons. Most notably, for both lessons, all six focal interns used several *talk moves* provided by the *talk moves tool* throughout their lesson enactments. Interns' use of the talk moves supported students to construct scientific claims based on multiple pieces of evidence. Use of the talk moves, for example, also helped students to consider alternative explanations be more systematic in their data collection, and allowed the students to do the intellectual work of finding patterns in the data they collected (Colley & Windschitl, 2016; Sassi et al., 2013).

Differences also existed in the types of tools used in the peer teaching and LiFE lesson enactments. For the peer teaching lesson, four of the focal interns (Ms. Andrews, Ms. Kramer, Ms. Chase, and Ms. Sawyer) encouraged students to use the versions of the *C-E-R template* they had created for their peer teaching lesson. In contrast, only one intern (Ms. Andrews) created and used a *C-E-R template* for her LiFE lesson. For both the peer teaching lesson and the LiFE lesson enactments, use of a *C-E-R template* seemed to have supported the students to record their data during the investigation and use that data as evidence when constructing evidence-based claims. Similar to the lesson plans, use of the *C-E-R template* in the enactments seemed to support interns to press students to move beyond sharing observations of the phenomena

(Zangori & Forbes, 2013). Additionally, use of the *C-E-R template* in combination with *monitoring tool*, in the case of Ms. Sawyer, allowed for formative assessment of students' understanding of scientific content at the conclusion of the lesson (Gotwals & Birmingham, 2015).

Justification for Tool Use: A Need for Cohesion

In several instances, interns justified their tool use because of the tool's cohesion with the goals of the science methods course and the teacher education program. Through the use of these types of consistent and cohesive conceptual themes and tools during an elementary teacher education program, interns may have developed a vision for teaching that aligned with the goals of the program (Anderson et al., 2000; Davis & Smithey, 2009; Zembal-Saul et al., 2000).

One such tool, the *lesson planning template*, served as part of the greater overall vision of the teacher education program (Davis & Boerst, 2014). Because the template was being used in all of the methods courses it provided cohesiveness and a clear trajectory within each lesson interns planned (Leinhardt, Zigmond, & Cooley, 1981; Leinhardt & Greeno, 1986), but also across their experiences within the teacher education program. Additionally, the modifications made to the *lesson planning template* meant to highlight the important aspects of science teaching became salient because of intern familiarity with the non-subject specific planning template, speaking to the need for a suite of tools that embody both the pillars of the teacher education program and the goals of the subject-specific methods course.

Similarly, the use of talk moves across the teacher education program likely made the science-teaching specific talk moves more accessible to interns. Interns reported the use of the talk moves as feeling intuitive, and described the moves as something they had seen and used iteratively throughout the program. It seems as though use of these moves became internalized as part of the interns' teaching practice given that several interns described not using the *talk moves tool* despite evidence of use of the science-teaching specific moves in almost 100% of the lesson plans. Use of the science-teaching specific talk moves within the *instructional planning template* allowed the interns to plan for additional opportunities for students to engage in scientific practices and sensemaking by sharing and justifying their ideas and the ideas of others (cf. Anderson et al., 2000; Zembal-Saul et al, 2000).

Summary: Tool Use for Development of Knowledge for Science Teaching

These findings are important in light of other studies that describe tools designed to support teachers to provide opportunities for students to engage in explanation construction and argumentation based on evidence – two science practices that prioritize student talk. Similar to Windschitl and colleagues' (2012) findings, the suite of tools provided to interns in this study likely supported them to think deeply about the salient features of science teaching that integrates science content and science practice. Prior studies typically considered teachers' abilities to enact this type of teaching practice with fewer forms of support (e.g., supports focusing primarily on talk moves designed to facilitate discussions). While the use of talk moves such as open-ended questions have been shown to foster student participation in English and social studies discussions (Nystand et al., 2003) and science discussions (e.g. Michaels et al., 2008; Sassi et al., 2013), fewer studies have investigated how use of talk moves in combination with other teacher-educator provided tools support beginning teachers to develop knowledge for science teaching and engage in teaching practices that capitalize on student contributions and are responsive to student ideas (Windschitl et al., 2011; Windschitl et al., 2012). In the next section, I describe interns' planned engagement in productive teaching practices that capitalize on student contributions.

Use of Productive Practices within Lesson Plans

Interns enrolled in the methods course used a range of teaching practices that are productive for capitalizing on student contributions within their peer teaching and LiFE lesson plans. Interns used productive teaching practices for capitalizing on student contributions more frequently and with more sophistication in their peer teaching lesson plans versus their LiFE lesson plans. For the peer teaching lesson, interns were provided with curriculum materials, eliminating the need for interns to select an appropriate investigation-based science lesson for students within the mentor teacher's classroom. Additionally, planning and enacting the peer teaching lesson took place over six course meetings. By increasing the amount of time interns had to plan and revise their lesson plans based on teacher-educator and colleague feedback, interns may have been able to think more deeply about how to prioritize student contributions and decompose the practices necessary for facilitating a student-centered investigation-based discussion (cf. Arias, 2015; Boerst, Sleep, Ball, & Bass, 2011; Grossman, Compton, et al., 2009; Nelson, 2011). Several interns, including focal intern Ms. Zabel, were not provided curriculum materials as a starting point for their LiFE lessons, adding additional complexity (Grossman, Compton, et al., 2009) to the task of planning the LiFE lesson and likely contributing to less sophisticated planned engagement in the productive teaching practices.

Across both sets of plans, the majority of interns were able to anticipate students' accurate scientific ideas. The majority of interns were also able to connect the science content of the peer teaching and LiFE lessons to larger scientific principles and reasoning with some sophistication, potentially due to interaction with the *card sort tool*. This finding is encouraging in light of reports that elementary teachers' understandings of scientific phenomena are unsophisticated and many elementary teachers enter the profession with the same alternative ideas as their students (Abell, 2007; Davis et al., 2006; Gess-Newsome & Lederman, 1993; Lederman, Gess-Newsome, & Latz, 1994). Interns' ability to accurately identify connections between the larger scientific ideas is particularly important given Windschitl and colleagues' (2012) findings that identification of the big science ideas was a necessary precursor to interns' engagement in more sophisticated teaching practices. Additionally, the majority of interns were able to craft questions that would elicit, extend, or challenge student thinking, likely drawing on the science-teaching specific talk moves provided during the methods course. By crafting questions to elicit students' thinking, interns likely provided students more opportunities to share their thinking with others (Colley & Windschitl, 2016; Michaels et al., 2008; Nystand et al., 2003; Sassi et al., 2013).

In contrast, evidence of planning to monitor students while they engaged in carrying out the investigation varied across the two plans, as did planned use of representations to organize and highlight student contributions. Limited plans to monitor student thinking during the investigation may have contributed to a lack of awareness of how students were thinking about the scientific content (Cartier et al., 2013, Ross, 2014). Finally, lack of use of a representation may have resulted in students struggling to notice important patterns or trends in their data, and missed opportunities to engage students in the science practices of data analysis and explanation construction (Arias, 2015).

Use of Productive Practices within Lesson Enactments

I observed similar variations of engagement in productive teaching practices for capitalizing on student contributions within the focal interns' lesson enactments. Across both lesson enactments, all six focal interns elicited students' initial ideas about the scientific phenomena and used follow up questions to probe and extend students' thinking. However, interns differed in how often they engaged in the practice of questioning. Ms. Andrews, Ms. Lawrence, Ms. Chase, and Ms. Sawyer used open-ended questions throughout both lessons, and use of these open-ended questions frequently related to increased use of dialogic voice and student engagement in data analysis, argumentation, and explanation construction. In addition, Ms. Andrews, Ms. Lawrence, Ms. Chase, and Ms. Sawyer seemed to be able to productively shift between the use of authoritative voice (e.g. reminding students of their initial ideas as the start of the Explain element or summarizing important content ideas contributed by students) and dialogic voice (e.g. asking open-ended questions to construct claims based on evidence).

On the other hand, Ms. Kramer and Ms. Zabel often only used open-ended questioning and dialogic voice while monitoring students as they were carrying out the investigation, relying on the use of authoritative voice and I-R-E style discussions during the whole group portions of the lesson. While use of open-ended questions and dialogic voice offered students opportunities to share their ideas with one another while making observations, limited use of open-ended questioning and dialogic voice in the Explain element of both Ms. Kramer's and Ms. Zabel's peer teaching and LiFE lessons limited students' opportunities to analyze data, argue, and construct explanations. Colley and Windschitl (2016) had similar findings when analyzing the types of teaching practices that related to responsiveness toward student contributions and student participation in rigorous whole-class discussions. Teacher use of open-ended questioning in isolation at any point in the lesson did not relate to increased opportunities for students to make sense of data and construct explanations of phenomena.

Rather than using open-ended questions in isolation, in their peer teaching enactments, Ms. Andrews, Ms. Lawrence, Ms. Chase and Ms. Sawyer used four of the productive practices synergistically. Consideration of students' initial ideas in the Engage element, and in the Explain element use of open-ended questions to elicit, extend, and challenge student thinking occurring in combination with two other practices (making connections across students' ideas and the disciplinary core ideas and using a representation to organize and highlight students' ideas) related to increased use of dialogic voice and additional opportunities for students to do the intellectual work while analyzing data and constructing explanations. The use of open-ended questions followed by a series of probing questions (either from the teacher or other students) to connect and extend students' thinking to that of others' and the overarching scientific principles, and use of a representation as a referent and scaffold for supporting data analysis (Mercer, 2008) seemed to be necessary for students to engage in productive scientific discourse (Colley & Windschitl, 2016). Ms. Kramer also used the same four teaching practices synergistically in her LiFE lesson; however, the representation served a different purpose (i.e. a public record of students' ideas throughout the investigation rather than both a public record and scaffold for data analysis) and her lesson was less successful, suggesting that the type of referent used during investigation-based discussions may be crucial.

First, these findings are encouraging given that prior research has identified that teachers struggle to enact the kind of teaching needed for students to engage in the discourses of science (Carlsen, 1987; Harris et al., 2012; Herrenkohl et al., 1999; Hogan et al. 1999; Lemke, 1990; McNeill & Pimental, 2010; Mehan, 1979; Penuel et al., 2012; Simon et al., 2006). Although not all focal interns were able to consistently use the synergistic teaching practices and dialogic voice to foster student participation in argumentation and explanation construction in both lesson enactments (e.g., Ms. Andrews frequently shifted into authoritative voice at the end of her LiFE enactment), findings from this dissertation provide evidence that beginning teachers, with support, are able to enact instruction that facilitates student discussion and engagement in science practices. Second, these findings complement those of Colley and Windschitl's (2016) study in which an experienced guest teacher was able to scaffold rigorous science discussions that were responsive to fourth grade students' ideas about a dying flashlight. Much like the focal interns' enactments, rigorous discussion and productive student talk about science content more frequently occurred when the expert teacher used open-ended questioning and follow up questions to probe student thinking, in combination with a referent (i.e., a representation and public record of student thinking over the course of the investigation).

Potential Relationships Among Intern Characteristics, Tool Use, and Lesson Plans and Enactments

As described previously, focal interns' use of the teacher-educator provided tools (e.g., use of open-ended questions from the talk moves tool) was related to intern engagement in productive teaching practices. However, use of the *talk moves tool* to pose open-ended questions to students, when used in isolation, did not relate to increased opportunities for student sensemaking. Intern characteristics (e.g., content knowledge and beliefs about science teaching, etc.) did seem to relate to the types of tools interns used to plan and enact their lesson. Additionally, for several focal interns with at or above threshold knowledge of science content specific to their lesson and threshold knowledge of fostering argumentation, use of the synergistic productive practices related to higher use of dialogic voice, and student engagement in data analysis, argumentation, and explanation construction. In this section, I summarize the similarities and differences in the focal interns' characteristics in relation to tool use, and planned and enacted investigation-based science lessons.

Andrews and Chase: Aligned beliefs, strong content knowledge, strong enactments. Ms. Andrews and Ms. Chase had beliefs about science teaching that were strongly aligned with the goals of the teaching program and the science methods course. Ms. Andrews's and Ms. Chase's beliefs likely allowed them to make use of tools aligned with those beliefs (e.g., the *talk moves tool* and the *C-E-R template*), taking up the vision of the teaching education program more willingly (Anderson et al., 2000; Thomson et al., 2013; Zembal-Saul et al., 2000).

In both Ms. Andrews's and Ms. Chase's peer teaching enactments, use of the *talk moves tool* to ask open-ended questions in combination with use of representations and dialogic voice (Mortimer & Scott, 2003) supported students to analyze data, engage in argumentation based on evidence, and construct explanations. Additionally, Ms. Andrews's and Ms. Chase's accurate knowledge of the concept of heat energy transfer and common alternative ideas seemed to allow them to recognize when students contributed both alternative ideas and accurate understandings of the scientific phenomenon in their peer teaching lessons. Once students had shared their ideas, both Ms. Andrews and Ms. Chase were able to use those contributions in productive ways shifting between authoritative voice and dialogic voice productively (i.e., to work toward an accurate explanation, or to foster argumentation), making connections between students' ideas and the disciplinary core idea. Ability to use and make connections between students' ideas productively provides evidence of Ms. Andrews's and Ms. Chase's knowledge in practice (Hammerness et al., 2005; Lampert, 2010), highlighting their strong subject matter knowledge and knowledge of content and students relative to the concepts of heat energy transfer (Ball et al., 2008; McDiarmid et al., 1989; Shulman; 1986).

Within their LiFE lesson plans and enactments, Ms. Andrews and Ms. Chase showed similar evidence of strong subject matter knowledge related to the spread of disease within a community (Ms. Andrews) and condensation (Ms. Chase). However, Ms. Andrews's lesson enactment provided students fewer opportunities to engage in scientific discourse and sensemaking. Ms. Andrews's frequent use of authoritative voice in her LiFE lesson may have been related to her relatively strong knowledge of the scientific content, using a lecture-style or I-R-E pattern of discourse toward the end of her LiFE lesson (Carlsen, 1991). Alternatively, Ms. Andrews's frequent use of authoritative voice may have been due to students being unfamiliar with the claim-evidence reasoning framework. Aligned with other studies showing that students often struggle to construct evidence-based claims (e.g., Lehrer & Schauble, 2006; Songer & Gotwals, 2012), Ms. Andrews may have determined a need for additional support for her students to construct the scientific claim. In contrast, Ms. Chase's successes in fostering productive scientific discourse in her Explain element of her LiFE lesson may have been attributed to her strong knowledge for fostering argumentation.

Lawrence and Sawyer: Varied strength across enactments. Like Ms. Andrews and Ms. Chase, Ms. Lawrence's beliefs about science teaching were aligned with the goals of the course. Ms. Lawrence's peer teaching enactment was also similar to Ms. Andrews and Ms. Chase. Throughout her peer teaching enactment Ms. Lawrence showed evidence of her strong content knowledge of the concept of heat energy transfer. Use of the *talk moves tool* to ask open-ended questions in combination with use of representations and dialogic voice supported students to analyze data, engage in argumentation based on evidence, and construct explanations.

Unlike Ms. Andrews, Ms. Chase, and Ms. Lawrence, Ms. Sawyer's initial beliefs about science teaching were less aligned with the goals of the course. Despite her less aligned beliefs, Ms. Sawyer's peer teaching lesson enactment was strong. Ms. Sawyer provides an example of the potential of teacher-educator provided tools, suggesting that, with support, interns with beliefs less aligned with goals of the methods course may still be able to enact instruction that privileges scientific discourse. In her peer teaching lesson, Ms. Sawyer used several of the tools provided during the methods course, potentially allowing her to develop knowledge for science teaching and enact instruction that she otherwise would not have been able to enact alone (Cole & Wertsch, 1996; Wertsch, 1991; Vygotsky, 1978).

Ms. Sawyer's use of the *talk moves tool*, *monitoring tool*, and *C-E-R template* during her peer-teaching enactment likely allowed Ms. Sawyer to formatively assess her students throughout the lesson having a sophisticated understanding of her students' ideas during each element of the peer teaching lesson (Cartier et al., 2013; Gotwals & Birmingham, 2016; Ross, 2014); thus enabling her to facilitate an investigation-based discussion that was centered largely on student contributions. Given Ms. Sawyer's initial beliefs that science teaching should be all hands-on all the time, she may have been able to shift those beliefs, building knowledge for science teaching that was more aligned with current learning theories (Anderson et al., 2000; Davis & Smithey, 2009; Zembal-Saul et al., 2000). Ms. Sawyer provides an example of the mutual adaptation that can occur between interns and tools (McLaughlin, 1976). Ms. Sawyers' use of tools that prioritized tailoring instruction around student ideas (e.g., the monitoring tool) may have mediated development of knowledge and beliefs about science teaching that were closely aligned with the student-centered focus of the methods course (Vygotsky, 1978; Werstch, 1998). Ms. Sawyer's comments during interviews further support the hypothesis that use of tools like the *EEE framework* supported Ms. Sawyer to develop knowledge for science teaching that valued student sensemaking.

Despite their strong peer teaching enactments, both Ms. Lawrence and Ms. Sawyer had missed opportunities in their LiFE enactments. Ms. Lawrence's LiFE lesson plan and enactment did not provide evidence of strong content knowledge in relation to the concept of transparency. Ms. Lawrence's inaccurate understandings of the science content in her LiFE lesson seemed to limit students' opportunities to come away from the investigation with an accurate understanding of the phenomenon. Ms. Lawrence's inability to identify the big ideas related to her LiFE lesson may have limited her ability to engage in the productive practices for capitalizing on students' ideas (Windschitl et al., 2012). Alternatively, due to weak subject matter knowledge and self-reported difficulties knowing how to move the lesson forward with unexpected student responses, she may have shifted into an I-R-E pattern of discussion toward the end of her lesson to maintain direction and linguistic control (Carlsen, 1987; 1991; Colley & Windschitl, 2016).

Another plausible explanation of Ms. Lawrence's struggles in her LiFE enactment may have been due to her developing knowledge for science teaching and the complexities of the curriculum materials used for her LiFE lesson. The original curriculum materials for Ms. Lawrence's LiFE lesson plan proposed students observe a pencil within a bottle of water and a bottle of oil, and text behind a magnifying glass to determine how light behaves when it reaches a transparent object. The large number of student observations, and challenges related to helping students understand both the concepts of transparency and refraction may have added "noise" to the lesson making it difficult for Ms. Lawrence to determine the aspects of the investigation that would be beneficial for student learning (cf. Hill & Charalambous, 2012). For example, with her limited content knowledge and developing knowledge for science teaching, Ms. Lawrence might have lacked the pedagogical design capacity (Brown, 2009) to modify the lesson for her students, struggling to determine which observations were most important for students to carry out to determine how light behaves when it hits a transparent object. Ms. Lawrence struggled to see the similarities in the three objects suggested by the lesson plan, failing to realize that the water, oil, and magnifying glass were the transparent objects rather than the straw; thus causing the investigation-based discussion to lack focus and direction.

In her LiFE enactment, with removal of the tools for support, Ms. Sawyer had difficulties supporting her students to construct evidence-based claims, indicating that a single lesson enactment did not allow Ms. Sawyer to develop the knowledge of content and teaching (Ball et al., 200) needed to enact an investigation-based science lesson without support when the complexity and authenticity of the task was increased (i.e., teaching elementary students) (Grossman, Compton, et al., 2009).

Kramer and Zabel: Beliefs less aligned and weaker enactments. Ms. Zabel and Ms. Kramer had initial beliefs about science teaching that were less aligned with the goals of the teaching program and the science methods course. Having less aligned beliefs might have made it more challenging for Ms. Kramer and Ms. Zabel to make use of tools aligned with the goals of the science methods course. Although both interns found value in student sensemaking and teaching lessons aligned with the *EEE framework* by the end of the course, taking up a reform-oriented vision for science teaching and using tools aligned with that vision might have been challenging (Anderson et al., 2000; Thompson et al., 2013; Zembal-Saul et al., 2000).

Ms. Kramer's and Ms. Zabel's peer teaching and LiFE lesson enactments reflected this challenge. Despite their use of talk moves from the *talk moves tool*, both interns returned to largely I-R-E style discussions toward the end of their lessons, limiting students' opportunities to reason dialogically (Lemke, 1990; Mehan, 1979; Windschitl et al., 2012). In both of her lessons, Ms. Zabel's questions lacked clarity. She also struggled to support students to analyze data and construct and compare explanations; similar struggles to those described in the literature (Biggers, Forbes, & Zangori, 2013; McNeill, 2009). Ms. Kramer also struggled to pose clear questions in her peer teaching lesson, and provided the scientific claim for her students rather than eliciting the claim from students. In her LiFE lessons, Ms. Kramer's questions were clearer, however, she struggled to support students to analyze their observational data of the fish.

In addition to difficulties being attributed to beliefs less aligned with the goals of the methods course, another plausible explanation for Ms. Kramer's and Ms. Zabel's struggles may be the disconnect between the expectations of the methods course and the classroom culture (Beyer & Davis, 2012; Forbes & Davis, 2010; Thompson et al., 2013). Because sensemaking science discussions happen rarely in U.S. elementary classrooms (Banilower et al., 2013; Pasley et al., 2004) and often students are not expected to engage in the intellectual work (cf. Stein, Grover, & Henningsen, 1996), Ms. Kramer and Ms. Zabel may have struggled to determine exemplars of the types of teaching practice that integrate science practice and content. For example, Ms. Zabel commented in her interviews that all of the science lessons she had observed her mentor teacher enact were text-based rather than investigation-based. While text-based science lessons engage students in science practices outlined by the *NGSS* (e.g., obtaining, evaluating and communicating information), the lessons did not provide students' opportunities to construct claims based on evidence they had collected by engaging in an investigation. Also, the science instruction Ms. Kramer and Ms. Zabel experienced was likely different than the instruction being modeled in the teacher education program (Lortie, 1975).

In their interviews, both Ms. Kramer and Ms. Zabel described seeing value in using the tools to prioritize student sensemaking, providing evidence that use of the tools may have supported Ms. Kramer and Ms. Zabel to develop knowledge and beliefs about science teaching more closely aligned with the methods course (cf. Vygotsky, 1978; Werstch, 1998). However, due to the compressed nature of the methods course, Ms. Kramer and Ms. Zabel may not have been able to fully develop the pedagogical content knowledge and teaching practice needed to enact investigation-based discussions (Arias, 2015).

Summary: Relationships between Intern Characteristics, Tool Use, and Planned and Enacted Lessons

In sum, similarities existed across the types of tools and teaching practices interns used most frequently to plan and enact investigation-based discussions. Interns also justified their use of tools in similar ways describing that the tools helped them to keep the goals of science teaching in mind and that the tools were coherent with the larger teacher education program. For the focal interns, combined use of a set of synergistic teaching practices throughout the lesson enactments--specifically consideration of students' initial ideas; use of open-ended questions to elicit extend, and challenge ideas; making connections across students' ideas and the disciplinary core ideas; and use of a representation to organize and highlight students' ideas—may have led to increased opportunities for students to share their ideas and engage in data analysis, argumentation and explanation construction. Student opportunities to engage in practices that prioritize engagement in scientific discourse also occurred when interns were using dialogic voice and the tools designed to foster development of teacher knowledge for facilitating investigation-based science discussions. However, several intern characteristics likely moderated intern use of tools, use of dialogic voice, and use of productive teaching practices to capitalize on student contributions. These characteristics included intern knowledge of the science content and practices and initial beliefs about science teaching. Missed opportunities to use a combination of several teaching practices and tools designed to foster the development of knowledge for science teaching resulted in fewer opportunities for students to engage in data analysis, argumentation based on evidence, and construction of scientific explanations.

Implications for Supporting Beginning Teacher Planning and Enactment of Investigation-Based Science Discussions

Findings from this study provide theoretical implications shedding light on the decomposition of the teaching practice of facilitating investigation-based discussions, methodological implications for studying investigation-based science lesson enactments, as well practical implications for the design of tools for supporting beginning teachers to engage in planning and enacting investigation-based discussions. This study also provides insights into relationships that exist between novice teacher characteristics and tool use and how those relationships shape planned and enacted investigation-based discussions, providing implications for teacher education programs and science education teacher educators.

Theoretical Implications

These findings provide empirical evidence to bolster current descriptions of the practices involved in facilitating discussions in elementary science classrooms. Figure 9-1 provides descriptions of how the literature has defined and decomposed the practice of facilitating science discussions. Then, I discuss how this dissertation extends the literature– composing a list of high-leverage sub-practices for facilitating investigation-based discussions in elementary science classrooms. Figure 9-2 provides a decomposition of the practice of facilitating investigation-based discussions based on findings from this dissertation and compares the decomposition with prior research. Figure 9-2 also lists the teacher-educator provided tools that aimed to develop teacher knowledge and practice of each of the sub-practices for facilitating investigation-based discussions.

Prior Research Decompositions of “Facilitating Discussions”			
	Windschitl et al., 2012	Cartier et al., 2013	Kloser, 2014
PLANNING PRACTICES	**W1:** Constructing the big idea: teachers develop subject matter knowledge related to the concept they are teaching while determining connections between the investigation and larger disciplinary core ideas	**C1**: Anticipating how students are likely to respond to a task including anticipating possible accurate and non-normative student understandings of phenomena.	**K1:** Creating opportunities for students to engage in science related talk by planning opportunities for students to discuss scientific phenomena in small groups or during whole-class discussions.
TEACHING PRACTICES	**W2:** Eliciting students’ ideas to adapt instruction: eliciting students’ ideas, representing publically selected elements of students’ thinking, adapting subsequent instruction based on partial student understanding. **W3:** Helping students make sense of the material activity: intentional interrogation of students’ ideas, revisiting students’ initial ideas. **W4:** Pressing students for evidence-based explanations: reorienting students to possible explanatory models and hypotheses, coordinating students’ explanations and prompting students to justify with evidence, applying the explanation to new contexts.	**C2:** Monitoring what students are doing while working on the task including development of a monitoring tool to keep track of students accurate and non-normative ideas. **C3:** Selecting particular students to present their work during the whole-class discussion. **C4:** Sequencing student work to be displayed in a particular order potentially ensuring that the lesson progresses toward accurate student understanding of the scientific phenomenon. **C5:** Connecting different students’ responses to each other and to key scientific ideas.	**K2:** Establishing normative rules for discourse between students and model common discursive practices. **K3:** Facilitating sharing of evidence, model-based explanations, or arguments. **K4:** Encouraging students to take up, clarify, and justify the ideas of others.

Figure 9-1: Prior research decomposition of teaching practices involved in facilitating discussions

	High-leverage teaching sub-practices involved in facilitating investigation-based discussions based on evidence from this dissertation	Related sub-practices from prior literature	Teacher-educator provided tool to support practice
PLANNING PRACTICE	**1:** Constructing subject matter knowledge, and using tools to support eliciting, anticipation of ideas and monitoring, and student explanation construction (this may be particularly important for interns with beliefs less aligned with the goals of the science methods course and teacher education program)	W1, C1, K1	Card sort tool EEE framework IPT Alternative ideas too Talk moves tool Monitoring tool CER template
TEACHING PRACTICES	**2:** Eliciting and considering students' ideas at multiple time points during the investigation-based lesson and record elements of those ideas for public record.	W2	Talk moves tool CER template
	3: Using open-ended questions to extend and challenge students' ideas encouraging justification based on scientific evidence.	W3, C2, W4, C3, K3	Talk moves tool Monitoring tool CER template
	4: Making connections across both students' ideas and the disciplinary core ideas appropriate for the investigation	W4, C4, C5	Talk moves tool Monitoring tool CER template
	5: Using a representation to organize and highlight students' ideas during data analysis and returning to that representation as a referent during explanation construction.		CER template

Figure 9-2: High-Leverage Teaching Sub-Practices Involved in facilitating investigation-based discussions

Windschitl and colleagues (2012), Cartier and colleagues (2013), Kloser (2014) and findings from this dissertation have similarities. For example, all four decompositions of facilitating discussions describe making connections among students' ideas and the disciplinary core ideas appropriate for the lesson, potentially encouraging students to take up, clarify, and justify responses based on evidence. The decompositions differ in respect to the specificity of the teaching practices and areas of concentration. For example, Kloser's (2014) decomposition stresses the need for the teacher to establish normative rules for discourse between students and model common discursive practices. I do not argue that this practice is unimportant. However, for interns enrolled in a condensed science methods course who are teaching investigation-based lessons within the course and mentor teacher's classrooms, it may be difficult for interns to gain experience establishing normative rules. Additionally, Windschitl and colleagues' (2012), Cartier and colleagues' (2013) and Kloser's (2014) decompositions of facilitating science discussions are intended for and developed from examining and describing the teaching practices of secondary science teachers. The difference in audience may account for some of the differences between the three decompositions and the sub-practices listed in Figure 9-2. For example, secondary science students may have additional experience creating and interpreting their own representations of scientific data, therefore use of a whole-class representation for students to refer to may be less important during secondary science investigation-based discussions.

Findings from this dissertation and Colley and Windschitl (2016), which examines the teaching practice of a single elementary teacher, speak to the importance of interns' use of open-ended questions to facilitate students' productive science talk. However, used in isolation, open-ended questions are not enough to engage students in productive scientific discourse. Using open-ended questioning is one of the synergistic practices that likely relates to increased use of dialogic voice and thus increased opportunities for student sensemaking through engagement in science practice. In addition to using open-ended questioning to elicit, challenge, and extend student thinking and recording elements of those ideas for public record, interns who were able to enact more successful investigation-based discussions, were also able to make connections among students' ideas and the disciplinary core ideas appropriate for the investigation and use a representation to organize and highlight students' ideas during data analysis, returning to that representation as a referent during explanation construction. Use of a representation during data analysis and discussion is likely specific to the practice of facilitating *investigation-based* discussions, recognizing other types of science lessons (e.g., text-based science lessons) might require different type of referent for student thinking to be more productive for student learning.

Engagement in the four synergistic practices occurred more frequently in cases of interns who had strong content knowledge and beliefs aligned with the goals of the program. In one case of a focal intern with beliefs less aligned with the goals of the methods course, Ms. Sawyer, engagement in the four synergistic practices occurred with simultaneous use of multiple tools designed specifically to foster development of knowledge for facilitating investigation-based discussions; thus, speaking to the need for continued development and revision of teacher-educator provided tools for use in practice-based teacher education programs.

Methodological Implications

In addition to the theoretical implications contributing to the decomposition of the practice of facilitating investigation-based discussions, this dissertation has methodological implications for the study of teachers' enactments of investigation-based discussions. By considering the ways in which multiple factors may shape the investigation-based discussions (e.g., intern characteristics; tool use; planned and enacted engagement in productive teaching practice; progression of the enactments through the Engage, Experience, and Explain elements of the lesson) this dissertation begins to shed light on the complexities of enacting investigation-based discussions. By considering intern characteristics, specifically their knowledge and beliefs about science content, science practices, and investigation-based science instruction, I was able to create typical "profiles" of interns (e.g. Anderson et al., 2000) with similar characteristics and look for patterns within profiles. Although I was unable to identify all characteristics that may shape intern enactment of investigation-based discussions, this study suggests that intern knowledge and beliefs about science content, science practice, and investigation-based science instruction likely influence the ways in which interns enact investigation-based discussions.

Looking more broadly at the characteristics (e.g., productive teaching practice, tool use, types of talk, and student engagement in science practice) of focal interns' teaching practice across focal teachers' enactments had additional affordances. Prior research has argued that it is important for teachers to engage in responsive teaching (e.g., Colley & Windschitl, 2016; Engle, 2006). In responsive teaching, the teacher provides opportunities for students to reason dialogically while making productive shifts between authoritative and dialogic talk (e.g., Mortimer & Scott, 2003). While past studies have illustrated what productive talk sounds like in science classrooms (e.g. Michaels et al., 2008), the conditions and teaching practice that shape this kind of talk remained unclear (Colley & Windschitl, 2016).

By analyzing entire lesson enactments for engagement in productive teaching practice and use of teacher-educator provided tools rather than looking solely at the enactments of the end-of-lesson investigation-based discussions, this dissertation provides evidence that teaching practice and use of tools that occurs prior to the sensemaking discussion might shape discussion enactment. Prior research investigating teacher facilitation of discussions in science has focused mainly on analyzing instances of whole and small group discussion, and did not consider the lesson enactments more holistically. For example, Sassi and colleagues (2013) analyzed samples of teachers' enactments of post-investigation science discussions for the occurrence of productive talk moves (Michaels et al., 2008), student reasoning, and student use of talk moves to co-construct understandings of science concepts. While helpful in identifying some of the characteristics of investigation-based discussions, this type of analysis fails to consider the potential impact teaching moves made prior to the discussion may have on the discussions themselves.

Findings from this dissertation and Colley and Windschitl’s (2016) study support that talk moves used in isolation are not enough to facilitate productive talk among students highlighting the importance of considering the enactments of investigation-based lessons more holistically. For example, in Ms. Sawyer’s peer teaching enactment, it was likely that her use of the *monitoring tool* to keep track of students' ideas in combination with her use of talk moves to question student understanding allowed her to have a better understanding of her students’ thinking while they were carrying out the investigation. The teaching moves Ms. Sawyer made during her Experience element allowed her to gain insight into student thinking and then enabled her to elicit student contributions in her Explain element that would drive the discussion forward in productive ways. Findings from this dissertation suggest it is important to consider the types of tools teachers use and synergistic teaching practices teachers enact to support students to engage in rigorous intellectual work.

Tool Design: Implications for Practice-Based Teacher Education and Connections to Teacher Knowledge

Data sources for this dissertation do not allow for causal claims describing how use of the tools led to development of teacher knowledge for facilitating investigation-based discussions. However, based on interns’ plans and enactments, this study has implications for the iterative design of tools used to support development of this type of teacher knowledge. Several of the tools provided for interns within the science methods course seemed to support development of multiple domains of subject matter knowledge and pedagogical content knowledge for facilitating investigation-based discussions (cf. Ball et al., 2008; Magnusson et al., 1999; McDiarmid et al., 1989; Shulman, 1986).

I argue, like educative curriculum materials designed specifically with the intent to support both teacher and student learning (Davis & Krajcik, 2005), tools used within a practice-based teacher education program have the ability to support interns in developing their knowledge for science teaching. Interns' use of these tools supported them to plan and enact lessons that allowed their students additional opportunities to learn science content through engagement in science practice. Many of these tools and their potential to develop knowledge for specific domains of teacher knowledge were described earlier in this chapter. For example, use of the *card sorting tool* seemed to support development of both core content knowledge and horizon content knowledge needed for facilitating investigation-based discussions (Ball et al., 2008). Additionally, use of the *alternative ideas tool* and *monitoring tool* seemed to support interns to anticipate alternative ideas students are likely to hold and to notice nuances in students' ideas during their lesson, contributing to development of knowledge of content and students. Use of these open-ended science-teaching specific questions from the *talk moves tool* allowed for increased opportunities for teacher-student and student-student discussion during the investigation-based lesson likely also supporting the development of knowledge of content and students (Ball et al., 2008).

These findings are promising in regard to the potential of teacher-educator provided tools supporting development of teacher knowledge for facilitating investigation-based discussions (Thompson et al., 2013; Windschitl et al., 2011; 2012). Interns' struggles enacting investigation-based discussions as well as intern justifications for tool use provide implications for the iterative design of similar tools. For example, interns describe that although the card sort activity was helpful for their own learning, the nature of the activity did not always meet intern needs. In future iterations of the methods course or similar courses, providing alternative ways for the interns to show their understanding of the science content (e.g., drawings, charts, summary essay) may make this tool more useful for the development of common content knowledge and horizon content knowledge of the scientific phenomena.

Because evidence suggests the importance of using a representation as a referent during the investigation-based discussions, a tool designed to help interns choose and evaluate the strengths and weakness of such representations would likely support interns to facilitate productive science discourse and students to construct evidence-based claims. Similar to the instructional planning considerations included in the *instructional planning template,* teacher educators could design as set of questions to help interns evaluate the appropriateness of different types of representations for scientific data (Arias, 2015). For example, the representation considerations might ask, "How does the representation support the organization of student ideas, and help to make potentially invisible patterns in the data more visible for students?". Similar suggestions were made by Arias (2015) in a study of interns' abilities to construct evidence-based claims. Additionally interns could be provided with templates for typical types of representations used to represent quantitative and qualitative data. I provide examples of these templates in Appendix R.

Additionally, a variety of tools as a form of support can be expected to work synergistically. Findings from this study also suggest the importance of cohesion between tools used both within a single methods course and throughout the teacher education program. Beginning elementary teachers may benefit from using similar tools across methods courses, and similarity across tools used throughout the teacher education program may make disciplinary differences more obvious for beginning teachers. For example, if within a teacher education program both the social studies methods course instructors and the science methods course instructors were using the *EEE framework* as a core tool for planning lessons, the teacher educators for both courses could work together to align the frameworks to allow interns to see parallels between the disciplines while highlighting the important disciplinary differences.

Finally, science teacher educators and teacher education programs should take into consideration the interplay among use of teacher-educator provided tools, interns' knowledge and beliefs about science teaching, and knowledge for science teaching. Ms. Sawyer's case provides evidence that beginning teachers whose beliefs about science teaching are less aligned with the current vision for reform-based science education may be able to use tools to begin to see value in prioritizing student contributions and sensemaking. Suggesting the use of different tools for interns with different beliefs or limited knowledge in specific domains of subject matter knowledge and pedagogical content knowledge may allow teacher educators to further differentiate their instruction, better meeting the needs of their learners.

Limitations and Future Research

This study shed light on the types of tools interns find useful in planning and enacting investigation-based science discussions and described the ways the interns used those tools. Additionally, taking a closer look at six focal interns' characteristics, lesson plans, and lesson enactments, the study also contributes to our understanding of how interns' characteristics and use of supportive tools may shape their planning and enactment of investigation-based science discussions. However, it is important to note that these findings and implications from this study are based only on a single science methods course. Additional studies are needed to determine if these same types of tools would be useful for supporting teachers' learning to facilitate investigation-based discussions to determine if the findings from this study extend to different contexts. Also, studying intern use of the suite of tools after iterative revisions based on the findings from this study would provide additional validity to this study's claims and suggestions.

While this study begins to illuminate potential relationships between interns' characteristics, tool use, and planned and enacted lessons, future studies could continue to explore additional aspects of the methods course, intern characteristics, and field placement characteristics which may support interns to learn to enact investigation based discussions. For example, how did the peer teaching co-planning experience shape the ways interns used the tools and planned the investigation-based lessons? How do the interns' experiences in their mentor teachers' classroom moderate or mediate learning to plan and enact investigation-based science lessons? Is there a temporal component that shapes the interns' lesson enactments in the field (e.g., teaching the investigation over multiple days versus in a single day)? Finally, how does the intern use of the tools change over time (e.g., over the course of the teacher education program and within the intern's first years of teaching)? Given I assume the tools mediate teachers' learning, does intern use of the tools decrease over time and how is the internalization of their meaning of the tools reflected in intern teaching practice?

Additionally, I hope to investigate if the similar relationships between intern characteristics, tool use, and planned and enacted lessons exist within a larger set of participants. Focal interns for this study were selected purposefully based on their interest in improving their science teaching; therefore the findings cannot be extended to all beginning teachers. Additional studies are needed to describe the full set of strengths and struggles interns are likely to have when using teacher-educator provided tools to plan and enact investigation-based discussions.

In addition, the primary researcher for this study was also the instructor for the methods course. Having the researcher in this dual role may have influenced the participants' use of tools during the methods course, or caused the interns to feel compelled to answer interview questions in specific ways. Although evidence exists to show consistency between what interns said during interviews and what was learned from the analysis of their lesson plans (e.g., interviews with a second researcher), lesson enactments, and end-of-course reflections, one must ask if the findings would be similar with other interns or consistent with additional data sources. Finally, each intern in this study only planned and enacted a total of two lessons. Future research could investigate interns' use of tools throughout their student teaching experiences and first few years in their own classrooms.

Conclusion

Beginning elementary teachers require support to facilitate investigation-based discussions that provide students opportunities to engage in scientific discourse. A practice-based approach to teacher education combined with the use of supportive tools has been suggested as one method to support interns to plan and enact investigation-based discussions that capitalize on student contributions. This dissertation contributes to the literature by describing the ways in which interns use teacher-educator provided tools and productive practices for capitalizing on student contributions to plan and enact investigation-based science lessons. The findings add to theoretical understandings of the types of teaching practices needed to engage students in productive science discussions, and ways in which tools may foster development of domains of subject matter knowledge and pedagogical content knowledge for facilitating science discussions. Finally, looking at how intern characteristics may relate to tool use, and planned and enacted investigation-based lessons, the study has implications for teacher education programs and science teacher educators. Thus, this research helps the field conceptualize how beginning teachers use tools and teaching practices to plan and enact investigation-based science lessons, and how intern characteristics (specifically knowledge and beliefs about science content and science practice and knowledge and beliefs about science teaching) relate to tool use and planned and enacted lessons within a practice-based teacher education program.

APPENDICES

APPENDIX A: EEE FRAMEWORK [17]

EEE Framework for Science Teaching and Learning – ED528 W14

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*)." You may wish to also support reasoning, for example with "The science idea or principle that helps me explain this is _______ (reasoning). This helps me use my evidence to support my claim because _____." 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.

ED528 Winter 2015 – Elementary Science Methods –Kademian (adapted from Benedict-Chambers, 2011)

[17] Adapted from Kademian, Marino and Davis EDUC421 course materials

APPENDIX B: INSTRUCTIONAL PLANNING TEMPLATE

INSTRUCTIONAL PLANNING TEMPLATE

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

Overview and Context

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

Learning Goals and Assessments

Connection to Standards (Michigan GLCEs and/or Next Generation Science Standards)	Learning Goals (1-2 in each)	Type of Assessment	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 and reasoning you hope students will generate:	I think ___________ (claim). I think this because I've seen or done ______________ (evidence 1), _________ (evidence 2), ______________ (evidence 3). *as appropriate [see annotation below]:* The science idea or principle that helps me explain this is _______ (reasoning). This helps me use my evidence to support my claim because _____.

Connections to the Big Idea

Describing how the	

content of this lesson fits in with the larger picture/big ideas of the unit	

Attending to the Learners

Anticipating student ideas including alternative ideas, misconceptions, and prior knowledge:	
Making the content accessible to all students:	

Instructional Sequence

Materials:	

Instructional Sequence: Engage Element

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

Instructional Sequence: Experience Element

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

Instructional Sequence: Explain Element

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

Reflection on Planning

Learning goal for self:	
Preparing to teach this lesson:	

INSTRUCTIONAL PLANNING TEMPLATE (Annotated)

Overview and Context

Section	Description	Main Connection to Instructional Planning Considerations
Your name(s):	Indicate your name(s).	
Grade level and school:	Indicate the grade level of the students and the school site for the lesson.	
Title of lesson/activity:	Indicate the title of the lesson/activity.	
Teaching date(s) and time(s):	Indicate the date and time you will teach the lesson/activity.	
Estimated time for lesson/activity:	Provide an estimate of the time needed for the lesson/activity.	
Overview	Provide a short description (2-3 sentences) of the lesson/activity.	C1: Quality of the Learning Goals C3: Quality of the Instruction
Context of lesson	Describe the unit of study, including the lesson that comes before and after your lesson, and explain how these lessons help develop a big idea or disciplinary practice.	
Sources	List the source(s) you used in the creation of your lesson plan—e.g., websites, curriculum materials, books. If you drew heavily on or adapted an existing lesson plan, note that. Please turn in copies of the original lesson plan from the teacher's guide (if relevant) with your assignment.	

Learning Goals and Assessments

Section	Description	Main Connection to Instructional Planning Considerations
Learning goals	List the learning goal(s) you have for your students. Use measurable behaviors that can be linked to the assessments. Focus on science content (core disciplinary ideas) *and* scientific practices. Particularly if you are drawing on the Next Generation Science Standards, you may integrate the core disciplinary ideas and scientific practices into a single learning goal. (The statement may also incorporate a crosscutting concept.)	C1: Quality of the Learning Goals C2: Quality of the Assessments C3: Quality of the Instruction
Connections to standards	State the content expectations from the Michigan GLCE(s), Next Generation Science Standards, Common Core State Standards [with specific connection to science]. You may also want to state the standard(s) from your local curriculum that you address in your lesson, but please be sure you include the state or national standard you are working toward.	
Type of Assessment	Name the type of assessment you will use to assess student learning (e.g., worksheet, exit slip, teacher observation, whole class discussion). Make clear how it connects to the learning goal(s).	
Connection to activities	Briefly describe how the activities in the instructional sequence help students make progress toward the stated learning goal(s).	
Investigation question	Write out the specific investigation question driving the lesson. This question should establish a meaningful purpose for experiencing the scientific phenomenon and should generate interest among the students.	
Claim with evidence and reasoning	Write out the claim (possibly two claims) that you hope students will generate. Identify the evidence from this lesson (and any relevant previous lessons) that students will use to support the claim. Identify the reasoning (scientific idea or principle) that students can use to support the claim and connect the claim to the evidence. Even if students are not providing the reasoning component as a part of your lesson, you need to articulate the big scientific idea or principle that applies.	

Connections to the Big Idea

Describing how the content of this lesson fits in with the larger picture/big ideas of the unit	Explain how the content you hope students will learn in this lesson fits into the larger picture/ or the big ideas discussed in the curricular unit. For example, explain how are students building on concepts learned in prior lesson during this investigation, and how students will use this knowledge in future lessons to understand more complex topics.

Attending to the Learners

Section	Description	Main Connection to Instructional Planning Considerations
Anticipating student ideas	Explain what you think will be students' prior knowledge about the content, including the alternative ideas or challenges you anticipate students might face and how you plan to work with each of these challenges during the lesson. Also explain your ideas about how students are likely to respond to the tasks in the lesson and how you might use these likely responses to focus students on the intended content. Draw on resources such as the MSTA list, Benchmarks chapter 15, or resources found on CTools. Connect back to specific readings or sources. Here, you may also want to anticipate inaccurate or inappropriate claims or evidence students may generate.	C3: Quality of the Instruction C4: Learners in My Classroom
Making the content accessible to all students	Describe how you will help ALL students engage productively in the lesson. This includes identifying assumptions made during the lesson about students' prior experiences, knowledge, and capabilities; making the representations, explanations, and/or vocabulary accessible and meaningful to all students; and making connections to students' personal, cultural, and social experiences during the lesson, if appropriate. Consider how you will use the equity practices for science teaching we've worked on: • 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	C4: Learners in My Classroom

Section	Description	Main Connection to Instructional Planning Considerations
	• 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)	

Instructional Sequence

Section	Description	Main Connection to Instructional Planning Considerations
Time	Structure your lesson/activity into chunks or segments in order to break it down into its component parts, and then list the time it will take to complete each part. You may even want to add an additional column to indicate larger chunks of instruction.	
Steps describing what the teacher and students will do	Describe the activities that you will do with your students. Communicate HOW, not just WHAT, you plan on teaching, and provide enough specificity that someone else could teach from your plan. This includes scripting the key questions you plan to ask. Identify at least 5 questions to use at specific points throughout the lesson that will foster students' scientific sense-making. The **first element** of your instructional sequence **(ENGAGE)** should detail how you will launch the lesson. This will include engaging students in the following tasks (as appropriate): • Posing a focal question/problem to establish a meaningful purpose for the lesson. • Sharing initial ideas about the focal question. • Potentially: Participating in an initial shared experience. The **second element** of your instructional sequence **(EXPERIENCE)** should detail how you will engage students in setting up and carrying out an investigation. This will include engaging students in the following tasks (as appropriate): • Establishing data collection protocols. • Carrying out the investigation. The **third element** of your instructional sequence **(EXPLAIN)** should detail how	C3: Quality of the Instruction C4: Learners in My Classroom

Section	Description	Main Connection to Instructional Planning Considerations
	you will promote students' sense-making. This will include engaging students in the following tasks (as appropriate): • Identify patterns and trends in the data for answering the investigation question or problem • Generate claims supported by scientific evidence and reasoning. (Write out the claims with evidence and reasoning that you hope students will generate.) • Applying knowledge to new situations. For each of the elements, specify what you will be expecting to observe as the students engage in the lesson and in what format they will be engaging. The format is the number of students who will be working together on a particular task such as whole class, small group (specify how many), or as individuals. You will want to specify any observable behaviors that you will to see and hear.	
Notes and reminders, including management considerations	Include additional things that you want to remember to do during instruction. This includes management considerations (e.g., how you will manage the distribution and clean up of materials, transitions between segments of instruction, group work (if relevant), and students who finish early from a task.)	C5: Classroom Management and Norms
Materials	List the materials you will need and the materials the students will need. Include quantities and indicate which are attached. <u>Attach all documents that you plan to use in your lesson</u>, including overheads, assessments, rubrics/answer keys, worksheets, and handouts. (In creating your handouts, be sure you think carefully about the specific questions you're giving students as well as the format for them to write any responses. For example, is there enough room for children's large writing? Are the page breaks in the right spots? Are the instructions clear and kid-friendly? Is everything spelled correctly and grammatically correct? Do the artifacts look professional?)	

Reflection on Planning

Section	Description
Learning goal for self	State at least one learning goal that you have for yourself, with regard to your teaching. In other words, what are you working on to improve your teaching practice? If someone will be observing your lesson, also think about what aspect of your teaching you would like the observer to focus on. This may or may not be the same thing as the learning goals you have for yourself.
Preparing to teach this lesson	Describe the things you did in preparation to teach this lesson. For example: practiced the activity with the actual materials, answered the worksheet questions myself, thought through timing, researched materials, etc.

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[18]?)
b. Do the learning goals focus on **worthwhile content**[19]? (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?

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[18] 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.

[19] "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 C: SKELETON LESSON PLANNING TOOL

Skeleton Lesson Plan Tool

ENGAGE

The investigation question and corresponding C-E-R statement guiding this lesson:

Important background knowledge students already have might be:

I plan to use the following questions to elicit students initial ideas about the scientific phenomenon:

EXPERIENCE

Before data collection, I want to make sure to give students these KEY reminders (e.g. reminders for safety or reminders to help them be systematic):

Students will use the following representation during data collection to support them to see patterns in the data:

Key pieces of data I want students to notice during data collection are:

I plan to use the following questions to probe student thinking during data collection:

EXPLAIN

I will use the following representation during the whole class discussion to support them to see patterns in the data (draw a quick sketch to remind yourself of what you would like to draw on the board/have on display):

The key pieces of evidence I need to elicit from students during the whole-class discussion are:

I plan to use the following questions to press students for explanations with justification:

The C-E-R students could generate to show evidence of their learning is:

I will encourage students to apply their knowledge by asking them to answer the following:

APPENDIX D: CARD SORTING ACTIVITY

Card Sorting Activity

Adapted from Windschitl, et al., (2015) card sort tool for secondary science teachers

Unpacking topics like "energy" or "volcanoes" begins with identifying all the big and not so big ideas mentioned in the curriculum materials. It means seeing how they are related to one another, then figuring at which ideas are really at the heart of really understanding the topic. This practice is important for you as the teacher – so that you can create cohesive lessons for you students and feel comfortable and confident supporting students to understand scientific phenomena. It is also important for your students – so they can begin to see how big ideas in science fit together and build on one another.

To begin to unpack some of the big ideas we will be focusing on EDU 528 – the science methods course – you will complete a card sorting activity. The first time you work through this activity, you will do so individually. This way you can get an idea of your current understanding of the big ideas relating to the topic you will be focusing on during science methods. Then, during the science methods course, you will have an opportunity to talk with your colleagues and work collaboratively on a second version of this activity. Throughout the science methods course you will have opportunities revise your thinking about how the big ideas relate to one another, and help each other answer any questions about the science content that may have come up with working through this activity.

To complete this activity you have been assigned a topic for a future lesson you will be teaching during the science methods course. Your topic is circled below:

Your Topic:	Structure and Function of Plant Stems	Transfer of Heat Energy
Lesson you will teach in Science methods:	Experimenting with Celery Stems	Hot Water, Cold Water: Transferring Heath Energy
Curriculum unit for lesson:	*Collecting and Examining Life*	*Energy*
Target grade levels for unit:	1^{st} through 3^{rd} grade	4^{th} through 8^{th} grade

We have provided a list of "big ideas" that relate to this topic (see page ____ of this document). The list of "big ideas" come from the major topics covered in the curriculum unit, and also the grade level standards for this topic area. Your task is to create concept map that depicts how these ideas are related. Here are some steps to help guide you through the activity:

<u>Step One</u>: Take a quick look at the big ideas listed on your set of cards accompanying this document. Note the ideas that you think are most central to the curriculum unit.

<u>Step Two</u>: Try laying the cards on a table and start by playing with different arrangements – not necessarily linearly, or in the order you would teach them, but spread out in a two-dimensional space, representing how you think the ideas are related to on another. You can do this by placing some cards closer to one another on the table, or use another strategy that makes sense to you. Try to take at least 20 minutes to sort and re-sort until your arrangement is somewhat stable.

Challenges that may arise: A few challenges may arise while you sort your cards (and both can be very productive!)

1- You may realize that an idea that you think is actually the "biggest idea" is not actually on any of your cards (meaning this idea may not have been named in the curriculum materials – but it is important for student understanding of the "smaller big ideas"). This is more common than you might think! If you feel this is the case – no problem – use one of the provided blank cards, write the on it, and include it in your concept map.

2- You may realize there are other important ideas that are not found on any one card – rather it is actually about the *relationships* between multiple cards. These ideas are often equally as important as the ideas written on the cards. Keep track of these ideas because they will likely be very helpful for completing step 3.

Step three: Once you are satisfied with how your cards are arranged, create your finalized version of your concept map using the *online software program*. The big ideas you were provided are already enclosed in bubbles, but you can feel free to add any additional big ideas you think are important. Wondering what to do with those ideas that came up describing the relationships between two or more big ideas? Be sure to include those on the lines that connect the bubbles.

Step four: Come up with at least three questions about the content ideas that arose for you while working on your card sort. These questions might be something like "I know Idea A and Idea B are related to each other some how, but I can't really remember how. How does Idea A relate to Idea B? Do students need to understand Idea A in order to make sense of Idea B?"

Step five: Save a version of your electronic version of your concept map and questions and submit a version in pdf form to CTools.

**Try to remember this is not a process that you should feel closure on in just an hour or so. It might be messy, and may make you feel unsure. That is okay and totally normal! Many teachers need to try this out first, and come back to it a few days later with insight that may have come to them while driving to school, doing the dishes, etc. This is part of the same creative process other professionals use: artists, architects, and engineers, etc. Also remember, you will have a chance to talk through these ideas, and your lingering questions, with your colleagues during the science methods course.

**This is an activity designed to help you think and gain awareness of your understanding of the big ideas. This will also help me, your instructor, to understand how you are thinking about the science content covered by these curricular units. You will not be graded for correctness, rather I am looking for evidence of how you use this activity to build your own understanding, and how you and your colleagues work together to answer lingering questions that arise.

APPENDIX E: TALK MOVES TOOL

Talk Moves for Science[20]

General Talk Moves – often used in whole class discussions

Talk Move	Example
Revoicing	"So let me see if I've got your thinking right. You're saying ____?" (with space for the student to follow up)
Who can repeat?	"Can you repeat what he just said in your own words?"
What do you think about that? Do you agree/disagree?	"Do you agree or disagree, and why?"
Who can add on?	"Would someone like to add on?"
Say more/Press for reasoning	"Why do you think that?" "What evidence helped you arrive at that answer?" "Say more about that."
Using wait time	"Take your time. We'll wait."

Talk Moves that may be helpful for the engage element

Talk Moves for Supporting Whole-group discussion of initial ideas	Example
Refocus on the investigation question	"How does that connect to our investigation question?"
Consider alternatives	"How does (idea/argument A) compare to (idea/argument B)?
Making predictions	"Given your thinking so far, what do you predict will happen during our investigation?

[20] Adapted from Kademian, Marino, and Davis version for EDU 421

Talk Moves that may be helpful for the experience element

Talk Moves for Supporting Small Group Collecting & Recording Data	Example
High-quality observations	"How you recording your observations so they are" • clear? • complete? • accurate? • objective? "Are you labeling your drawings?" "Does your drawing match what you're actually seeing?"
Recording data	"Are you writing down your data? You may not remember it otherwise."
Systematic measurement	"Tell me how you are making sure you are being systematic."
Comparing observations to predictions	"Is that what you thought would happen? Why or why not?"
Guiding to notice particular features	"What are you noticing about __________?" (e.g., "What are you noticing about the temperature of Bag A? What are you noticing about the temperature of Bag B?") "What are you noticing when you _______?" *(think in advance about the key things you want to be sure kids notice about the investigation)*
Refocus on the investigation question	"How might that help us to answer our investigation question?"
Graphing data	"Will your axes map on to your data table?" "Double-check to make sure your data points on your graph match with the data in your data table."

Talk Moves that may be helpful for the explain element

Talk Moves for CER-Informed Approach for Supporting Student Talk ***	Example
Refocus on the guiding question	"How does that help us answer our question, _________?"
Look for patterns in the data	"What patterns are you beginning to notice in your data?"
Make a draft claim	"What claim can you make based on the data you have so far?"
Consider alternatives	"Is there a different claim that explains the data better?" "How does (idea/argument A) compare to (idea/argument B)? Which is better supported by our data?
Make new predictions	"Given your results so far, what do you predict will happen next?"

***See Zembal-Saul, C., McNeill, K., & Hershberger, K. (2013). *What's your evidence?: Engaging K-5 students in constructing explanations in science*: Pearson Education. See Table 4.2 "Using the CER Framework to Support Small Group Talk."

APPENDIX F: ALTERNATIVE IDEAS TOOL

Example provided below is a section of the Michigan Science Teacher Associations list of common alternative ideas for teaching physical science

MEGOSE objective	Naive Conceptions	Scientific Explaination
PCM 8	There is no empty space between molecules, rather students believe there is dust, germs or "air" between the particles of air.	There is empty space between the particles of a gas, liquid, or solid. This seems to be the most difficult concept for students to accept according the research done in the Private Universe Project.
PCM 8	Particles of solids have no motion.	Only at absolute zero does molecular motion stop. Temperature measures the average kinetic energy of the molecules. A gas and a solid at the same temperature have the same average kinetic energy. The speed of the molecules would depend on their molecular mass.
PCM 8	Relative particle spacing among solids, liquids, and gases is incorrectly perceived and not generally related to the densities of the states.	The difference in spacing between solids and liquids is not as large as students tend to represent it--density difference is usually very small. Students also have an idea that there are far fewer air molecules in a room than are actually present because they perceive the distances between molecules in gases to be vast when in fact there are over 2×10^{19} molecules of air in a cubic centimeter at room temperature.
PCM 8	Frequent disregard for particle conservations and orderliness when describing physical changes.	Matter is never created or destroyed in ordinary physical and chemical changes.* Must have the same numbers and kinds of atoms before and after physical and chemical changes. Nuclear changes can involve changes of mass to energy and energy to mass. *Mass changes are too small to detect.
PCM 9	Gases are not matter because most are invisible.	Gases are made up of particles (atoms and molecules) that have mass and occupy space. Private Universe Project found this was one of the least problematic aspects of scientists' view of matter.
PCM 13	Absence of conservation of particles during a chemical change.	Matter is never created or destroyed in ordinary physical and chemical changes. Must have the same numbers and kinds of atoms before and after physical and chemical changes.

APPENDIX G: MONITORING TOOL

Monitoring Tool Exemplar[21]

Monitoring students' work while they are carrying out investigation is important (and sometimes challenging) work. When planning what you should do while students are collecting data you might have goals similar to the following:
I want to:

1. make sure my students are staying on task.
2. make sure I am getting around the room to all of the groups of students.
3. support my students to begin to find patterns in their data even before we discuss it as a class.
4. get information about how they are thinking, and use that to structure the whole class discussion.

All of these are important goals to consider, and one way teachers can facilitate this monitoring process is by creating a tool to help them accomplish some of the goals listed above. Often these monitoring tools contain a list of anticipated student ideas, both scientifically accurate thinking as well as common alternative ideas. This list can help you track which students produced or brought up particular ideas that you want to capture in the whole-group discussion. This can also help you keep track of which groups had the same ideas to enable you to support students to make connections across their ideas. Additionally, by using this list while students are carrying out the investigation, it allows you to see which groups you have checked in with, and which you still need to talk to.

On the next page, I have provided an example of this type of monitoring tool that could be used while students make and draw their observations of circuits during the "Batteries and Bulbs" lesson. To make this tool, for the "Scientifically accurate ideas" column, I considered the scientific ideas about circuits I wanted students to understand at the conclusion of the lesson. For the "Common alternative ideas" column, I considered common alternative ideas students have about circuits drawing on resources such as the MSTA list, Benchmarks chapter 15, or resources found on CTools. For the "Investigation struggles" column anticipated potential struggles students might face when working with the materials, or struggles they may have being systematic in their data collection. Lastly, I provided myself some blank space in the "other" column to record students' ideas I didn't anticipate or other notes about things I wanted to be sure to bring up during the whole class discussion[22].

You may find this structure works well for the lesson you have planned, or you may find that the tool needs to be "tweaked" to fit your needs – either is fine! The overall goal is to create something that is useful in your own teaching practice, and something that allows you to purposefully monitor students ideas. *The exemplar on the next page is meant to be just that, an example, please feel free to edi*

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[21] Tool is adapted from monitoring tool used in Cartier and colleagues (2013) Five Practices for Orchestrating Productive Task-Based Discussions

[22] I only included space for Groups A, B, and C, but when using this I would have a row for each student group.

Student Group	Scientifically accurate Ideas	Common alternative ideas	Investigation Struggles	Other (Order/ notes about unanticipated)
A	___ Electric current only flows if there is a complete path. ___ Path includes connections to battery at both terminals. ___ Short circuit is a still a complete path, without a resistive component ___ Wires have lower resistance than the bulb	___ Current flows from battery to bulb but not from bulb back to battery ___ Current comes from both terminals and "clashes" to light bulb ___ Wires are hollow, electrons move through them like water through a straw ___ Short circuit has some sort of break in the path	____ Did not record observations ____ Did not record if bulb lit ____ Was not systematic in recording observations Observation drawings were not ____ Clear or complete ____ Labeled ____ Accurate	
B	___ Electric current only flows if there is a complete path. ___ Path includes connections to battery at both terminals. ___ Short circuit is a still a complete path, without a resistive component ___ Wires have lower resistance than the bulb	___ Current flows from battery to bulb but not from bulb back to battery ___ Current comes from both terminals and "clashes" to light bulb ___ Wires are hollow, electrons move through them like water through a straw ___ Short circuit has some sort of break in the path	____ Did not record observations ____ Did not record if bulb lit ____ Was not systematic in recording observations Observation drawings were not ____ Clear or complete ____ Labeled ____ Accurate	
C	___ Electric current only flows if there is a complete path. ___ Path includes connections to battery at both terminals. ___ Short circuit is a still a complete path, without a resistive component ___ Wires have lower resistance than the bulb	___ Current flows from battery to bulb but not from bulb back to battery ___ Current comes from both terminals and "clashes" to light bulb ___ Wires are hollow, electrons move through them like water through a straw ___ Short circuit has some sort of break in the path	____ Did not record observations ____ Did not record if bulb lit ____ Was not systematic in recording observations Observation drawings were not ____ Clear or complete ____ Labeled ____ Accurate	

APPENDIX H: CLAIM-EVIDENCE REASONING EXEMPLAR

Investigation-based Science Lessons
Claim-Evidence-Reasoning Exemplar
(meant to be a starting point for a possible worksheet for students – feel free to edit!)

Remember our ***important ideas*** from the last lesson:
(insert important ideas from past lessons here)

Our Investigation Question: *(insert investigation question here or have students write the investigation question below)*

My prediction (draw or write):

What I know from my own life that makes me think this:

What I observed during our investigation (draw or write):

My Explanation:

- **C**laim (this answers our investigation question)
- **E**vidence (this is the data from our investigation that supports our claim)
- **R**easoning: (this is the scientific idea that helps us explain why our data counts as evidence)

Claim: I think…

____

____

____

I think this because I've seen or done…
Evidence 1:

____

____

Evidence 2:

____

____

Evidence 3:

____

____

Reasoning…
The science idea or principle that helps me explain this is

____

____

____

____.

This helps me use my evidence to support my claim because…

____

____

____.

APPENDIX I: HIGH LEVERAGE PRACTICES

High-leverage practices[23]

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 work
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

[23] List of high leverage practices obtained from administrative materials available to course instructors for University of Michigan School of Education and Davis and Boerst (2014).

APPENDIX J: PRE-COURSE SURVEY[24]

Science Survey for ELMAC Interns W16

Teacher Beliefs About Effective Science Teaching

Questionnaire Instructions:
This questionnaire asks you to respond to a series of 21 statements to help us understand what you believe about effective science instruction; that is, what does science instruction that helps students learn science concepts well look like?

We recognize that teachers have to make many trade-offs when they are responsible for teaching many standards in one year. Teachers may not be able to emphasize the instructional strategies they believe are effective and still cover the entire curriculum. When you respond to the statements below, we ask that you put those trade-offs aside. Imagine that you are not constrained by state/district standards, or available time/resources, or feasibility issues. We want to know what you think effective instruction looks like, without all the constraints that limit what you can do in the classroom.

When responding to the statements, please try to think about students in general, not one student or a particular group of students. We know that's hard to do, but please try.

Finally, this questionnaire makes frequent use of two terms that teachers may interpret differently depending on the context. For the purpose of this questionnaire, we ask that you use the following definitions of "data" and "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.

These definitions are repeated on each page of the questionnaire.

1. Practical constraints aside, do you agree that doing what is described in each statement would help most students learn science?

	Strongly disagree	Moderately disagree	Slightly disagree	Slightly agree	Moderately agree	Strongly agree
At the beginning of instruction on a science concept, students should be provided with definitions for new scientific vocabulary that will be used.	○	○	○	○	○	○
Hands-on activities and/or laboratory activities should be used primarily to reinforce a science concept that the students have already learned.	○	○	○	○	○	○
Students should rely on evidence from classroom activities, labs, or observations to form conclusions about the science concept they are studying.	○	○	○	○	○	○
Teachers should have students do hands-on activities, even if the data they collect are not closely related to the concept they are studying.	○	○	○	○	○	○
Teachers should explain a concept to students before having them consider evidence that relates to the concept.	○	○	○	○	○	○
Teachers should provide students with opportunities to connect the science they learn in the classroom to what they experience outside of the classroom.	○	○	○	○	○	○
Teachers should ask students to support their conclusions about a science concept with evidence.	○	○	○	○	○	○

[24] TBEST survey developed by Smith and Colleagues (2014) and argumentation questions developed by McNeil and Colleagues (2015)

Science Survey for ELMAC Interns W16

2. Practical constraints aside, do you agree that doing what is described in each statement would help most students learn science?

	Strongly disagree	Moderately disagree	Slightly disagree	Slightly agree	Moderately agree	Strongly agree
Students should do hands-on or laboratory activities, even if they do not have opportunities to reflect on what they learned by doing the activities.	○	○	○	○	○	○
At the beginning of instruction on a science concept, students should have the opportunity to consider what they already know about the concept.	○	○	○	○	○	○
Students should do hands-on activities after they have learned the related science concepts.	○	○	○	○	○	○
Teachers should provide students with opportunities to apply the concepts they have learned in new or different contexts.	○	○	○	○	○	○
Students should use evidence to evaluate claims about a science concept made by other students.	○	○	○	○	○	○
Teachers should have students do interesting hands-on activities, even if the activities do not relate closely to the concept being studied.	○	○	○	○	○	○
At the beginning of lessons, teachers should 'hook' students with stories, video clips, demonstrations or other concrete events/activities in order to focus student attention.	○	○	○	○	○	○

3. Practical constraints aside, do you agree that doing what is described in each statement would help most students learn science?

	Strongly disagree	Moderately disagree	Slightly disagree	Slightly agree	Moderately agree	Strongly agree
Students' ideas about a science concept should be deliberately brought to the surface prior to a lesson or unit so that students are aware of their own thinking.	○	○	○	○	○	○
Teachers should provide students with the outcome of an activity in advance so students know they are on the right track as they do the activity.	○	○	○	○	○	○
Students should have opportunities to connect the concept they are studying to other concepts.	○	○	○	○	○	○
Students should consider evidence that relates to the science concept they are studying.	○	○	○	○	○	○
When students do a hands-on activity and the data don't come out right, teachers should tell students what they should have found.	○	○	○	○	○	○
Students should know what the results of an experiment are supposed to be before they carry it out.	○	○	○	○	○	○
Students should consider evidence for the concept they are studying, even if they do not do a hands-on or laboratory activity related to the concept.	○	○	○	○	○	○

Supporting Students' Scientific Argumentation

In the next part of the survey, you will be given three vignettes. Each vignette focuses on one teacher. Each vignette is followed by four multiple-choice questions.

The vignettes focus on how teachers engaged their students in science explanation and argumentation. The Next

Science Survey for ELMAC Interns W16

Generation Science Standards state:
"Argumentation is a process for reaching agreements about explanations and design solutions. In science, reasoning and argument based on evidence are essential in identifying the best explanation for a natural phenomenon. ... Student engagement in scientific argumentation is critical if students are to understand the culture in which scientists live, and how to apply science and engineering for the benefit of society. As such, argument is a process based on evidence and reasoning that leads to explanations acceptable by the scientific community...."

4. Vignette #1: Mr. Cedillo's Class

Mr. Cedillo's 7th grade science class is doing a unit on force and motion. Near the middle of the unit his students explore friction by analyzing the data table from an investigation they conducted that answered the question: Which type of surface material will allow a toy car to have the greatest average speed? The students let a toy car go from the top of a ramp and timed how long it took to travel 1 meter after reaching the bottom of the ramp, over four different surface materials: felt, top of lab table, sand paper, and ice.

They then calculated the toy car's average speed by dividing the distance over the time. The table below shows the students' experimental results.

SURFACE MATERIAL....DISTANCE TRAV. (m).......TIME (seconds).....AVG SPEED (m/sec)
Felt.................................1.0......................................2.4.........................0.42
Top of lab table..............1.0......................................1.5.........................0.67
Sand paper....................1.0.......................................2.2.........................0.45
Ice..................................1.0.......................................1.0........................1.0

Ellen raises her hand in class and states the following argument: "The car on the ice will always go the fastest. I've been in a car driving on ice, and I know a car can skid because ice is the smoothest surface. My dad has a really big truck and it doesn't slide as far, so maybe next time we should try this experiment with larger cars."

Mr. Cedillo should respond by saying:

- "Interesting point, Ellen. Does anyone have similar reasoning?"
- "Great connection. Can anyone suggest data to support this?"
- "Nice argument. What additional evidence could Ellen add?"
- "Well done. Does anyone else want to share their argument?"

Science Survey for ELMAC Interns W16

5. Mr. Cedillo next asks his students to engage in oral argumentation, during which they debate their ideas about the relationship between surface material and average speed. The excerpt below is from the beginning of their conversation.

Maya: "My claim is that rough materials cause cars to go faster."

Elana: "I think the data table shows that rough materials make cars go slower."

Ben: "Well, I think there are lots of reasons a car would go faster or slower."

Mr. Cedillo should speak up and encourage his students to:

- ○ Debate other possible reasons a car might go faster or slower
- ○ Focus the class discussion on the scientifically accurate claim
- ○ Research and include what expert scientists say about friction
- ○ Convince their fellow classmates that their claim is the best

6. After Mr. Cedillo intervenes, Elizabeth speaks.

Elizabeth: "I think the surfaces with more friction caused the cars to slow down sooner. This means that they will take longer to go 1 meter. Friction is when two surfaces rub against each other creating a force in the opposite direction an object is moving. Something has more friction when it is rougher."

Elizabeth:

- ○ Should explain her argument's relevant science concept
- ○ Needs to incorporate evidence to support her claim
- ○ Requires help stating an accurate claim about the surfaces
- ○ Does not require any modifications to her argument

Science Survey for ELMAC Interns W16

7. For homework, Mr. Cedillo asks the students to write out their arguments. Gustavo writes the following argument: Our car went the fastest on ice also. It had a speed of 1.0 meters per second. This was faster than the felt, where the car averaged 0.42 meters per second. This is because of friction.

Mr. Cedillo should say to Gustavo:

- "Describe how you calculated the speed of the toy car."
- "Identify scientific principles that link to your claim."
- "Clarify how the evidence connects to your claim."
- "This argument looks good, no further work needed."

Vignette #2

8. Vignette #2: Mr. Luongo's Class

Mr. Luongo asked his students to read an article and construct a scientific argument about whether Elysia chlorotica, a unique species of sea slug, should be characterized as a plant or animal. The article described the ways in which the slug exhibits characteristics of both plants, such as performing photosynthesis, and animals, such as being heterotrophs. Two of his students' written arguments are provided below:

Beatriz: I think that Elysia chlorotica should be classified as plants. The article we read said that these slugs eat algae and once they eat those algae they have the genes for performing photosynthesis. That's why I think that Elysia chlorotica should be considered a plant more than an animal.

Joao: I think that the green sea slugs Elysia chlorotica should be considered animals. I've seen slugs when I play in the park and I know that they move and eat like other animals do. Plants are autotrophs, which means they make their own food. Animals are heterotrophs, which means that they need to eat other things to live.

After reading these students' responses, Mr. Luongo should:

- Tell students to critique each other's arguments about the sea slug's classification
- Encourage students to read more about distinguishing between plants and animals
- Remind students that personal observations do not count as evidence for a claim
- Have students analyze a scientific video that explains why this sea slug is an animal

Science Survey for ELMAC Interns W16

11. After talking with her group members, Sam and Jan, Daniela writes the following argument:

Elysia chlorotica could be either a plant or an animal. Sam thought Elysia chlorotica could be an animal because it eats other organisms. Animals get their energy from consuming other species. But Jan thought it could be a plant because it performs photosynthesis. Photosynthesis allows plants and algae to use energy from the sun to create sugar.

Daniela needs help:

- ○ Including scientific reasoning in her written argument
- ○ Critiquing alternative explanations about this species
- ○ Understanding how photosynthesis occurs in organisms
- ○ Distinguishing between plant and animal characteristics

Vignette #3

Science Survey for ELMAC Interns W16

12. Vignette #3: Ms. Strong's Class

Ms. Strong's students are preparing for a science seminar in which they will engage in oral argumentation to consider whether or not humans could survive in settlements on Mars. Before taking part in the science seminar, the students compile the following pieces of information into a large table on a poster to display in the front of the room:

Similarities between Earth and Mars:
- Mars has seasons much like Earth, though they last nearly twice as long because the Martian year is about 1.88 Earth years
- The Martian day is very close in duration to Earth's
- Recent observations by NASA confirmed the presence of frozen water on Mars

Differences between Earth and Mars:
- Mars is much colder than Earth. It can get to a low of -104 degrees Celsius. The lowest temperature ever recorded on Earth was -89.2 degrees Celsius in Antarctica.
- There are no bodies of liquid water on the surface of Mars.
- Mars' atmosphere contains more carbon monoxide than the Earth's atmosphere.

To get her students ready for the science seminar, Ms. Strong has them use the table to write arguments. Alicia and Thomas write the following arguments:

Alicia: I don't think humans can survive on Mars. The chart shows that Mars can get much colder than Earth and I saw a show on the Discovery Channel about the special clothes scientists have to wear when they do experiments in Antarctica because of the cold. It would be really awful to wear these clothes all the time just to go outside and it would cost a lot of money to get everyone these clothes.

Thomas: I think that settling on Mars would be great for humans. Days on Mars and Earth are almost the same length so we wouldn't have to change watches and clocks. Mars also has seasons like Earth so we'd have those too but they'd just be twice as long. Imagine how long summer break would be! No school for almost six months. Awesome.

After reading Alicia and Thomas' responses, Ms. Strong should begin by:

- ○ Having students collect more numerical data about the planets under study
- ○ Telling students to critique each other's claims about human survival on Mars
- ○ Asking students to analyze their current understanding of the scientific topic
- ○ Encouraging students to organize the evidence in the table with a Venn Diagram

Science Survey for ELMAC Interns W16

13. After writing arguments, Ms. Strong's students engage in the science seminar. During the discussion the following exchange takes place:

Alex: "I think we could live on Mars. It would be awesome!"

Melanie: "My claim is the opposite of Alex's. I don't think that humans could live on Mars."

Alex: "Why not? What's your evidence?"

Melanie: "Well there aren't any bodies of water on Mars' surface and humans need water to live."

Tina: "There might not be lakes and oceans on Mars like there are here on Earth, but I still agree with Alex because NASA scientists saw frozen water on Mars so humans could use that to live."

Melanie: "Yeah, but how much water did they find? Did they measure how much there is?"

What could have Ms. Strong said before beginning this science seminar to encourage Melanie, Alex and Tina to have this type of discussion?

- ○ "The purpose behind a science seminar is for everyone to share their ideas."
- ○ "The objective of a scientific argument is to use all the evidence in the data table."
- ○ "The point of this seminar is to make sure we all understand your argument."
- ○ "The goal of argumentation is to convince each other of the strength of a claim."

14. By having students engage in a science seminar, Ms. Strong's main goal is to help students:

- ○ Develop more interest in the seminar topic
- ○ Generate accurate answers to the question
- ○ Evaluate their classmates' different claims
- ○ Practice sharing out ideas with their peers

Science Survey for ELMAC Interns W16

15. Later in the science seminar Justin says, "Humans couldn't live on Mars because its atmosphere has carbon monoxide." If no other students respond, after an appropriate wait time, Ms. Strong should say:

- "Explain how the data supports your claim"
- "What are some key elements of a strong claim?"
- "We need some quantitative data for this idea"
- "What gasses can we find in the atmosphere?"

APPENDIX K: SCIENCE IDEAS CONVERSATION ASSIGNMENT [25]

Science Ideas Conversation

The purpose of this assignment is to help you anticipate students' ideas about science topics you are likely to teach. There will be two topics for this science ideas conversation assignment, (a) *Seasons* AND (b) either *Heat Energy Transfer* or *Plant Parts*. As a class, we will be focusing on *Seasons* in order to consider patterns in ideas. The second topic will be associated with the topic you will be teaching for the peer teaching assignment, either a Heat Energy or Plant Parts lesson. These foci for the science ideas conversation will allow you to begin planning for this experience. Therefore, it is in your best interest to focus on the topic you are assigned for peer teaching. For the science ideas conversation, you will:

(1) Identify potential alternative ideas that students are likely to have about Seasons AND Heat Energy or Plants
(2) Talk with a person about those questions using the prompts provided
(3) Analyze your conversation and write up the results.

Thus, for this assignment, you will *anticipate*, *elicit*, and *interpret* thinking. Submit this assignment as a Word document by uploading it to your CTools Assignments Tab by **Sunday, January 11th at 10pm**.

Please use the naming convention: LastName_FirstName_ScienceIdeasConv. We'll discuss the conversations in class on Friday, synthesizing ideas that came up across different individuals.

Part 1. Anticipating Alternative Ideas
Find out likely alternative ideas in each of your two topics. You can use a variety of resources to find out what some of the common alternative ideas are about your topic:

- AAAS Benchmarks (http://www.project2061.org/tools/benchol/bolframe.htm)– Use Chapter 15, section C, parts 4, 5, or 6 or pages 335-346 in the book. This chapter is devoted to what the research says about kids' ideas on different science concepts.
- The Michigan Science Teachers Association list of students' alternative ideas in science (on CTools).
- The Uncovering Students' Ideas Series (on Ctools under the Resources – Students' Ideas)

Then, plan additional probing questions that might enable you to find out about these alternative ideas. Use the chart included on page 5 for this anticipation.

Part 2: The Plan and Conversation
Find a volunteer interviewee of any age. This can be a relative, friend, roommate, partner, or student in your mentor teacher's classroom. I ask that you find someone who is:

- not a member of our class, and
- preferably not a scientist.

[25] Adapted from Arias (2014) EDU 528 course materials and Palincsar & Arias (2013) Children as sensemakers course materials

The prompts on pages 3-4 should be used as a starting point for eliciting your volunteer's ideas about Seasons and Energy or Stems. You will want to plan additional questions before you begin the interview.

Useful tips for talking about science content

Remember, the conversation is intended to *elicit* the interviewee's ideas to give you information so you can *interpret* the interviewee's thinking. This is not the same thing as developing instruction to address the interviewee's ideas—you're not *facilitating* the interviewee's thinking in this assignment—so **don't try to teach the interviewee the concept**. Also remember, the prompts are just starting points. Be sure to think through and write down a series of prompts to further probe the interviewee's thinking.

Consider what you'll ask if the interviewee gives an unexpectedly sophisticated or confusing response. Some useful generic probes include:

- Tell me more about that
- I'm not sure I understand what you mean.
- Can you say that again?
- Can you explain that another way
- Why does that happen?
- So what would happen if … [pose a thought experiment—for example, "what if the Earth stop spinning?" or "what if there was no leaves?"].

Some hints (some of which apply more to interviewing a student in your classroom):

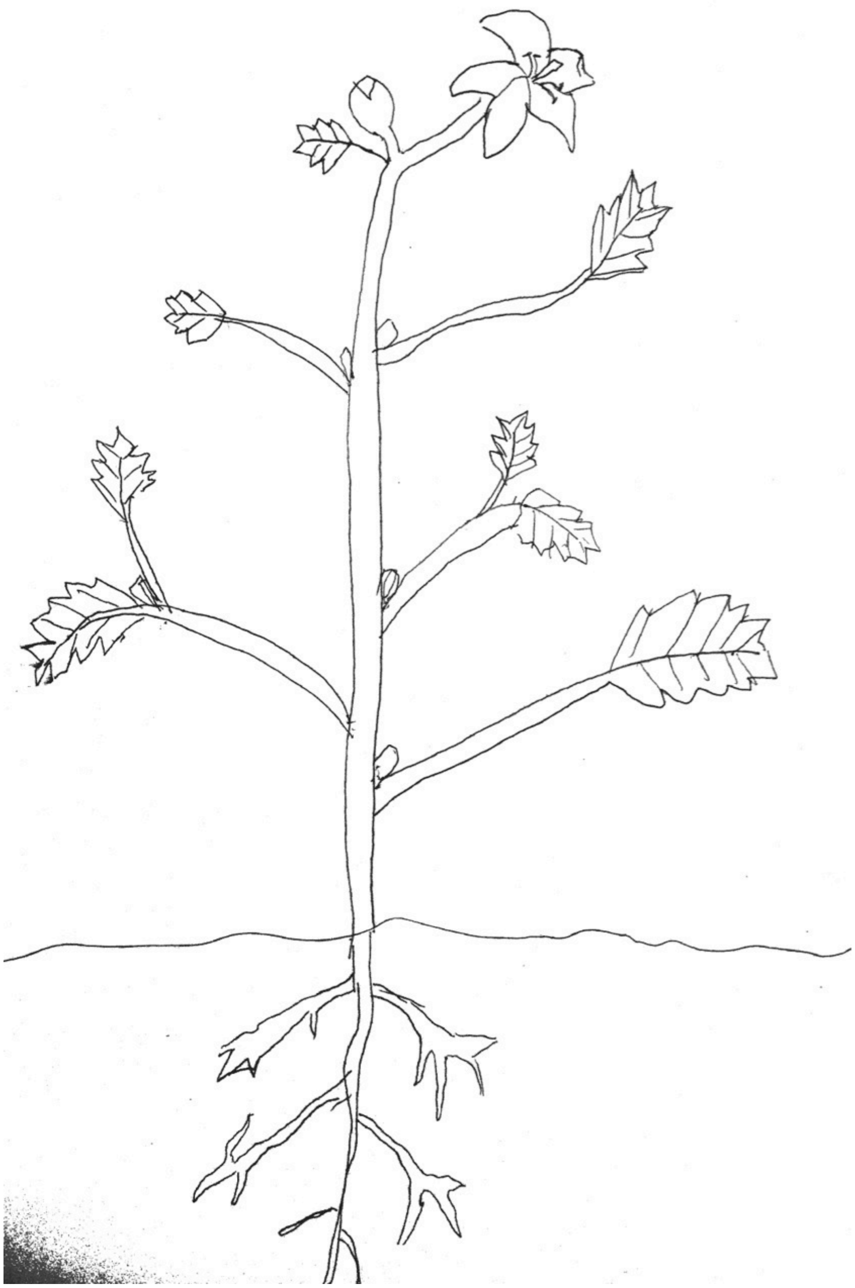
- Reassure the interviewee that nothing they say or do will be judged. You are just trying to understand what they think about something. They won't be judged on how right or wrong their answer is.
- Let the interviewee talk as much as possible. Say as little as possible yourself.
- If you're at all unsure what the interviewee means, ask them to say it again or clarify.
- Record the session if possible, so you don't have to take notes and listen at the same time. Make sure you have permission! If applicable, check with your mentor teacher and your field instructor.
- Remember that you're not trying to change their ideas. This assignment is focused on the part of teaching that involves listening to kids and getting a sense of their ideas.
- Try to be conversational. This will make you and the interviewee less nervous.
- Be sure to probe beneath the interviewee's ideas by asking them questions like: How do you know? Why do you think that?

Part 3: Analysis and Write-up

Describe and analyze the interviewee's responses to your questions. Use the analysis charts and questions on pages 5-6 for this work.

Seasons Prompt:
What causes the seasons? Or Why do we have warm weather in the summer and cold weather in the winter? (Be sure to probe interviewee thinking, particularly thinking about common alternative ideas.)

Plants Parts Prompt:
What are the parts of a plant in this picture (if over phone, what are the parts of a plant?) What is the function of each part? or What does each part do for the plant?



Energy Prompt:
Show or describe the following situation to your interviewee. Then, probe interviewee thinking about why they think this happens and how they think this happens.

Mixing Water

Melinda filled two glasses of equal size half-full with water. The water in one glass was 50 degrees Celsius. The water in the other glass was 10 degrees Celsius. She poured one glass into the other, stirred the liquid, and measured the temperature of the full glass of water.

What do you think the temperature of the full glass of water will be after the water is mixed? Circle your prediction.

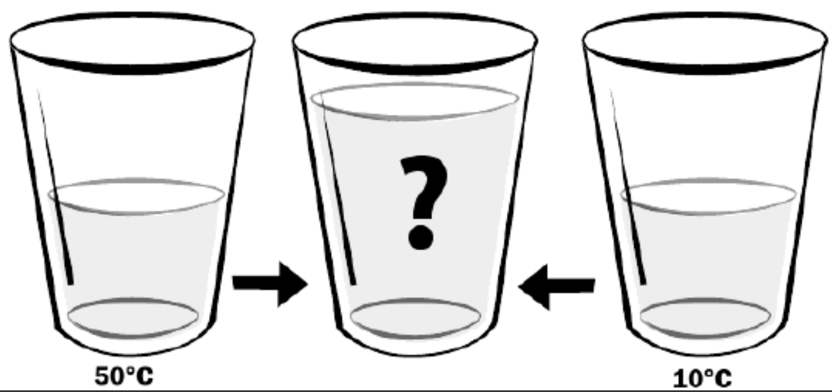
A 20 degrees Celsius

B 30 degrees Celsius

C 40 degrees Celsius

D 50 degrees Celsius

E 60 degrees Celsius



(Keeley, Page. Uncovering Interviewee Ideas in Science, Volume 2 : 25 More Formative Assessment Probes. National Science Teachers Association, . p 97)

APPENDIX K: STUDENT IDEAS CONVERSATION

Report of Science Ideas Conversation

Intern: **Age and profession of interviewee:**

Please use complete sentences and blue text for your responses.

Anticipating Alternative Ideas (to be completed before the interview)
For each of your two topics, write down at least 2 possible alternative ideas and an additional set of probes for finding out if your interviewee has these alternative ideas.

Possible alternative ideas for Seasons	
Possible probes for these alternative ideas	

Possible alternative ideas for Energy or Plants	
Possible probes for these alternative ideas	

Analysis (to be completed after the interview)

1. Watch the video of your interview with your interviewee. Use the tables below to describe your interviewee's explanations for the topics. The table will expand when you type in it.

What was your interviewee's explanation for the seasons? Provide evidence of what the person did or saw that supports your claims.	
How would you characterize your interviewees' response? Please provide evidence for the assertion you are making about your interviewee's thinking. (Does the interviewee	

anthropomorphize? Does the interviewee engage in tautological reasoning? Is their explanation complete? Accurate? Consistent?)	

What was your interviewee's explanation for Energy or Plants? Provide evidence of what the person did or saw that supports your claims.	
How would you characterize your interviewees' response? Please provide evidence for the assertion you are making about your interviewee's thinking. (Does the interviewee anthropomorphize? Does the interviewee engage in tautological reasoning? Is their explanation complete? Accurate? Consistent?)	

2. Choose of one of the two topics. How does your interviewee's explanation *compare and contrast* with what you anticipated as possible alternative ideas or areas of confusion? Describe what evidence you have for your claims.

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3. What do you think went well with respect to eliciting and probing interviewee thinking during this interview? Why do you think this went well?

4. What was challenging about eliciting and probing your interviewee's thinking during this interview? What made these aspect challenging? (Please consider beyond the aspect of the person not necessarily being a child.)

APPENDIX L: PEER TEACHING ASSIGNMENT

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 528 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. Additionally, the lessons we will be using for peer teaching allow us to have conversations about common "problems of science teaching practice". For example, what will you do when student collected data doesn't align with patterns you want them to see? By having a communal experience with the two peer teaching lessons, it will allow us to uncover these problems of practice and discuss them together.

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. In acting as a student, this experience will also allow you to learn about scientific phenomena in a way that is similar to how your students will learn through investigation-based lessons. 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 changes 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.

Pre-Planning for Peer Teaching
Before you begin planning for the lesson, it is essential to be familiar with the lesson you are assigned and its strengths and weaknesses. Use the **Instructional Planning Considerations** in the lesson planning template (last page) as a guide for analyzing the lesson.

After reading the lesson thoroughly, **select two of the planning considerations** (e.g. **#**1 Quality of Learning Goals and #3 Quality of the Instruction) and use the questions below to evaluate that aspect of your lesson plan. Describe how the lesson meets these criteria, how it doesn't, and what you might adjust to improve the lesson in light of the consideration. **Use the template below to organize your analysis.**

Consideration _ :	
Strength: •	Weakness: •
Changes and Adaptations to Make •	

Consideration _ :	
Strength: •	Weakness: •
Changes and Adaptations to Make •	

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, providing a sketch for the other portions will facilitate your ability to meet the learning goals of the lesson. For example, during your planning for the *engage* portion, identifying the claims with evidence you expect your students to make later (in the *explain* portion) will allow you to focus your eliciting of students' ideas meaningfully.
Your lesson plan for each Peer Teaching Element using the Instructional Planning Template is due the **on the dates specified in the syllabus** (also see final page of this document for dates). Please upload your lesson plan to the appropriate assignment folder on CTools.

Co-planning group card sort for Peer Teaching
Unpacking topics like "energy" or "volcanoes" begins with identifying all the big and not so big ideas mentioned in the curriculum materials. It means seeing how they are related to one another, then figuring at which ideas are really at the heart of really understanding the topic. This practice is important for you as the teacher – so that you can create cohesive lessons for you students and feel comfortable and confident supporting students to understand scientific phenomena. It is also important for your students – so they can begin to see how big ideas in science fit together and build on one another.

The first time you worked through this activity, you did so individually (science methods orientation). Now, you will have an opportunity to talk with your colleagues and work collaboratively on a second version of this activity. Throughout the science methods course you will have opportunities revise your thinking about how the big ideas relate to one another, and help each other answer any questions about the science content that may have come up with working through this activity.

I will provide you a second set of cards of "big ideas" and poster board for your co-planning group. The "big ideas" come from the major topics covered in the curriculum unit, and also the grade level standards for this topic area. Your task is to create concept map that depicts how these ideas are related. Here are some steps to help guide you through the activity:

Step One: Take a quick look at the big ideas listed on your set of cards. Note the ideas that you think are most central to the curriculum unit.

Step Two: Try laying the cards on a table and start by playing with different arrangements – not necessarily linearly, or in the order you would teach them, but spread out in a two-dimensional space, representing how you think the ideas are related to on another. You can do this by placing some cards closer to one another on the table, or use another strategy that makes sense to you. Feel free to consult resources to help you make sense of the cards (e.g. teacher resource section within the curriculum materials, online sources, text books, etc.).

Challenges that may arise: A few challenges may arise while you sort your cards (and both can be very productive!)

3- You may realize that an idea that you think is actually the "biggest idea" is not actually on any of your cards (meaning this idea may not have been named in the curriculum materials – but it is important for student understanding of the "smaller big ideas"). This is more common than you might think! If you feel this is the case – no problem – use one of the provided blank cards, write the on it, and include it in your concept map.

4- You may realize there are other important ideas that are not found on any one card – rather it is actually about the *relationships* between multiple cards. These ideas are often equally as important as the ideas written on the cards. Keep track of these ideas because they will likely be very helpful for completing step 3.

Step three: Once you are satisfied with how your cards are arranged, create your finalized version of your concept map. Wondering what to do with those ideas that came up describing the relationships between two or more big ideas? Be sure to include those on the lines that connect the cards.

Step four: Come up with at least three questions about the content ideas that arose for your group while working on your card sort. These questions might be something like "We know Idea A and Idea B are related to each other some how, but we can't really remember how. How does Idea A relate to Idea B? Do students need to understand Idea A in order to make sense of Idea B?"

**Try to remember this is not a process that you should feel closure on in just an hour or so. It might be messy, and may make you feel unsure. That is okay and totally normal! Many teachers need to try this out first, and come back to it a few days later with insight that may have come to them while driving to school, doing the dishes, etc. This is part of the same creative process other professionals use: artists, architects, and engineers, etc.

**This is an activity designed to help you think and gain awareness of your understanding of the big ideas. This will also help me, your instructor, to understand how you are thinking about the science content covered by these curricular units. You will not be graded for correctness, rather I am looking for evidence of how you use this activity to build your own understanding, and how you and your colleagues work together to answer lingering questions that arise.

Enacting and Debriefing the Peer Teaching

What do I do for the peer teaching in ED528? 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

Schedule for Peer Teaching

Engage Element	
Pre-Planning for Peer Teaching Due	Wednesday 1/6 at 10pm
Co-planning for Engage Peer Teaching	Thursday 1/7 in class
Lesson Plan for Engage Peer Teaching Due	Sunday 1/10 at 10pm
Enactment of Engage Peer Teaching	Monday 1/11 in class
Experience Element	
Co-planning for Experience Peer Teaching	Thursday 1/14 in class
Lesson Plan for Experience Peer Teaching Due	Monday 1/18 at 10pm
Enactment of Experience Peer Teaching	Tuesday 1/19 in class
Explain Element	
Co-planning for Explain Peer Teaching	Monday 1/25 in class
Lesson Plan for Explain Peer Teaching Due	Monday 1/25 at 10pm
Enactment of Explain Peer Teaching	Tuesday 1/26 in class
Final Revised Lesson Plan and Co-planning group Card Sort Due	Thursday 1/28 start of class

APPENDIX M: LESSON IN FIELD EXPERIENCE ASSIGNMENT

THE TASK – Description and Rationale.

You will teach a full science lesson in your practicum classroom this semester. For this Lesson in Field Experience (LiFE) assignment, you will use existing curriculum materials to analyze and adapt a science lesson, develop a concept map connecting the "big ideas" of your lesson to the science unit, video record yourself teaching your lesson to students in your placement classroom, reflect on your teaching, and analyze some student work. This LiFE 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, moving toward more complex and more authentic experiences with science teaching
- build your understanding of disciplinary core ideas (DCIs) and cross cutting concepts (CCC) being addressed in the curriculum materials used in your field placement classroom
- 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

THE LESSON – How to plan and what to 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 ask me for help in finding one (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 the first week of the semester. 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. 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. Often can be difficult teaching all three elements of the lesson in a single day, so you may want to consider teaching the lesson over two class days if your mentor's schedule can accommodate this option. In the past, it has worked well to teach the engage and experience portion of the lesson the first day, and the explain portion the following day.

If you and a colleague(s) are teaching the same lesson, you may collaborate on your plan. Please be sure to include all individual's names on the lesson plan you submit for the assignment. If your individual plan deviates from your collaborators in any way, please indicate these differences using a different color font (e.g. blue font) within the lesson planning template.

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).

THE CONTENT – Understanding the "BIG IDEAS"[26].

Unpacking topics like "energy" or "volcanoes" begins with identifying all the big and not so big ideas mentioned in the curriculum materials. It means seeing how they are related to one another, then figuring at which ideas are really at the heart of really understanding the topic. This practice is important for you as the teacher – so that you can create cohesive lessons for you students and feel comfortable and confident supporting students to understand scientific phenomena. It is also important for your students – so they can begin to see how big ideas in science fit together and build on one another.

A version of this activity has been modeled for you in connection with the peer teaching assignment. Now it is time for you to apply the process to the lesson you will teach in your field placement. *Feel free to work with others in the cohort that are teaching the same lesson or another lesson within the same science unit* (if you do work collaboratively be sure to list all collaborating individual's names on your finished product and each person is responsible for turning in their own copy of the finalized card sort).

This version of the activity will be a bit different than the version associated with your peer teaching lesson in that you will be coming up with the big ideas on the cards. Here are a few steps to help you work through the activity:

<u>Step One:</u> Start by taking a section of curriculum that you think will take two or three weeks to teach – this should be the section of curriculum that includes the lesson you plan to teach for your LiFE assignment. This may be a sub-unit within a larger science unit your mentor teacher usually teaches (for example, "Energy Transfer" within the "Energy" unit). As you page through the curriculum materials, note the most prominent ideas that are mentioned in the text. These are often written in bold or used as headings in the teacher resources section of the curriculum. Write each of these ideas on an index card. Try not to use more than 12 index cards; if you do, you have likely chosen too large of a chunk of curriculum to explore in depth. If your mentor teacher does not use curriculum materials, discuss the concepts he or she plans to cover in the science unit, and use those as a starting point. If you are finding it difficult to start this activity – please see me as soon as possible - I am happy to help!

<u>Step Two</u>: Try laying the cards on a table and start by playing with different arrangements – not necessarily linearly, or in the order you would teach them, but spread out in a two-dimensional space, representing how you think the ideas are related to on another. You can do this by placing some cards closer to one another on the table, or use another strategy that makes sense to you. Feel free to consult resources to help you make sense of the cards (e.g. teacher resource section within the curriculum materials, online sources, text books, etc.).

Challenges that may arise: A few challenges may arise while you sort your cards (and both can be very productive!)

5- You may realize that an idea that you think is actually the "biggest idea" is not actually on any of your cards (meaning this idea may not have been named in the curriculum materials – but it is important for student understanding of the "smaller big ideas"). This is more common than you

[26] Activity adapted from Windschitl et al., 2015

might think! If you feel this is the case – no problem – use one of the provided blank cards, write the on it, and include it in your concept map.

6- You may realize there are other important ideas that are not found on any one card – rather it is actually about the *relationships* between multiple cards. These ideas are often equally as important as the ideas written on the cards. Keep track of these ideas because they will likely be very helpful for completing step 3.

<u>Step three</u>: Once you are satisfied with how your cards are arranged, create your finalized version of your concept map. Wondering what to do with those ideas that came up describing the relationships between two or more big ideas? Be sure to include those on the lines that connect the cards.
<u>Step four</u>: Come up with at least three questions about the content ideas that arose for you while working on your card sort. These questions might be something like "I know Idea A and Idea B are related to each other some how, but I can't really remember how. How does Idea A relate to Idea B? Do students need to understand Idea A in order to make sense of Idea B?"

**Try to remember this is not a process that you should feel closure on in just an hour or so. It might be messy, and may make you feel unsure. That is okay and totally normal! Many teachers need to try this out first, and come back to it a few days later with insight that may have come to them while driving to school, doing the dishes, etc. This is part of the same creative process other professionals use: artists, architects, and engineers, etc.

**This is an activity designed to help you think and gain awareness of your understanding of the big ideas. This will also help me, your instructor, to understand how you are thinking about the science content covered by the curricular unit. You will not be graded for correctness, rather I am looking for evidence of how you use this activity to build your own understanding and how you work to answer lingering questions that arise.

THE VIDEO – Recording and Commenting.

After you have taught your lesson, upload your video to Edthena. **Then, mark two teaching moves for each element of the EEE framework: Engage, Experience, and Explain**. In total, you will select 6 teaching moves. These teaching moves can represent either strengths or missed opportunities in terms of the components of the EEE framework. In your comments on the teaching move, **please describe why you think this is either a strength or missed opportunity**. If it is a missed opportunity, also explain how you would revise it.

Your marked teaching moves should be related to the components of the EEE framework. (For example, I might mark where I discuss the investigation question or how I missed discussing how to collect data clearly. Then, I would provide a sentence description of why I chose these moves). As you have done this semester in your peer teaching experiences, you can use the following components to guide your thinking:

- Engage:
  - supporting the students to establish an investigation question or problem
  - eliciting students' initial thinking about the problem or questions based on their prior knowledge and experiences
- Experience:
  - supporting the students in establishing a data collection plan
  - supporting the students in carrying out the investigation
- Explain with evidence:
  - supporting students to make sense of the data
  - facilitate students to use data as evidence to answer the investigation question or problem
  - providing opportunities for students to share their explanations with others
  - supporting students in applying their knowledge to new learning tasks

THE REFLECTION –Reflecting and Analyzing (you AND your students).

After you've taught your lesson, reflect on your lesson enactment and on your students' work. This should be written as prose rather than a bulleted list. Use the reflection template included in the LiFE folder on CTools to complete this reflection.

What is due when?

Aspect of assignment	Due date
• **A date and subject for LiFE** ○ Discuss a date and subject for your Lesson in Field Experience with your Mentor Teacher and submit this online	When: Tuesday, January 12 Start of class Where: CTools
• **Original lesson plan and lesson plan analysis** ○ your original lesson plan (the one you received from your mentor teacher, or found)—please scan this and upload a PDF if possible; an annotated (marked-up) version is fine ○ your lesson plan analysis using the Lesson Analysis Template with naming convention: LastName_FirstName_LiFELessonAnalysis	When: Monday, January 25th Start of class Where: CTools
• **Card sort and C-E-R statement for lesson/subunit** ○ Card sort detailing the "big ideas" for the unit or subunit that contains your LiFE lesson; paper copy is fine or PDF if you choose to use electronic concept mapping software ○ C-E-R statement for the lesson/subunit – the C-E-R statement can be specifically for your lesson, or one students will be working toward over the course of a few lessons. If you are submitting one for a subunit – you should be sure to include the pieces of evidence students will be able to use from lesson you plan to teach.	When: Monday, February 1st Start of class Where: C-E-R to CTools; Card sort may be a paper copy or PDF to CTools if using electronic concept mapping software
• **Revised lesson plan** ○ your revised lesson plan, as a Word document and using the science Instructional Planning Template—and, of course, informed by your Original Lesson Plan Analysis with naming convention: LastName_FirstName_LiFELessonPlan ○ any handouts, activity sheets, etc. for your lesson (Word or PDF)	When: Tuesday, February 2nd At 10pm Where: **CTOOLS (updated 1/28)**
• **Analysis of student work** ○ 4 examples of student work with your written feedback to the students (scanned to create a PDF; make sure these are blinded)	When: Friday, February 12th At 10pm Where: Edthena
• **Video** ○ upload your video to Edthena with LastName_FirstName_LiFETeachingVideo ○ 6 time stamps marking teaching moves: 2 for each element with a description of why this teaching move is a strength or weakness	When: Friday, February 12th At 10pm Where: Edthena
• **Reflection** ○ your responses to the reflection questions above, as a Word document with naming convention: LastName_FirstName_LiFEReflection	When: Friday, February 12th At 10pm Where: Edthena

LiFE Assignment Grading Rubric

Intern name:

1. Completeness & Writing (25 points)

All Pieces Included		**Total points**
Assignment is complete (8 points -1 point per piece)	Does the assignment contain… ○ Copy of original lesson plan ○ Original Lesson Plan Analysis ○ Card sort and C-E-R statement ○ Revised lesson plan using the science Instructional Planning Template ○ Any handouts, activity sheets, etc. ○ 4 examples of student work with your feedback ○ Reflection ○ Video with time stamps	
Assignment components on time (2 per component)	Date by Tuesday, 1/12 Original Curriculum Lesson Plan and Analysis by 1/25 Card sort and CER statement by 2/1 Revised Lesson Plan by 2/2 Reflection and student work by 2/12 Video by 2/12	
Grammar and writing style (5 points)	Is each section written with proper grammar? Is the style of writing fluid, clear, and coherent?	

2. Lesson Plan Analysis Worksheet (10 points)

Relevant section	**Questions**	**Total points**
Original Lesson Plan Analysis (Strengths and Weaknesses) (5 points -1 point each)	Are strengths and weaknesses for each consideration addressed with specificity?	
Original Lesson Plan Analysis (Changes and Adaptations) (5 points - 1 point each)	Are the changes and adaptations for each of the considerations clear? Do they address the relevant consideration and improve the lesson?	

3.Card Sort (20pts)

Relevant section	**Questions**	**Total points**
Big ideas identified (8pts)	Are the big ideas identified for the subunit? Do the ideas seem relevant to each other and important? Do several of the ideas connect to DCIs and CCCs for the lesson?	
Connections between big ideas identified (8pts)	Did the intern make a strong effort to make connections between the big ideas?	
Identifies questions that arose (4pts)	Does the intern identify three questions that arose while completing the card sort?	

4.Revised Lesson Plan - Instructional Planning Template (25 points total)

Relevant section		**Questions**	**Total points**
Overview and Context (1 point)	Grade level & school, Title, teaching date	Is there a grade level, school, title, and teaching date specified?	
	Estimated Time	Is the estimated time appropriate?	
	Overview	Does the overview provide a short, clear description of the lesson?	
	Context	How does the lesson connect to the other lessons within the unit, across units, and to longer-term goals?	
	Sources	Are the sources used for planning present, providing content and context for the lesson?	

Learning Goals and EEE Connection (5 points)	Learning goals	Do the learning goals specify what students should know, understand, and/or be able to do as a result of engaging in the lesson and described in measureable behaviors? Do the learning goals focus on worthwhile content (including science content and practices,)?	
	Connection to standards	Are the learning goals aligned with standards documents (either GLCEs or NGSS)?	
	Connection to activities	Do the activities enable students to make progress toward the learning goals?	
	Investigation Question	Is the investigation question appropriate and able to facilitate an investigation? Will answering the investigation question enable students to make the claims supported with evidence and reasoning?	
	Claims with evidence	Is there a statement of what scientific explanation(s) (claim[s] supported by evidence) students should be able to make at the end of this lesson? Does this align with the learning goals?	
Attending to the Learner (2 points)	Anticipating student ideas	Does the lesson describe what students' prior knowledge about the content might be? Are students' alternative ideas/misconceptions addressed? Does lesson explain how students might respond to the tasks in the lesson? Does the intern make use of the student ideas documents (MSTA misconceptions, benchmarks, etc.)?	
	Making the content accessible to all students	What assumptions, if any, does the lesson make about students' prior experiences and about their prior knowledge and capabilities? Does the lesson introduce concepts, vocabulary, and discipline-specific language in meaningful ways to all students and that supports them in using and practicing with these ideas? Does the lesson describe possible equity practices for science teaching that might facilitate all students' learning?	

Assessments (2 points)	Type of assessment	Do the assessments enable every student to demonstrate his/her understanding and/or skills?	
	Learning goals connection	How well are the learning goals reflected in the assessment?	
Instructional Sequence (13 points)	Materials	Are the materials for both the instructor and the students listed? Do the student materials support students in engaging in key disciplinary practices?	
	Time	Are the times for each phase of the lesson reasonable?	
	The teacher will	**Engage** – *Is there evidence of planning for (as appropriate)* ▪ supporting the students to establish an investigation question or problem ▪ eliciting students' initial thinking about the problem or question based on their prior knowledge and experiences	
		Experience – *Is there evidence of planning for (as appropriate)* ▪ supporting the students in establishing data collection ▪ supporting the students in carrying out the investigation	
		Explain with Evidence - *Is there evidence of planning for (as appropriate)* ▪ supporting students to make sense of the data ▪ facilitate students to use data as evidence to answer the question or problem ▪ providing opportunities for students to share their explanations with others ▪ supporting students in applying their knowledge to new learning tasks	
		Throughout: Is the content being taught in a way that is both accurate and accessible?	
	The student will	Are the descriptions of what the students will do in each element of the lesson specific, giving a clear understanding of what and how the students are engaged with the lesson?	
	Management Considerations	Does the lesson include ways of managing materials and transitions? Are the directions for students clear? Do the work formats (whole class, small group, individual work) support students' engagement with the content?	
Reflection on planning (2 points)	Goal for self	Is there a clearly stated, reachable goal identified? (Connected to the goal stated after the *experience* phase lesson video discussion)	
	Preparing to teach the lesson	Is there a short description of how the lesson was prepared and why decisions were made that led up to the revised lesson plan?	

5. Video of Enactment in the field with Time Stamps (20 points)

Sub-goals		Total points
Teaching the Engage Element (4 points)	*Do the provided time stamps in the lesson effectively include (as appropriate) and discuss:* ▪ supporting the students to establish an investigation question or problem ▪ eliciting students' initial thinking about the problem or question based on their prior knowledge and experiences	
Teaching the Experience Element (4 points)	*Do the provided time stamps in the lesson effectively include (as appropriate) and discuss:* ▪ supporting the students in establishing data collection ▪ supporting the students in carrying out the investigation	
Teaching the Explain with Evidence Element (4 points)	*Do the provided time stamps in the lesson effectively include (as appropriate) and discuss:* ▪ supporting students to make sense of the data ▪ facilitate students to use data as evidence to answer the question or problem ▪ providing opportunities for students to share their explanations with others ▪ supporting students in applying their knowledge to new learning tasks	
Management and Safety (4 points)	*Does the enactment of the lesson include the use of teaching practices that (you do not need to include timestamps for this):* • facilitate safe and appropriate use of science materials? • provide meaningful learning opportunities for students through the management of the lesson?	
Science Content and Science Practices (4 points)	*Does the enactment of the lesson include the use of teaching practices that (you do not need to include timestamps for this):* • accurately represent the science content and scientific practices? • represent the science content and scientific practices in a way that is accessible to students?	

5. Feedback to Student (5 points)

Relevant section	Questions	Total points
Feedback provided to each student	Is the feedback provided appropriate and could push the student thinking forward?	

6. Reflection (40 points)

Sub-goals		Total points
Reflection on Teaching (20 points)	Does the reflection appropriately and sufficiently address: • 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? • 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 your use of the specific practices that can promote equitable learning opportunities described in the assignment and worked on throughout the course. • 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? 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?	
Reflection on use of tools to plan and enact lesson (20 pts)	• What items from EDU 528 did you find useful for planning and/or enacting your lesson? • Why were these items useful or not useful? • What items suggest be provided to future ELMAC interns? Are there any areas you felt you could have used additional scaffolding or support?	

Total score: **/145 points**
Comments:

APPENDIX N: LiFE REFLECTION TEMPLATE AND TOOL USE SURVEY

Reflection on Lesson in Field Experience (LiFE)
EDUC 528
Name:

PART ONE:

The first section of this reflection will focus on your enactment. This should be written as prose rather than a bulleted list. Please write your responses to questions 1-9 in blue text.

1. What went well? What didn't go so well? Refer to specific portions of your lesson plan.

2. How well did your plans prepare you for what actually happened in the lesson? (think about timing, logistical issues, surprises). Did the changes you made to the original plan help students meet the learning goal?

3. 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).

4. How will did your enactment go with regard to *engaging* students in an investigation question/problem, supporting them in *experiencing* the scientific phenomenon, and *explaining* the phenomenon with evidence? Refer to the marked teaching move in your video as evidence.

5. To what extent do you feel you promoted equitable learning opportunities for your students? Describe two instances that demonstrate either strengths or missed opportunities. Consider the equity practices we have discussed.

6. How accurately did you represent the science content and practices in your lesson? Give an example from your lesson where knowing the science well improved your lesson o*r* an example of a place where you recognize that you needed to know the science better.

7. 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?

8. What would you change next time?

9. 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.

PART TWO:

The second part of this reflection focuses on the things from EDU 528 you found most useful in planning and enacting your lesson. Please highlight or bold face your response to the questions below and provide justification for your response. Justifications for your response should be written in prose rather than a bulleted list.

How useful were the following in planning and/or enacting your lesson:

1. Engage-Experience-Explain Lesson Framework:

Very Useful Somewhat Useful Neutral Not at all Useful Didn't Use

Explain:

2. Lesson Planning Template for Science Lessons

Very Useful Somewhat Useful Neutral Not at all Useful Didn't Use

Explain:

3. Skeleton Lesson Planning template

Very Useful Somewhat Useful Neutral Not at all Useful Didn't Use

Explain:

4. Card Sorting Activity

Very Useful Somewhat Useful Neutral Not at all Useful Didn't Use

Explain:

5. Talk Moves Reminder Sheet

Very Useful Somewhat Useful Neutral Not at all Useful Didn't Use

Explain:

6. Alternative ideas resources (e.g. MSTA list of alternative ideas, benchmarks)

Very Useful Somewhat Useful Neutral Not at all Useful Didn't Use

Explain:

7. Monitoring Tool

Very Useful Somewhat Useful Neutral Not at all Useful Didn't Use

Explain:

8. Claim-Evidence-Reasoning Example Worksheet

Very Useful Somewhat Useful Neutral Not at all Useful Didn't Use

Explain:

9. Are there any other tools from EDU528 you found useful? If so please list the tool and explain why it was useful for you.

10. Imagine you were giving advice to future ELMAC interns – which items would you suggest they use? Why? Which items would tell them not to bother with? Why?

APPENDIX O: INTERVIEW PROTOCOLS

INTERVIEW 1:

Question	RQ
First, I would like to talk you about things that influence your planning of discussions in science lessons. What resources did you use when planning this science lesson? (Interview 2 – focused on peer teaching lesson, interview 3 – focused on reflective teaching lesson) *a. Does the curriculum influence how you plan? In what ways?* *b. Does your mentor teacher or school context influence how you plan? In what ways?* *c. Does your field instructor influence how you plan? In what way?* *d. Do other preservice teachers in your cohort influence how you plan? In what way?* e. *Does the science methods course influence how you plan? In what ways?*	2c, 3c
I would like to understand how useful different tools provided during the methods course were in your planning and enactment of your science lessons? (*Interviewer will have a packet of the tools provided during the methods courses that preservice teachers can refer to)* *a.* Which tools from the methods course have been most helpful in your planning? *How did you use those that tool? Why was it useful?* *b.* Which tools from the methods course have been most helpful for teaching science lessons? *How did you use those that tool? Why was it useful?* *c.* Were there any tools you created yourself that were helpful for your planning and/or teaching of science lessons (e.g. worksheets)? *How did you use those that tool? Why was it useful?* *d.* What tools do you wish you had to better support your planning or teaching science lessons? *How did you use those that tool? Why was it useful?* e. Please rate how much you used the tools and the usefulness of the following tools (provide Likert scale on next page, and ask the preservice teacher to talk through her thinking as she fills out the sheet).	2c, 3c

Please rate how much you have used the following tools provided during the science methods course.

EDU 528 Resource	Not At All	A little	somewhat	A lot
EEE Framework	1	2	3	4
Instructional Planning Template	1	2	3	4
Card sorting activity	1	2	3	4
Talk moves tool	1	2	3	4
Monitoring tool	1	2	3	4
Skeleton Lesson Planning Template	1	2	3	4
C-E-R Scaffolding Tool	1	2	3	4
Other:____________________	1	2	3	4
Other:____________________	1	2	3	4

Please rate how useful you found the following tools provided during the science methods course to be.

EDU 528 Resource	Not At All	A little	somewhat	A lot
EEE Framework	1	2	3	4
Instructional Planning Template	1	2	3	4
Card sorting activity	1	2	3	4
Talk moves tool	1	2	3	4

Monitoring tool	1	2	3	4
Skeleton Lesson Planning Template	1	2	3	4
C-E-R Sentence Starter Tool	1	2	3	4
Other:____________________	1	2	3	4
Other:____________________	1	2	3	4

Thoughts about investigation-based discussions

Interview	Question	RQ
2,3	Describe how you planned to teach the whole-class discussion in the explain element of your (peer teaching/reflective teaching lesson). a. What teaching moves did you plan use? b. Why did you plan to use these moves? c. Did anything happen during the engage and experience elements that influenced your plan for the explain element? If yes, what happened? How did that influence your plan for the explain element?	2c, 3c
2,3	Describe how you facilitated the whole-class discussion during the explain element. a. What teaching moves did you use? b. Why did you use these moves? c. Did anything happen during the engage and experience elements that influenced what you did during the explain element? If yes, what happened? How did that influence your plan for the explain element? d. What moves seemed productive? How do you know? e. What moves would you like to revise? Why? How would you revise them?	2c, 3c
3	Stimulated recall interview: Before the interview: "We are going to watch your enactment of your reflective teaching lesson together. I would like to know more about how you made the decisions you made during your instruction, where you felt you were successful, and where you felt there was a missed opportunity. I would like you to stop the tape as we watch if you notice something you would like to tell me about." After watching the video: "There are a few points in your enactment that I wanted to ask you about in particular. I would like to know more about your thinking during those particular points in the lesson" (rest of	1b, 1c, 1d, 3c

	interview will be specific to participant).	

INTERVIEW 2

FOR EACH INTERN HAVE:

- Packet of tools
- Interview questions printed out to write on
- LiFE assignment reflection
- LiFE Lesson plan

Introduction:
The video taping that you have permitted us to do has been and will be invaluable to our understanding of how interns plan for and carry out investigation-based science lessons. But, in addition, we are eager to learn more about the decision-making that goes on behind the scenes. This is why we ask to interview you occasionally. We are curious, for example, to understand what is guiding your thinking as you plan for and teach your lesson in the field. Please be candid and if you are unsure of any of our questions, please ask me to clarify. Also, remember that your responses to these questions in no way influence the grades you receive within the teacher education program, or in the science methods course EDUC 528. We greatly appreciate the many contributions you are making to this important work.

1. First, I would like to talk you about things that influence your planning of investigation-based science lessons. For your LiFE lesson, what resources did you use when planning this science lesson?
Follow up questions:

a. *How did the curriculum influence how you planned?*
b. *How did your mentor teacher or school context influence how you planned?*
c. *How did your field instructor influence how you planned?*
d. *Did other preservice teachers in your cohort influence how you planned? In what ways?*
e. *How did the science methods course influence how you planned? In what way?*

2. Next, I would like to understand how useful different tools provided during the methods course were in your planning and enactment of your science lessons. You can also feel free to refer back to your responses from your LiFE reflection and this packet of tools. (*pull out the set packet of the tools provided during the methods courses that preservice teachers can refer to and their responses on their LiFE reflection).*

f. Which tools from the methods course were **most helpful** in your **planning for the LiFE lesson**? *How did you use those that tool? Why was it useful?*
g. Which tools from the methods course were most helpful **for teaching** the **Life lessons**? *How did you use those that tool? Why was it useful?*
h. Were there any tools (e.g. worksheets for students) you created yourself that were helpful for your planning and/or teaching of science lessons? *How did you use those that tool? Why was it useful?*
i. What tools do you wish you had to better support your planning or teaching science lessons? *How did you use those that tool? Why was it useful?*

****** CHECK to see if there are anything from the reflection survey you want to ask them about specifically ******

3. Now I am interested in hearing a bit about how you planned for the explain element of your LiFE lesson. Please Describe how you planned to teach the whole-class discussion in the explain element of your LiFE lesson – you can feel free to refer back to your plan if that is helpful.

d. What teaching moves did you plan use?
e. Why did you plan to use these moves?
f. Is there anything that you planned for in the engage or experience elements that influenced your plan for the explain element? *For example you and your students may have had a collective experience during the engage that you wanted to touch back on*.
    a. How did that influence your plan for the explain element?

4. The next set of questions focuses on the science content and practices that were focuses of your LiFE lesson. I would like to get a better understanding of the main ideas and practices you wanted your students grasp during the lesson.

a. What was the major content idea of the lesson?
b. What did you do to prepare to teach that content?
c. How comfortable were you about your own understanding of the content?
d. Do you feel your students were able to come away from the lesson with an accurate understanding of that content?
e. What was the major scientific practice you wanted students to engage in in your LiFE lesson?
f. How comfortable were you about engaging your students in this scientific practice
f. Do you feel your students were able to come away from the lesson having engaged in that scientific practice? Why or why not?

Before watching video: We are going to watch your enactment of the explain element of your LiFE lesson together. I would like to know more about how you made the decisions you made during your instruction, where you felt you were successful, and where you felt there was a missed opportunity. These may or may not be the same points you identified for your LiFE assignment. I would like you to stop the tape as we watch if you notice something you would like to tell me about.

After watching the video: "There are a few points in your enactment that I wanted to ask you about in particular. I would like to know more about your thinking during those particular points in the lesson" (rest of interview will be specific to participant).

IF NO VIDEO!!!!!
Please describe how you facilitated the whole-class discussion during the explain element.

f. What teaching moves did you use?
g. Why did you use these moves?
h. Did anything happen during the engage and experience elements that influenced what you did during the explain element? If yes, what happened? How did that influence your plan for the explain element?
i. What moves seemed productive? How do you know?
j. What moves would you like to revise? Why? How would you revise them?

Conclusion

Acknowledge that the interns have been answering the questions and thank them for their time.

APPENDIX P: FOCAL INTERN LIFE LESSON ENACTMENT EVENT MAPS

*Bold outlining indicates investigation-based discussion

Time (minutes)	**Ms. Andrews**	**Ms. Lawrence**	**Ms. Zabel**	**Ms.** Kramer	**Ms. Chase**	**Ms. Sawyer**
0-2			Explains investigation	Explains investigation		Elicits predictions
2-4	Draws attention to C-E-R exemplar		Elicits student ideas about investigation		Reviews states of matter	
4-6	Elicits initial ideas	Reviews opaque and translucent		Models use of magnifying glass		
6-8					Describes investigation	Models investigation
8-10	Explains simulation	Describes investigation question	Describes procedures	Procedural reminders	Poses investigation question	Elicits observations and records on board
10-12		Gives procedural reminders	Students move to seats	Small group work	Elicits predictions	
12-14		Students make predictions	Distribution of materials			
14-16	Distributes simulation materials				Students move to desks	
16-18			Small group work		Distributes materials	
18-20	Students trade "germs"	Gives procedural reminders		Students move to carpet		Procedural reminders
20-22				Student share observation with partners		
22-24	Tests solutions	Distributes supplies		Records observations		
24-26		Students begin investigation		Labels fish drawing	Small group work	Small group work
26-28		Small group work				
28-30						
30-32						
32-34	Students come to carpet		Students move to carpet			
34-36	Lists infected students		Records observations			Students move to carpet
36-38						Elicits ideas about claim
38-40				Students move to carpet		
40-42	Models germ trades	Records observations	Writes claim on board	Elicits claims; reading fibook		
42-44	Writes evidence on board		Elicits ideas about reasoning		Students move to carpet	
44-46	Students craft CER statements				Records observations	
46-48	Elicits ideas about CER				Elicits ideas about CER	
48-50						
50-52		Students craft claim				
52-54						
54-56		Writes reasoning on board				
56-58	Students finish CER statement	Checks predictions against observations			Defines condensation	
58-60						
60-62						

APPENDIX Q: EXAMPLE TYPES OF TALK CODING – MS. ANDREWS

Interaction Unit	Code
T So let's say my claim was—so I think that disease spreads through—by one infected person sharing body fluids with another person. So your claim might look like this. But if I showed this to another scientist they would say, "Ms. Andrews, I need evidence. I need proof. I don't believe you." So I can prove it by showing him the data from our investigation. And we collected this evidence together, right? So the first round we know only Gene was infected, right? And we're saying that you have to have an infected person share body fluids with another person in order for that other person to get infected. They have to share body fluid. So that—so Geno, the first person traded with someone and then both people were infected. So Gene traded with Cory. You can even write their names. Gene traded with Cory and Cory got infected. That's evidence that it's spreading through body fluid. And then we know that Cory traded with Mr. Klein and Mr. Klein got infected. So that's more evidence. So you can use their names or you can just say in round one, one person was—two people were infected. After round two, three people were infected—or four people were infected. So try to write some evidence. Take a minute to do that. Use what you have on the board in your own words.	Authoritative
T Oh, I just thought of something. What about the purple group? Hi, purple group. We kind of forgot about you. Was anyone in the purple group infected? S1 No. T Why? Natalie, why weren't you infected? S1 Because we didn't trade with anybody else who go infected from Gene. We traded—[inaudible]. T Laura, did you hear what Nina said? S2 She only traded with people in their group. S3 Yeah. They only traded within their group so no one got infected. They didn't bring the infection into their group. Could be another piece of evidence if we want to use that? T Yes!	Dialogic
T So take—stop for a second and look up here—or actually, look on your paper and look at the reasoning section at the bottom.	Authoritative

	Reasoning, how I know. I know my claim is true because—what could you write here?	
S1	I said it.	
T	I said it is not really—no scientist is going accept that as a good reason.	
S2	Because we have evidence.	
T	Lily, what do you have? Or what do you think?	
S2	Because we tested it to observe what happened. We did the experiment to answer the questions, and showed it in that thing.	
T	So this is called the model. I think you were trying to say that we used this model to explain our experiment. So we also—we kind of said it a little bit in the claim, but we also wrote about it in our evidence. Could you say that, "I know this because every time an infected person looked at an uninfected person they got the disease." Could I say that?	Dialogic
S1	No.	
T	No. Why not? What's wrong with that? Trinity?	
S1	It's not true.	
T	It's not true. So how do I make that true? What can I say instead?	
S2	Saying that when they passed it on they trade the fluids.	
T	So we need to talk about fluids? So what if I said I know this because whenever a non-infected person exchanged with someone that was infected they got it.	
S2	Yeah.	
T	You think so?	
S2	Mm-hmm.	
T	Anyone have a different idea? Colin?	
S3	We used a model and we tested it and we have evidence.	

APPENDIX R: EXAMPLES OF REPRESENTATION TEMPLATES

Representation Template 1: Qualitative Data Over Time (in context of the Stems lesson)

Instructions:

PART 1. In the chart below, describe your observations. After you have finished filling out the chart move on to PART 2.

OBSERVATIONS	**Celery placed in red water**	**Celery place in clear water**
DAY 1		
DAY 3		

PART 2: Below draw or write what was the SAME and DIFFERENT and then describe WHY you think they are different**:**

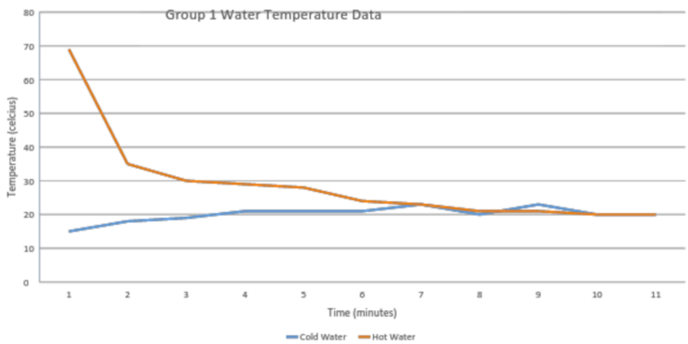
DAY 1 RED WATER CELERY and DAY 1 CLEAR WATER CELERY	
SAME	**DIFFERENT**
I think they are different because…	

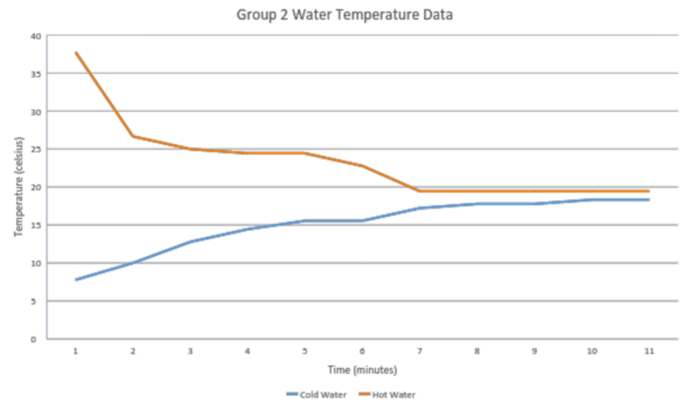
DAY 1 RED WATER CELERY and DAY 3 RED WATER CELERY	
SAME	**DIFFERENT**
I think they are different because…	

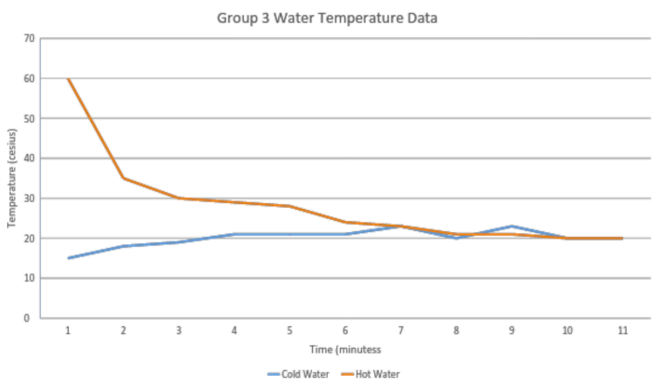
DAY 1 CLEAR WATER CELERY and DAY 3 CLEAR WATER CELERY	
SAME	**DIFFERENT**
I think they are different because…	

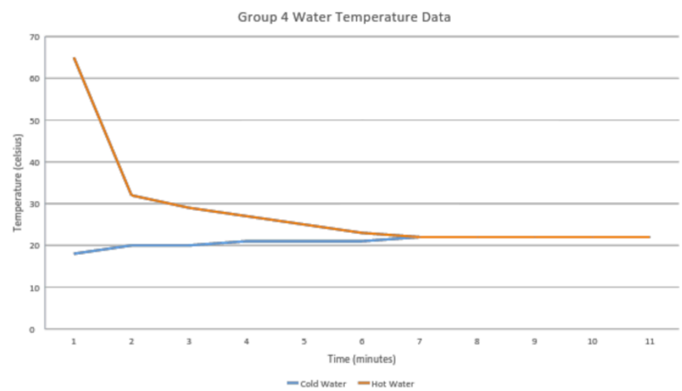
DAY 3 RED WATER CELERY and DAY 3 CLEAR WATER CELERY	
SAME	**DIFFERENT**
I think they are different because…	

Representation Template 2: Quantitative Data Over Time (in context of the Energy lesson)









Instructions:
PART 1: Using the graphs above fill out the chart below:

	Warm water start temperature	Warm water end temperature	Cold water start temperature	Cold water end temperature
Group 1				
Group 2				
Group 3				
Group 4				

PART 2: Use your chart on the previous page to answer the questions:

1. What do you notice about the warm water start temperature for all four groups?

2. What do you notice about the cold water start temperature for all four groups?

3. What do you notice about the warm water end temperature for all four groups?

4. What do you notice about the cold water end temperature for all four groups?

5. What do you notice about both the warm water and cold water temperatures for all groups?

6. Why don't all the graphs look exactly the same?

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