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GETTING TO THE WHY: EXPLORING EARLY CAREER PHYSICAL SCIENCE TEACHERS’ DISCOURSE AND ASSESSMENT PRACTICES.

by

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A DISSERTATION

Presented to the faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Doctor of Philosophy

Major: Educational Studies

Under the Supervision of Dr. Elizabeth B. Lewis

Lincoln, Nebraska

June, 2018
GETTING TO THE WHY: EXPLORING EARLY CAREER PHYSICAL SCIENCE TEACHERS’ DISCOURSE AND ASSESSMENT PRACTICES.

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University of Nebraska, 2018

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Formative assessment, or *assessment for learning*, is an essential component of the interactions between teachers and learners. Teachers elicit statements of understandings to decide their next instructional steps. Similarly, students communicate what they know, and apply teachers’ responses. Formative assessment is as much assessment as discourse; teachers use both to determine and respond to student needs. When teachers use formative assessments effectively, they can guide student understanding, extend discussions, probe for deeper meanings, and provide feedback. Formative assessment provides an understanding of how students are growing (or struggling), which teachers can use to adjust instruction. Frequent formative assessment is strongly linked to student learning and is an indicator of adaptive teaching.

Because of its importance for learning, formative assessment practices are emphasized in national teacher preparation standards. Therefore, it is important to understand how beginning teachers use discourse and assessment as part of formative assessment. Understanding supports and obstacles teachers encounter will help identify and address specific subject matter and pedagogical knowledge for development in teacher education and professional development programs.

The purpose of this study was to identify and describe assessment and discourse practices where early career teachers showed strengths and to illuminate areas in which they encountered challenges. Data sources include classroom observation data, coded to measure alignment with inquiry-based practices, of six beginning physical science teachers. Additionally, teaching self-
efficacy survey data, in-field course hours and GPA were extracted from a larger, longitudinal data set, collected by a calibrated research team, of which I was a member.

I collected data from teaching beliefs interviews, classroom observations and video recordings, cognitive interviews, stimulated-recall interviews using video recordings, artifacts from teacher education program assignments, and post-study member-checking interviews.

These teachers showed strengths in inquiry-aligned discourse practices and confidence in using questions, and encountered challenges in assessing prior knowledge, adapting instruction, and providing opportunities for student reflection.

This study includes explorations of two third-year science teachers’ assessment and discourse practices, using a model developed by Bell and Cowie (2001), and documents how one physical science teacher developed and used an assessment plan to support student learning in a diverse urban school.
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Chapter 1

Introduction

“Language is the essential condition of knowing, the process by which experience becomes knowledge” (Halliday, 1993, p. 94).

An ability to learn beyond mimicry may be the factor that defines humans as a species (Laland, 2017). Whether our understanding of ourselves and our taxonomic classification depends on the depth of our learning is certainly a matter of debate, that “language is the way we conduct our social lives” is not (Kramsch, 1998, p 4).

Within the constructed social event of a science lesson, “teachers and students do an awful lot of talking” (Mortimer & Scott, 2003, p. 21). While there are different modes of communication present in a science lesson, the primary way teachers and students communicate is through spoken language. The ongoing dialogue in a classroom “is an essential feature of the school’s work with and for its students” and provides evidence of learning progress to the teacher, and support for learning for the student (Black & Atkin, 2014, p780).

We know more now about ways to initiate and sustain discourse, and have the capacity to use assessment for learning more than we have in the past. Research continues to describe the strong positive connections between effective assessment and feedback practices, and student learning. This growing body of research and research-informed instructional practices provides teachers and teacher educators with a curated set of effective assessment strategies.
This chapter introduces a study of the discourse and assessment practices of a group of early career physical science teachers. I begin with a brief review of relevant research, and follow with a statement of the problem, purpose, research questions, and justifications of this study. I conclude with an overview of the research methods I used, my position and philosophy of my research approach, and the organization of the study.

**Review of Relevant Literature**

In the sociocultural frame, a learning event happens when a “more competent person and a less competent person” develop understanding “such that the less competent person becomes independently proficient” (Chaiklin, 2003, p. 41). As the more competent person, a teacher may support concept or skill development by assisting students as they connect interrelated ideas. Two examples of direct teacher support of concept development are Lemke’s (1990) description of “thematic condensation” (p. 95) and Chin’s (2006) description of a “cognitive ladder” (2006).

Developing understanding of one chunk of interrelated ideas, atomic orbitals and bonding, was an example Lemke (1990) used to illustrate how concepts, or “thematic patterns,” are linked together in a process of “thematic condensation” (p. 95-96). Lemke (1990) noted thematic condensation required iterations and rehearsals as “the science in the dialogue” became more well-understood over time (p. 87).

In contrast to thematic condensation, where many ideas are packaged into more easily applied concepts, a “cognitive ladder” expands an already condensed idea into individual “rungs” of ideas students can more easily understand (Chin, 2006, p. 837). Chin (2006) described an example of providing single-answer questions in a sequence intended to lead to a larger concept. Teachers provided a “cognitive ladder” so students
could “gradually ascend to higher levels of knowledge and understanding” (Chin, 2006, p. 837).

Two other iterative processes that support student learning, similar to Lemke’s rehearsals of thematic condensation and Chin’s cognitive ladders, are interactive formative assessment and planned formative assessment. Bell and Cowie (2001) developed a model of formative assessment from teachers’ use of different assessment practices in support of their students’ learning. Interactive formative assessment is part of the action of teaching; it is adaptive and often improvised. As teachers use interactive formative assessment, they notice, recognize, and respond to their students’ conceptual misunderstandings as well as their emotional conditions and social needs (ibid). Planned formative assessments are developed before instruction, usually involve skills or scientific practices, tend to be conducted with an entire class, and are often repeated iteratively over longer periods of time (ibid). An example of planned formative assessment is assessing student prior knowledge about a lesson topic.

**Prior Knowledge.** One foundational tenet of the constructivist approach to learning science is that students construct new knowledge within the context of what they already know. Prior knowledge is simultaneously “both the necessary building blocks and impediments of learning” (Treagust, 1996, p. 44). For example, student misconceptions can be a useful start to a conceptual change lesson, which involves restructuring existing knowledge in response to dissatisfaction with their current beliefs (Posner, et al, 1982). Alternatively, persistent misconceptions can inhibit learning of new and essential ideas such as chemical bonding (Mamlok-Naaman, Hofstein, & Nahum, 2017).
Understanding what students already know is the first step in differentiating instruction for individual students. Teachers need to know what students understand and at what level in order to modify lesson content for students who are struggling, as well as for students who may be accessing the content easily or who have learned the content in prior classes (Grant & Fisher, 2010). Assessing and activating student prior knowledge requires teachers to ask questions (Meltzer & Hamann, 2004). In order for instruction to be responsive to student needs, teachers must adjust lesson content to use and build upon existing student understandings.

**Adjusting instruction based on assessment data.** Teacher assessment of existing knowledge, coupled with a change in instructional strategy in response to the assessment, defines formative assessment (Black, 1993). Assessments are formative when they are intended and designed to promote student learning, and when the assessment data are used to modify instruction to meet the needs revealed by the assessment (Black, Harrison, Lee, Marshall, & Wiliam, 2002).

A teacher’s response to student misunderstanding can take many forms; however, much of “teaching and learning occur through processes constructed through discourse and interaction” (Kelly, 2007, p. 443). Students and their teachers use the social interactions in the classroom as feedback; for students, the feedback informs their developing conceptual understandings, and for teachers, the feedback informs their understanding of the effectiveness of their instruction.

The importance of quality feedback to student learning, which Wiggins (1998, p. 46) defined as “highly specific, highly descriptive…clear to the performer, and available...in terms of specific targets and standards” has been affirmed in numerous
For teachers, providing immediate, individualized, and nuanced feedback depends on their accurate assessment of their students’ understanding in the moment of teaching (Sarroub & Pearson, 1998).

**Student reflection.** The National Research Council (2000) identified conceptual understanding, performance of scientific inquiry, and an understanding of inquiry as primary outcomes of inquiry-based teaching. Metacognitive reflection as a part of an integrated assessment plan is a reliable way to support each of the three outcomes identified by the NRC. Student reflection has been identified as contributing to learning gains in science content and scientific practices (e.g., Peters & Kitsantas, 2010) and has an essential role in developing student self-regulation (Pintrich & DeGroot, 1990). However, the focus of this study is the questioning and assessment practices teachers use to support conceptual development as planned or improvised interactions.

**Statement of Problem**

Pre-service teacher preparation standards address the importance of developing effective assessment practices. National standards established by the Interstate Teacher Assessment and Support Consortium (InTASC) require teachers to use assessments and assessment data to “engage learners in their own growth, to monitor learner progress, and to guide the teacher’s and learner’s decision making” (CCSSO, 2011, p. 15). In-service teachers are expected to “engage in ongoing assessment of their teaching and student learning” through the use of multiple sources of data, and to use the data to guide their teaching (National Research Council, 1996, p. 38).

The participants in this study were all graduates of a central plains land grant university’s graduate-level science teacher education program (STEP). STEP science
teaching methods classes centered curriculum development and lesson planning on the national framework for K-12 science education (National Research Council, 2012) and the resulting Next Generation Science Standards (National Research Council, 2013). The STEP was specifically designed to emphasize constructivist teaching principles and student-centered instruction, such as inquiry and active learning approaches.

During the four years between 2011 and 2015, I participated in a still-continuing longitudinal study of early-career science teachers who graduated from this master-level science teacher education program (STEP). The research group observed science teachers as they taught, and used the Electronic Quality of Inquiry Protocol (EQUIP) to rate the alignment of science teachers’ instruction with inquiry practices (Marshall, Horton, Smart, & Llewellyn, 2008). Early analysis of our participants’ inquiry-aligned instruction revealed strengths in discourse practices, and persistent challenges in some assessment practices (Lewis, et al, 2016). Specifically, our participants’ use of questions in support of conceptual development was an area of developing strength for teachers in the larger study, as well as for the participants in this study. Importantly, our participants encountered persistent challenges in assessing their students’ prior knowledge, using assessment data to adjust their instruction, and in providing opportunities for their students to reflect on their learning.

With these early results in mind, I purposefully selected six recent STEP graduates from three consecutive cohorts, who were teaching physical science, physics, or chemistry, in order to investigate their discourse and assessment practices more closely.
Statement of Purpose

The purpose of this multiple methods study was to identify areas of developing strengths and persistent challenges in the discourse and assessment practices of physical science teachers during their first three years teaching, identify and describe the supports and obstacles to enacting effective discourse and assessment practices, and describe how discourse is sustained and used for assessment once early career teachers have teaching experience.

Research Questions

Question 1: In what areas do these purposefully selected teachers show developing strengths, and in what areas do they encounter challenges, in enacting inquiry-aligned discourse and assessment practices?

Question 2: To what extent, and how, did induction-phase physical science teachers employ inquiry-aligned discourse practices, and adapt to obstacles in implementing inquiry-aligned assessment practices?

Question 3: How do two third year teachers initiate and sustain classroom discourse, and how do they use discourse and formative assessment to support student learning and engagement?

Overview of Methods

I used multiple data sources investigate these questions. I was a member of a research team investigating STEP graduates’ instructional practices, and I used quantitative data, generated by this research team, to identify discourse and assessment practices that were aligned with inquiry-based teaching practices. I analyzed EQUIP ratings of assessment and discourse practices, subject matter knowledge measures, and teaching self-efficacy survey data to address Research Question 1. I analyzed field notes and interview transcripts, and conducted in-field observations to address Research Question 2.
I recruited two third-year teachers for in-depth case studies. I generated data in the form of in-person classroom observations and field notes, EQUIP ratings, audio and video recordings of lessons, and participant interviews. At the start of the study, I interviewed participants about their beliefs about teaching and learning, using an open-ended Teacher Beliefs Interview protocol (Luft & Rohrig, 2007). After each lesson I observed, I interviewed teachers about specific instructional decisions. At the conclusion of the study, I conducted stimulated recall interviews and asked my participants to explain their teaching decisions as they watched video clips of specific situations that typified their teaching practices. Additionally, I analyzed STEP course syllabi, specific assignments these two teachers completed as part of their pre-service teaching preparation, and their action research reports. I used the case study data to address Research Question 2 and Research Question 3.

**Rationale and Significance**

Assessment is an inseparable component of education, and typically, teachers use assessments that are informal and often verbal (Mortimer and Scott, 2003). Teacher questions, student statements, and teacher-student and student-student interactions are the conduits through which information and feedback move. This study identifies some of the strengths and challenges in the discourse and assessment practices of a group of highly qualified early career physical science teachers. This study adds to the understanding of how an inquiry-focused teacher education program prepared these teachers to implement the active-learning and inquiry-based instructional practices the program emphasized. Additionally, this study explores possible positive relationships between teacher subject matter knowledge and their use of questions to support
conceptual development, and explores ways in which early career teachers structure their lessons to sustain discourse and generate assessment information. This study also provides a view of how one early career physical science teacher developed, used and refined an integrated assessment system.

For educators at all levels, developing and using effective formative assessment practices is an essential component of effective teaching; Black and Wiliam (1998) concluded improving teachers’ use of formative assessment practices can significantly advance student learning and performance. Formative assessment, when used to generate quality feedback, has large positive effects on student learning (Hattie & Timperley, 2007). Further, the National Research Council (2001) has stated formative assessment is central to meeting national science education standards.

This study is of interest to teacher education program designers, teacher educators, district- and school-level teacher supervisors and science curriculum directors, and secondary science teachers. Identifying areas in need of emphasis in pre-service teacher education, as well as areas of strength upon which to build, helps inform program-level decisions about the content of teacher education programs. Understanding the obstacles new teachers encounter when enacting assessment decisions helps inform support measures and professional development content for practicing teachers as they grow in their practice.

**Role of Researcher**

I was a member of a research team during the time of this study. I participated in classroom observations, used quantitative research instruments to rate alignment of instruction with inquiry-based practices, and conducted interviews about teachers’ beliefs
about teaching and learning science as part of a longitudinal study of early career teachers’ use of inquiry instruction. I extracted data from this longitudinal study to use in the investigation of Research Question 1 and Research Question 2. I designed and conducted the investigation of Research Question 3, and constructed the case studies as discussed earlier in this chapter and explained in detail in Chapter 3.

I was closely connected to both research sites, and I detail my connections with the “St. Sebastian” and “Honeydew” schools where I conducted this research in Chapter 3. In brief, I taught chemistry and physics for 12 years prior to the study at St. Sebastian, and taught physical science at Honeydew in a classroom adjacent to one of my participants during the academic year following the study. These associations with my research sites provided a valuable access to my participants and an experienced understanding of their instructional environments. For the same reasons, my association with both schools and my continuing association with both case study participants informed and perhaps influenced the findings and claims generated in this study. I address the steps I took to ensure validity of findings in greater detail in Chapter 3.

**Researcher Statement**

I approached this study as a science educator and as a science teacher educator. I chose to focus on the assessment and discourse practices of physical science teachers based on my experience as a physical science teacher, and approached this study from the perspective of teacher development, with an understanding that a teacher’s ability, technique, and awareness grow over time.

**Organization of the Dissertation**
I describe the study in detail in the next five chapters. In Chapter 2, the literature review, I explain the concept of formative assessment and a model for understanding formative assessment. I explore how formative assessment fits within the sociocultural model of teaching and learning, and discuss how formative assessment is essential for conceptual development in chemistry and physics specifically. I also describe and support how I grouped specific indicators of inquiry-aligned discourse and assessment practices to measure specific formative assessment practices.

Chapter 3 details the design of this study, as well as my approach as a researcher, and situates the design of this study within a theoretical frame. I describe the participants in the study and how I selected them, methods for generating and analyzing the quantitative and qualitative data, and how I assessed findings for validity. For an organizational structure, I present a conceptual diagram of each research questions’ data generation and analysis. Finally, I identify and explain the limitations of my approach to the research questions, and detail the steps I took to ensure the validity of the findings.

I use the research questions as the organizational structure to discuss the findings of this study in Chapter 4. Each finding is structured using a conceptual diagram, and I include the conceptual diagram in the discussion of each finding. I begin with the analysis of quantitative data that identified the areas of strength and challenges in discourse and assessment practices, and compare the questioning practices of teachers with well-developed subject matter knowledge to the questioning practices of teachers with less-developed subject matter knowledge. I use teaching self-efficacy survey data to explain the observed strengths in questioning practices. After identifying the areas of strength and challenges, I use classroom observations and teacher statements, as well as
subject matter knowledge measures, to construct examples, or lesson cameos, of teachers applying their strengths and adapting to challenges in their discourse and assessment practices. Next, I develop a typology of the two case study teachers’ lessons, and use EQUIP data to assess how teachers use formative assessment and support classroom discourse with each lesson type. I use my direct observations of these teachers’ science lessons, their direct statements about their teaching decisions, and their narration of their decisions as they viewed video clips of their teaching.

In Chapter 5, I connect the findings of the individual research questions to specific claims, and situate each claim upon foundational theory and within current research. Finally, in Chapter 6, I describe limitations, relevance, and implications of this study.

The two case studies generated findings beyond the scope of this study, and I include relevant methods, conceptual framing, and results in a separate appendix. Some of the claims and implications of this study, discussed in Chapter 5 and Chapter 6, draw support from materials included in the case study appendix. In these instances, I direct readers to specific sections of the case studies in the appendix.
Chapter 2

Review of Literature

I begin this review of foundational and current literature relevant to this study with definitions of student-centered instructional practices and a general definition of formative assessment. A general model of formative assessment, and definition and description of quality feedback and the role of feedback in the socio-cultural model of instruction follows. The discussion of feedback is interlinked with the definition and explanation of the sociocultural model of instruction. I relate the key concepts of the sociocultural model to science instruction.

Next, I summarize how formative assessment applies to specific science content (i.e., cross-cutting concepts included in Next Generation Science Standards) and explore how learning these interconnected ideas require expert guidance and interaction.

In the concluding section of this review, I review literature relevant to the conceptual frame of this study. Two methods of formative assessment, interactive formative assessment and planned formative assessment, form the central component of the conceptual frame. These two formative assessment practices are supported by teacher subject matter knowledge, teaching self-efficacy, and pedagogical knowledge.

Definitions of Student-Centered Instructional Practices

At its core, the National Science Education Standards is oriented to “science for all” (National Research Council, 1996, p20). In order to achieve this goal, the Standards approach science instruction from a student-centered perspective. In general, in student-centered instruction, students are doing the activities of science. The verbs used in the standards make it clear students are active in their learning. Students describe, ask,
Approaches to student centered learning include inquiry, constructivism, and active learning. Each are defined below.

**Inquiry.** Inquiry in science education mirrors the work of scientists. In the science classroom, inquiry involves a set of related scientific practices teachers support and students apply to “conceptualize a question, and then seek possible explanations to that question” (National Research Council, 2000, xxi). The Next Generation Science Standards lists a set of eight scientific practices scientists and science students use as they engage in authentic scientific learning (NGSS Lead States, 2013).

**Constructivism.** Minner, Levey, and Century’s (2010) review of inquiry-based instructional practices also generated a consensus definitions of constructivism. As reported by Minner, Levy, and Century (2010), constructivism is generally viewed as an approach to learning which assumes knowledge is generated by the learner internally rather than by transmission, as in a traditional lecture. Further, the learner organizes and integrates information actively, or replaces existing understandings with new understandings (ibid). Finally, learning is social and often mediated by more knowledgeable others (ibid).

Williams and Veomett (2007) offer a more immediately practical illustration of the core principles of constructivism. Active learning approaches include materials, opportunities to manipulate objects, student choice, language, and adult support (Williams & Veomett, 2007). Materials are the actual physical “things” learned about in the lesson. Purposeful manipulation of objects or conditions allow students to experience, explore, and test different arrangements of objects. For example, students might construct
an electrical circuit in different ways. Constructivism requires some level of student autonomy, and Williams and Veomett (2007) include providing students with choices about how they learn. Finally, language and adult support are closely aligned. Students develop and rehearse understandings with their peers, and teachers moderate these developing understandings (ibid).

Central components of active learning. Active learning is an overly general term for instructional practices that engage students in learning (Arthurs & Kreager, 2017; Prince, 2004). Active learning includes, and is not limited to, collaborative and cooperative learning, problem-based approaches to content (Prince, 2004), and more generally includes instructional approaches that support a student’s thoughtful interactions between learning goals, the physical and social environment (Hohmann, Weikart, & Epstein, 1995).

Formative Assessment

Assessment that serves student learning is broadly considered formative assessment. Although others have defined formative assessment, Black, Harrison, Lee, Marshall, & Wiliam (2002) define formative assessment as “any assessment for which the first priority is in its design and practice is to serve the purpose of promoting student learning” and which “provides information to be used as feedback” (front matter). Importantly, the essential determinant of formative assessment is that the data is used by the teacher to “adapt the teaching to meet learning needs” (ibid). Similarly, Wiggins (1998) describes the goal of formative assessment is “to educate and improve student performance, not merely to audit it” (p. 7). In practice, as Coffey, et al (2011) maintain,
formative assessment strategies must provide the teacher with an “awareness and understanding of the students’ understandings and progress” (p. 1128).

**Formative assessment and feedback.** Black (in Atkin & Coffey, 2003) framed a formative assessment process as setting explicit learning goals and sharing these goals with students, explanation of the criteria used to judge performance, and an exchange of feedback between student and teacher that is used to advance the student to the intended learning goal. Feedback is reciprocal; as described by Black and Wiliam (1998), the use of feedback in formative assessment extends beyond the “self-evident proposition that teaching and learning must be interactive” and places both the teacher and the students in the role of learner; the teacher learns what a student knows, and can adapt instruction or provide feedback, and the student uses the feedback provided by the teacher to move closer to the learning objective (p. 140). Sadler (1989) includes student self-monitoring as a component of formative assessment, and distinguishes between feedback and student self-monitoring. If the assessment is initiated by the learner and the learner produces the assessment information, the process is self-monitoring; however, if the “source of information is external to the learner” it is feedback (Sadler, 1989, p. 122). Sadler (1989) notes the overall goal of an effective assessment program is for learners to transition from dependence on feedback to self-monitoring.

Using formative assessment effectively requires a willingness of teacher and student to provide information and to respond to the information; on the part of the student, to respond to questions or otherwise demonstrate understanding, and, on the part of the teacher, to respond to the learners’ needs these answers and demonstrations reveal (Meltzer & Hamann, 2004). Formative assessment requires sharing learning goals and
performance standards with students; in order to be effective, the overarching goal of formative assessment must be shared collectively between teacher and students, and valued as a way to improve learning (Hattie & Timperley, 2007). As with all other assessments or evaluations, formative assessment, whether planned or spontaneous, requires judgement of a product or statement against a predetermined standard of performance. In order for formative assessment and the feedback it generates to be useful to the student, the student must welcome the feedback (Hattie and Timperley, 2007).

Formative assessment is an integral component of the sociocultural model of learning. Teachers often are the more knowledgeable other who supports students’ developing understanding, and the support is often provided through dialogue.

The Sociocultural Model

Within the sociocultural model of learning, a learning event happens when a “more competent person and a less competent person” develop understanding “such that the less competent person becomes independently proficient” (Chaiklin, 2003, p. 41). Learning in the science classroom involves acquisition of skills, as well as the development of conceptual understandings. Learning happens in a zone of proximal development (Vygotsky, 1987), a space on a continuum between fully independent and fully supported work. This zone of proximal development describes a student’s capacity to comprehend an idea or perform a task by seeking help, utilizing resources in the environment, and asking questions of peers and teachers (Black & Wiliam, 2009).

Mortimer and Scott (2003) summarize the sociocultural model of learning as a process of encountering a new ideas or phenomenon, talking about these new ideas and rehearsing understandings in social contexts and eventually internalizing the
understanding as socially rehearsed ideas pass from “social contexts to individual understanding” (p. 9). These new understandings are rehearsed and refined with peers, and teachers may guide the developing understandings using questions to “extend students’ ideas” as students talk about a topic (Chin, 2007, p. 1319). Teachers’ questions can also be used to “scaffold students’ thinking” as their new thoughts are internalized (ibid).

**Question level, complexity, and conceptual development.** Rowe (1986) identified the importance of providing students with enough time to think before answering questions. Sufficient wait time is required for students to formulate answers requiring analysis or connections to other ideas; however, time to think is sometimes insufficient if a concept is too complex. Teachers, as content experts, provide guidance in support of their students’ conceptual development. Wood, Bruner, & Ross (1976) called this temporary support “scaffolding” (p. 98). Teachers “simplify the task by reducing the number of constituent acts” required to construct a solution, keep the learner focused on the objective, bring attention to relevant components of the problem, and moderate the learner’s frustration (ibid). Chin (2006) described a modification to teacher-centered questioning practices similar to scaffolding, a *teacher initiate, student respond, teacher feedback* or *IRF* interaction. Chin (2006) reported using “cognitive ladders” was effective in supporting students’ development of complex and abstract ideas that required scaffolding (p. 837).

As mentioned in the previous chapter, multiple interrelated ideas may be “chunked” into “thematic patterns,” then linked together in a process of “thematic condensation” (Lemke, 1990, p. 95-96). Similarly, Chin (2006) described teacher use of
a “semantic tapestry” as helping “students weave disparate ideas together into a conceptual framework” (p. 823).

Chin (2006) also reported when more traditional, teacher-centered questioning was used during whole class discussions, the class constructed understanding together. By providing single-answer questions in a sequence intended to lead to a larger concept, teachers provided a “cognitive ladder” so students could “gradually ascend to higher levels of knowledge and understanding” (Chin, 2006, p. 837). Cognitive ladders are constructed purposefully, and require teachers to understand both the immediate content of the science lesson, but also the content prior to the lesson and immediately after in order to construct meaningful connections with their students.

**Formative assessment and conceptual development in physical sciences.**

Formative assessment is a central component of teaching and learning across all subjects (Black & Wiliam, 2009). Learning and teaching science requires numerous and iterative formative cycles as students begin to understand the complex interactions between topics. The Next Generation Science Standards list the scientific practices and “cross cutting concepts” required.

<table>
<thead>
<tr>
<th>Science practice</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asking questions and defining problems</td>
<td>Ask and refine questions that lead to descriptions and explanations…that can be empirically tested</td>
</tr>
<tr>
<td>Developing and using models</td>
<td>Use and construct models as helpful tools for representing ideas and explanation</td>
</tr>
<tr>
<td>Planning and carrying out investigations</td>
<td>Plan and conduct investigations in the field or laboratory, working collaboratively as well as individually</td>
</tr>
<tr>
<td>Analyze and interpret data</td>
<td>Analyze data to derive meaning, identify trends and patterns using a variety of analytical</td>
</tr>
<tr>
<td>Use mathematical and computational thinking</td>
<td>Construct simulations, analyze data statistically, recognize quantitative data</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>-----------------------------------------------------------------</td>
</tr>
<tr>
<td>Engage in argument from evidence</td>
<td>Use argument to reach explanations and solutions.</td>
</tr>
<tr>
<td>Obtain, evaluate, and communicate information</td>
<td>Critique and communicate ideas individually and in groups in a critical professional activity.</td>
</tr>
</tbody>
</table>

### Cross Cutting Concepts

<table>
<thead>
<tr>
<th>Patterns</th>
<th>Observed patterns in nature guide classification &amp; organization, and suggest questions about causes of patterns.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cause and Effect</td>
<td>Events are caused. Identifying causal relationships and their mediating mechanisms is a major activity of science. Mechanisms can be tested and used to predict and explain events in new contexts.</td>
</tr>
<tr>
<td>Scale, Proportion, and Quantity</td>
<td>It is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system’s structure or performance.</td>
</tr>
<tr>
<td>Systems and Systems Models</td>
<td>Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.</td>
</tr>
<tr>
<td>Energy and Matter</td>
<td>Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems’ possibilities and limitations.</td>
</tr>
<tr>
<td>Structure and Function</td>
<td>The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.</td>
</tr>
<tr>
<td>Stability and Change</td>
<td>For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.</td>
</tr>
</tbody>
</table>
Although these ideas are prevalent throughout the sciences, students have few interactions with these ideas within the context of science. Additionally, students may hold naive or inaccurate understandings of any of these concepts. For example, energy is a particularly difficult concept to understand beyond colloquial terms (Lacey, et al, 2014) or misunderstood due to inconsistent approaches between science subjects (Needham, 2014). The ways in which students misunderstand these cross cutting concepts exceeds the capacity of a concise review (Treagust & Duit, 2009); the complexity of these ideas in concert with students’ persistent misconceptions necessitates inclusion of formative assessment practices in teaching these essential ideas.

Chemistry. Scaffolding is particularly important as students begin to connect ideas, especially if these individual ideas are only understood at a novice level. Chemistry concepts are interconnected and become complex even at introductory levels (De Jong & Taber, 2014), and developing accurate conceptual understanding requires students to consider multiple ideas simultaneously. As students learn chemistry, they are often required to describe an observable phenomenon, explain the phenomenon on a microscopic level, and relate the phenomenon using symbols and terms specific to chemistry (Johnstone, 1991). Johnstone (1991) represented these three domains, macroscopic or observable, microscopic or theoretical, and symbolic, as the vertices of a triangle. Johnstone suggested learners can conceptually manage working with two of the three domains simultaneously, and De Jong and Taber (2014) contend developing advanced concepts requires keeping all three domains in mind. DeJong and Taber (2014) recommend “chunking” these advanced and interrelated concepts for easier understanding and application (p. 465). High school chemistry students encounter
difficulty engaging with these three different domains, especially if their understanding of each is underdeveloped (Johnstone, 1991). In order to support the connections between observable reactions, theoretical explanations, and the language of chemistry, chemistry teachers must provide significant scaffolding as their students develop these “chunks” of related understandings (DeJong & Taber, 2014, p. 465).

Developing chunks of interrelated conceptual understandings requires connecting physical examples to theoretical explanations and mechanisms, which can be generalized to larger patterns. Oversby (2002) identified five levels of increasing conceptual understanding. Definitional understanding is characterized by stating a concept with no details, and descriptive understanding is characterized by the inclusion of details such as providing physical examples of the concept. Interpretative understanding is evidenced when a theoretical explanation is included in the explanation, and causal understanding is evidenced by the identification of the mechanism driving the phenomenon. Predictive understanding requires producing a generalizable statement about the phenomenon (ibid).

To support their students’ conceptual development, teachers must first assess what students already know in order to identify and address existing misconceptions (Treagust, 1996). Assessing prior knowledge, and planning instruction based on assessment data, is an essential step in presenting a new concept to students (Windschitl, Thompson, & Bratten, 2009). As students develop understanding of individual chemistry concepts, teachers must assess how their students are progressing, and provide necessary and temporary support (Wood, Bruner, & Ross, 1976). Chemistry students are expected to understand a concept as an observable event, describe the event as a microscopic process, and communicate the concept using symbols and terms unique to chemistry.
(Johnstone, 1991). This sophisticated understanding requires expert support, and in order to provide this support, teachers must continually assess their students’ developing understanding. As the chemistry curriculum progresses, students are expected to make connections between concepts, uncover causes, extend their understandings to explain general patterns, use these patterns predictively, and communicate these understandings symbolically (Johnstone, 1989; Driver, Asoko, Leach, Mortimer, & Scott, 1994).

Physics. Although just as complex as chemistry, physics lends itself to compartmentalization more easily. Duit, Schenker, Hottecke, and Niedderer (2014) reported difficulties in learning physics for nearly opposite reasons Johnstone identified for chemistry; physics concepts are often presented without context and as mathematical representations only. Further, “physics is distinguished from other sciences by its high level of abstraction, idealization, and the predominant role of mathematics (Duit, Schecker, Hottkcke, & Neidderer, 2014, p. 438).

If approached from the sociocultural and constructivist perspective, a conceptual change models for teaching physics and addressing misconceptions can be used. Teachers who use the conceptual change model elicit student statements in order to reveal understandings, provide a test of the understandings, and mediate the developing new conception (Posner, Strike, Hewson, & Gertzog, 1982). Teachers using conceptual change must apply both planned formative assessment and interactive formative assessments during lessons (Bell & Cowie, 2001).

Conceptual change science lessons are intentionally constructed in order to evoke the “uncertainty, judgments, values, and interests” of students, and involve students in the process of understanding science (Lemke, 1990, p. 130). Teachers must carefully support
students’ developing understandings, as “science teaching also tends to pit science against common sense and undermine students’ confidence in their own judgment” (Lemke, 1990, p 129).

Using a conceptual change approach includes the “ingredients” of constructivism listed Williams and Veomett (2007), and often provides the student an opportunity to choose a prior understanding or a more scientifically accurate understanding. Further, when the conceptual change lesson involves a phenomenon and opportunities to manipulate and test conditions, there is more alignment with constructivist practices. Minner, Levy and Century (2010) conducted a review of 20 years of physics education research on inquiry and other active learning principles, and reported “consistent evidence...that hands-on experience with science phenomena is important for student conceptual learning, especially when coupled with teacher-guided hypothesis testing and debate” (Minner, Levy, & Century, 2010, p 491).

Conceptual change lessons require advance planning and preparation. In addition to the actual materials used to demonstrate the misunderstood phenomena, teachers must plan to elicit statements of understanding from their students, anticipate how students will respond, and plan their own responses to help students resolve conflicts prior to the lesson (Smith, Blakeslee, & Anderson, 1993).

Interactive formative assessment is also included in conceptual change lessons. In a 1997 study of discourse practices, vanZee and Minstral identified specific discourse moves physics teachers used to collectively construct understanding with whole-class discussion. Teachers in the study elicited student statements, then followed the statements with a question to either the class or to another student as a way to support discussion and
monitor student conceptual development. These *reflective toss* routines provided teachers with statements of student understanding they could use for interactive formative assessments.

In one sense, a conceptual change lesson represents the interactive and planned components of formative assessments. These two approaches to formative assessment form the central core of the conceptual frame of this study.

**Conceptual Framework**

I review literature relevant to the conceptual frame of this study. Two methods of formative assessment, interactive formative assessment and planned formative assessment, form the central component of the conceptual frame. These two formative assessment practices are supported by teacher subject matter knowledge, teaching self-efficacy, and pedagogical knowledge.
Figure 2.1. Conceptual framework for the current study. Teachers enact decisions based on their pedagogical knowledge, teaching self-efficacy, and subject matter knowledge. External factors not directly observed during data collection for Research Question 1 and 2, but for Research Question 3 are factors affecting teacher decisions: curricular factors and school- and district-specific obstacles or supports. Teacher beliefs about teaching and learning are important to decisions about assessment and discourse, and are discussed in the teacher case studies in Appendix D.

This study focuses on teacher questioning in support of their formative assessment practices; therefore, I will focus the review of literature of pedagogical knowledge related to teacher questioning. Similarly, I confine the discussion subject matter knowledge to the relationship it has with teacher questioning practices. Teacher subject matter knowledge is discussed in context of the models of formative assessment that form the central core of the conceptual framework.
**Two models of formative assessment.** Teacher-mediated iterative process that support student learning, similar to Lemke’s rehearsals of thematic condensation and Chin’s cognitive ladders described in the previous chapter, are interactive formative assessment and planned formative assessment. Bell and Cowie (2001) closely examined the formative assessment practices of ten teachers over a period of two years, and developed a model of formative assessment from teachers’ use of different assessment practices in support of their students’ learning. Interactive formative assessment is part of the action of teaching; it is adaptive and often improvised. As teachers use interactive formative assessment, they notice, recognize, and respond to their students’ conceptual misunderstandings as well as their emotional conditions and social needs (ibid). Planned formative assessments are developed before instruction, usually involve skills or scientific practices, tend to be conducted with an entire class, and are often repeated iteratively over longer periods of time (ibid). Figure 2.2 shows the model of interactive and planned formative assessment developed by Bell and Cowie (2001).
Figure 2.2. Planned and interactive formative assessments (Bell & Cowie, 2001). Planned formative assessment is determined prior to instruction in order to assess all students in a class, and consists of a teacher acting to elicit statements of student understanding for the teacher to interpret. Interactive formative assessment is spontaneous, requires a teacher to notice evidence of student understanding or emotional condition in the moment, recognize the importance of what is noticed in context of the lesson, and respond with feedback or support to advance student understanding or moderate emotional condition.

**Interactive formative assessment.** Interactive formative assessment (IFA) is iterative, spontaneous and immediate, deeply situated within the lesson, and is largely unplanned and improvised (Bell & Cowie, 2001). It is also highly complex yet nearly tacit. Teachers used IFA to assess a wide range of learning outcomes, to monitor and mediate individual students’ learning, and to monitor and refine their own near-term goals for individual students. Teachers accessed student understanding through verbal and non-verbal modes. Teachers asked questions and listened to student talk, but they also monitored students’ hands-on work and body language. Teachers in the study noted they needed to be present and notice the evidence of student understanding or emotional condition; information was not permanently retained for later use as with written work (Bell & Cowie, 2001, p. 87). Noticing was not limited to science understanding; it also included social and emotional conditions students communicated through non-verbal means (e.g., body language).

Figure 2.3. Interactive formative assessments (Bell & Cowie, 2001). Interactive formative
Noticing student cues alone was insufficient; teachers had to recognize the importance of a particular student action or statement in the context of the content being learned. Additionally, teachers in the study noted their knowledge about their students was essential to understanding what they had noticed (Bell & Cowie, 2001, p. 87). Successful interpretation of what was noticed required understanding of the science content, lesson objectives, and predetermined quality markers, as well as their students’ level of understanding prior to the student action or statement (ibid). Further, teachers needed to assess the information within the context of the lesson and from their students’ perspectives; they had to determine if the situation required a response, or if the students’ understanding was emerging and needed to develop further before a response would be useful.

Once teachers noticed and recognized the importance of student cues, teachers responses varied by the needs of the student they perceived. In some cases, teachers responded to address their students’ emotional needs, and in other instances, they responded to specific misunderstandings of the science content. Teachers would occasionally switch from interacting with individuals or small groups to addressing the whole class if they determined a misunderstanding was more widely held.

Even though IFA is a spontaneous process, teachers in the study (Bell & Cowie, 2001) reported preparing opportunities for IFA to happen by allotting time for interactions with students as part of the lesson, or by providing opportunities for students
to ask questions individually. Importantly, teachers indicated they prepared for IFA by building and maintaining relationships with their students (ibid). Teachers’ whole class formative assessments required more formal preparation, and Bell and Cowie (2001) described these forms of formative assessment as “planned formative assessment” (p. 82).

**Planned formative assessment.** Like interactive formative assessment (IFA), planned formative assessment (PFA) is iterative and cyclic. Unlike IFA, teachers intend to assess the understanding of an entire class with planned formative assessment. Bell and Cowie (2001) provide an example: teachers assess their students at the start of an instructional unit in order to plan the unit to address gaps in understanding and reassign instructional time if a topic is already well understood.

![Figure 2.4. Planned formative assessment (Bell & Cowie, 2001). Planned formative assessment is determined prior to instruction in order to assess all students in a class, and consists of a teacher acting to elicit statements of student understanding for the teacher to interpret.](image)

Teachers in the study (Bell & Cowie, 2001) used both formal and informal planned formative assessments. Formal assessments were written, and provided permanent evidence for later interpretation. Informal assessments were often verbal responses to planned questions asked to the entire class, sometimes in a brainstorm format. Planned formative assessments were usually focused on science content, and did
not include opportunities for teachers to respond to individual students’ specific needs immediately.

Teachers in the study (Bell & Cowie, 2001) reported relying on their subject matter knowledge to interpret student responses to planned formative assessments, and their understanding of the curriculum they were teaching to plan their instruction in response to assessment data. Instructional responses to student needs required flexibility within the curriculum. Bell and Cowie (2001) included a lesson cameo from a teacher who planned conceptual change lessons in response to student misconceptions revealed in a planned formative assessment.

**Subject matter knowledge.** Loewenberg Ball, Thames, and Phelps (2008) describe content knowledge for teaching mathematics as “what teachers need to know and be able to do to effectively carry out the work of teaching mathematics” (p. 4). Loewenberg Ball, et al, describe their approach to determining the particular content knowledge teachers need, situated within the practice of teaching, as “bottom up,” or as a “job analysis” (p. 5). Loewenberg Ball, et al, build upon Schulman’s (1986) conception of “subject matter knowledge for teaching” (1989, p. 6). Ball, et al, focused on “how teachers need to know” the mathematics they taught, and contrasted this way of knowing with their content knowledge (p. 4). Ball and colleagues illustrate content knowledge for teaching by comparing the work accountants do, such as adding and multiplying, to the work teachers do when teaching multiplication. Loewenberg Ball, et al, show that accountants, and others who use math regularly, do not think about nor do they explain the reasoning and deeper patterns that undergird the process of multiplication. Science teachers, like math teachers, know how students develop their understandings of science
concepts. More importantly, science teachers must know how their students misunderstand science concepts.

Misconceptions about science topics are abundant and persistent. Duit (2007) surveyed research on science misconceptions and found over 4400 publications on student ideas about science. Kind (2014) similarly surveyed research on common misconceptions in the sciences. Paralleling Wandersee, et al (1994), Kind’s (2014) survey of research revealed that teachers often held the same misconceptions as their students. If science teachers hold misconceptions about key topics in their field, they may pass along the misconceptions to their students (Sadler & Sonnert, 2016).

Sadler and Sonnert (2016) tested science teachers for their subject matter knowledge and their knowledge of misconceptions, and measured these teachers’ students’ gain scores on specific science concepts. Sadler and Sonnert (2016) reported students whose teachers understood a science idea and also understood how the science idea is misunderstood were more likely to learn the science idea than students of teachers who understood the science idea but not the misconception.

When teachers understand their subject well, they also understand the interconnected ideas within their fields, and which topics are essential to understanding ideas that appear later in the curriculum (Windchitl & Calabrese-Barton, 2016). With experience, these teachers develop a coherent subject matter structure within their curriculum to plan long-term instruction (Lederman & Gess-Newsome, 1999). Having a knowledge of student misconceptions, as reported by Sadler and Sonnert (2016), will help teachers identify specific content within their curricula that are particularly rich in misconceptions.
**Intersection of subject matter and pedagogical knowledge.** Shulman (1986) identified major categories of teacher knowledge. Teacher knowledge encompassed by this study’s conceptual frame include general pedagogical practices, knowledge of learners, content knowledge and curricular knowledge (Shulman, 1986). This study focuses on teachers’ pedagogical knowledge about formative assessment practices and uses the formative assessment model described by Bell and Cowie (2001). Teachers’ subject matter knowledge influences their formative assessment abilities as well as their questioning practices (Sadler, 1989). Content knowledge for teaching, as described by Ball, Thames, and Phelps (2008) provides a frame for understanding subject matter knowledge for teaching science. Subject matter knowledge is the essential base component of a teachers’ understanding of the content to be taught, as well as the understanding of the depth and sequence of the content within the curriculum (Schwab, 1978). Teachers’ knowledge of learners, in the context of this study, is the knowledge the participating teachers had about how their students learn science content.

**SMK and formative assessment.** Sadler (1989) argued a student’s transition from depending on feedback to self-monitoring requires the student to know the indicators of quality for the task. By necessity, the teacher must also know and explain the markers of acceptable quality. Sadler (1989) notes teachers themselves may have difficulty describing what they intend their students to produce. When a teacher’s subject matter knowledge is insufficient, defining proficiency becomes more difficult. As Ball (1988) noted, “teachers cannot help children learn things they themselves do not understand” (p.5).
Hill, Rowan and Ball (2005) point to the fundamental link between teacher subject matter knowledge to effective teaching practices: teachers’ subject matter knowledge helps students learn only if the knowledge is used “to perform the tasks they must enact as teachers” (p. 376). In context of formative assessment, in order to effectively use assessment to support students’ conceptual development, a teacher must be able to identify evidence of students’ understanding that aligns with scientific understanding, and have sufficient subject matter knowledge to either provide alternative explanations or to ask follow-up questions that guide their student to a scientifically aligned understanding.

In contrast to the effectiveness of low-level questions in cognitive ladders and semantic tapestries reported by Chin (2007), Koufetta-Menicou and Scaife (2000) report teachers’ use of low-level questions are not positively connected with students’ understanding of the intended learning outcome of the lesson. As Chin (2007) noted, the effectiveness of low-level questions in helping students develop complex understandings depends on how well the questions are connected, as with a cognitive ladder. Strong subject matter knowledge is foundational to effective questioning practices (Pierson, 2008), and the ability to connect ideas sequentially to scaffold understanding, as with a cognitive ladder or semantic tapestry (Chin, 2007), is dependant on teachers’ understanding of content. However, Koufetta-Menicou and Scaife’s findings echo Dillon’s (1982) findings. Dillon (1982) reported when questions are used to evaluate recall-level knowledge and are the prevalent form of questioning, students are limited, and perhaps prevented, from articulating their thoughts (Dillon, 1982).
Sanders, Borko, & Lockard (1993) reported when teaching unfamiliar content, even with teaching experience and well-developed pedagogical knowledge, teachers used more novice-like teaching practices. The authors (ibid) report experienced teachers relied on their pedagogical knowledge to buoy inadequate subject matter knowledge.

**Pedagogical knowledge.** Pedagogical knowledge manifests as adaptive teaching. Instructional environments vary widely; no two schools are exactly alike, and no two classrooms within a school are exactly alike. Instructional decisions, made in the moment of teaching, address the specific needs of specific students, and are intended to achieve specific learning objectives. Change from moment to moment is the norm. Enacting routines in a classroom may reduce the cognitive load for a moment (Darling-Hammond & Bransford, 2007), but many other teaching decisions “cannot be routinized because they are contingent on student responses and the particular objectives sought at a given moment.” (p. 359). Pedagogical knowledge of teachers can be viewed as teachers’ systematic thinking about the complexity they encounter. For example, systematically thinking about lesson planning includes anticipating how students may misunderstand the intended learning objective.

Schwartz, Bransford, and Sears (2005) define efficiency as the ability to retrieve and apply, rapidly and accurately, the knowledge and skills required to solve a practiced problem; efficiency is achieved through repetition of same or same type of problem. Schwartz, et al, (2005) define innovation as the ability to unlearn and move beyond prior beliefs, comfort with the discomfort associated with reconsidering a new perspective, willingness to consider approaches other than the ones they are currently expertly
applying. Adaptive experts are balanced between efficiency borne of practice, and innovation wrought through necessity.

Parsons, Williams, Burrowbridge and Mauk (2011), in an exploratory study of adaptive teaching in middle school reading instruction, provided an example of adaptive teaching during a middle school language arts lesson. Based on her knowledge of her students, a teacher brought a pomegranate to class to support their understanding of a reading that featured the fruit. By providing an example, she created an experience to support her students’ learning. Within science instruction, Koufetta-Menicou and Scaife (2000) reported when students in their study were asked to recall an event in support of a teacher question, the question made little contribution to student learning. The authors (ibid) contend “unless a teacher offers students appropriate experiences” in support of the learning objective, the question will not help students develop higher-level thought (p. 83).

Teachers often use questions to assess student understanding, and nearly universally use informal assessments, such as verbal questioning, during activities as checks for understanding (Banilower, et al, 2013). Earlier, Chin (2006) reported teachers generally used questions to “elicit student ideas, scaffold student thinking, prompt students to think aloud and verbalize their ideas, and nudge students toward conceptual development” (p. 837). Koufetta-Menicou and Scaife, (2000) reported that when teachers in their study asked students for evidence as they encountered cognitive conflicts, and used questions to provide guidance in resolving cognitive conflicts, there was a positive correlation with students’ attainment of the intended learning outcome of the lesson.
Teachers often rely on in-class dialogue to provide information about their students’ understandings. Student answers and contributions, “the interactive exchanges between teacher and students, and between students themselves,” provide teachers with data essential to their instructional decision-making process (Black & Atkin, 2014, p.780). Ruiz-Primo (2011) described these “instructional dialogues as assessment conversations” as an unobtrusive way to use “any student–teacher and student–student interaction” as a source of assessment data (p. 16).

Adaptive teaching includes supporting students as they develop academic dispositions. Feedback is adaptive, and teachers can use feedback to help students modify their approach to learning in general. In content-area instruction, teachers and students describe current performance in relation to the explicit learning goals and identify specific steps to close the gap between current and expected performance (Atkin, Black, & Coffey, 2001). To support academic dispositions, Johnston (2012) suggests using process-oriented feedback. Process-oriented feedback is focused on product, strategy, and goals, rather than on personal attributes. Using this form of feedback promotes effort and strategy, promotes enjoyment of learning, resiliency, willingness to take risks, and generating positive self narratives (Master & Dweck, 2009).

Teachers’ adaptive expertise provides flexibility to construct lessons and learning events that engage their students and actively involve them in the generation of their own understandings.

**Teaching self-efficacy.** Teaching self-efficacy is defined by Tschannan-Moran, Woolfolk Hoy, and Hoy (1998), as a “teacher’s belief in her or his ability to organize and execute the courses of action required to successfully accomplish a specific teaching task
in a particular context” (p.22). Few science-specific studies of teacher self-efficacy and teaching practices of secondary science teachers exist in recent literature; however, research of non-science teachers’ teaching self-efficacy provides a view of the effect of teaching self-efficacy in teachers’ adaptability, persistence, and responsiveness to students.

Special education teachers with high personal teaching efficacy (i.e., a positive belief in their own skills and resources for teaching) were more likely to use new approaches to teaching, be more planful and organized, and more confident in their teaching (Allinder, 1994). Midgley, Feldlaufer, and Eccles (1989) reported among early secondary math teachers, teachers with high teaching self-efficacy have a greater effect on student performance with low-performing students than with high-performing math students. The authors suggest low-performing students may be more responsive to their teachers’ high self-efficacy, or that teachers with high self-efficacy communicate high expectations to their low-performing students.

**Summary**

This chapter reviewed foundational and current literature relevant to this study with definitions of student-centered instructional practices and a general definition of formative assessment. In this review, I presented the general model of formative assessment, and defined and described quality feedback and the role of feedback and formative assessment as part of the socio-cultural model of instruction.

I summarized how formative assessment applies to specific science content (i.e., cross-cutting concepts included in Next Generation Science Standards) and explored how learning these interconnected ideas requires expert guidance and interaction.
This chapter concluded with support from research relevant to the conceptual frame of this study. Two methods of formative assessment, interactive formative assessment and planned formative assessment, formed the central component of the conceptual frame, the enacted discourse and assessment teaching decisions.
Chapter 3: Methodology

The overarching purpose of this study was to determine how induction-phase teachers’ use of discourse and assessment practices developed during their induction phase, what their practices “looked like,” and to better understand teachers’ decisions as the decisions were made.

Approach

A research approach that captures a broad view of evolving discourse practices and the interactions of experience, teacher efficacy and beliefs about teaching of a group of physical science teachers as well as a closer investigation of the decisions about the use of discourse teachers make during lessons is needed. A case study approach is the best research tool available to investigate teachers’ use of discourse in their classrooms as well as provide for a close-up, detailed exploration of two individual teachers’ instructional decision making (Miles & Huberman, 1994; Yin, 2003). This study uses multiple methods, and employs quantitative measures of inquiry-aligned instruction as well as qualitative measures to answer the following research questions:

Research Questions

This chapter details the methods used to answer the following questions:

RQ1: In what areas do these purposefully selected teachers show developing strengths, and in what areas do they encounter challenges, in enacting inquiry-aligned discourse and assessment practices?

RQ2: To what extent, and how, did induction-phase physical science teachers employ inquiry-aligned discourse practices, and adapt to obstacles in implementing inquiry-aligned assessment practices?

RQ3: How do third year teachers initiate and sustain classroom discourse, and how do they use discourse and formative assessment to support student learning and engagement?
Conceptual Framework

I present the conceptual frame for this study in Figure 3.1 and Figure 3.2. Figure 3.1 shows the data sources and analysis for research questions 1 and 2; Figure 3.2 shows the data sources and analysis for Research Question 3.

**Strengths, challenges, and adaptation in discourse and assessment.** Teacher experience may influence the extent to which they use inquiry-aligned discourse and assessment practices. Use of inquiry-aligned discourse and assessment practices is a teacher’s choice, and is mediated by perceived deficiencies in their own preparation or obstacles to enacting their choices. Teacher decisions are influenced by school-level restrictions or supports, the pedagogical knowledge they bring from their STEP or personal professional development, and by their confidence in their own subject matter knowledge.

![Conceptual Framework Diagram](image)

Figure 3.1: Conceptual diagram for research questions 1 and 2. Data were collected to
measure the alignment of instruction with inquiry principles using the EQUIP instrument, teacher pedagogical knowledge (PK) was inferred from teacher statements and direct observation of teaching practices, and teacher subject matter knowledge (SMK) was approximated using number of credit hours in physical science courses, GPA, and scores on a test of misconceptions.

**Initiating, sustaining, and using discourse for assessment.** Teacher’s decisions about assessment and discourse practices are influenced by their subject matter knowledge (SMK), pedagogical knowledge (PK), and teaching self-efficacy (TSE). Additionally, external influences from the school or district, and the specific requirements of the curricular content influence teachers’ assessment and discourse choices. These internal and external influences are mediated by their beliefs about teaching and learning science.
Figure 3.2. Conceptual framework for the current study. Teachers enact decisions based on their pedagogical knowledge, teaching self-efficacy, and subject matter knowledge. External factors not directly observed during data collection for Research Question 1 and 2, but for Research Question 3 are factors affecting teacher decisions: curricular factors and school- and district-specific obstacles or supports. Teacher beliefs about teaching and learning are important to decisions about assessment and discourse, and are discussed in the teacher case studies in Appendix D.

**Research Design**

A broad overview of this study’s research questions, data sources and analytical approaches, and validation methods is summarized in Table 3.1, and expanded in greater detail for each research question later in this chapter.

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Data sources</th>
<th>Data analysis</th>
<th>Verification method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. In what areas do these purposefully selected teachers show developing strengths, and in what areas do they encounter challenges, in enacting inquiry-aligned discourse and assessment practices?</td>
<td>EQUIP Assessment and Discourse factors.</td>
<td>Relative frequency distribution of inquiry proficiency levels during each of first three years teaching (EQUIP). Year-to-year trends in self-reported teaching self-efficacy in using instructional strategies.</td>
<td>EQUIP is a validated instrument. EQUIP instrument used by a calibrated research team; multiple observers and multiple observations at regular intervals.</td>
</tr>
<tr>
<td>2. To what extent, and how, did induction-phase physical science teachers employ inquiry-aligned discourse practices, and adapt to obstacles in implementing inquiry-aligned assessment practices?</td>
<td>All Teachers: Lesson observation field notes, post-observation cognitive interviews, post-study member checking interviews. <strong>Year 3 Teachers only:</strong> Video recordings and transcripts of observed lessons, video clip cognitive interview, post-lesson cognitive interviews.</td>
<td>Explicit statements of teachers’ intent and decision-making process while teaching, beliefs about teaching and learning which led to the decision, and the supports and obstacles they perceive in their instructional setting.</td>
<td>All Teachers: Multiple methods: direct observation of, and interviews with all teachers; <strong>Year 3 Teachers only:</strong> Alignment of statements from video stimulated-recall / cognitive interviews, post-study member-checking interviews</td>
</tr>
</tbody>
</table>
Research Question
3. How do third year teachers initiate and sustain classroom discourse, and how do they use discourse and formative assessment to support student learning and engagement?

<table>
<thead>
<tr>
<th>Data sources</th>
<th>Data analysis</th>
<th>Verification method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video recordings and transcripts of observed lessons, video clip cognitive interview, post-lesson cognitive interviews. EQUIP factors grouped into IFA, PFA, and ENG clusters</td>
<td>Presence or absence of instructional practices specific to science content. Extent to which IFA, PFA, and ENG practices were aligned with inquiry-centered instruction.</td>
<td>EQUIP ratings of inquiry-aligned instructional methods conducted by a calibrated researcher, multiple data sources used to generate “authentic portrait” of representative lessons (Miles and Huberman, 1994, p 278)</td>
</tr>
</tbody>
</table>

Research Instruments

Inquiry-aligned instruction was rated using the EQUIP instrument (Marshall, Horton, Smart, & Llewellyn, 2008). A calibrated research team, of which I was a member, observed and rated teachers using the EQUIP instrument and a coding guide. The EQUIP instrument and the team’s coding guide are included in Appendix A, Research Instruments.

The EQUIP instrument measures teachers’ use of inquiry-aligned instruction, discourse, assessment, and curriculum (Marshall, Horton, Smart, & Llewellyn, 2008). Instruction factors associated with inquiry-aligned lessons are instructional strategies, order of instruction, teacher role, student role, and knowledge acquisition. Discourse factors associated with inquiry-aligned lessons are questioning level, complexity of questions, questioning ecology, communication pattern, and classroom interactions. Assessment factors associated with inquiry-aligned lessons are prior knowledge, conceptual development, student reflection, assessment type, and role of assessing. Curriculum factors associated with inquiry-aligned lessons are content depth, learner centrality, integration of content and investigation, and organizing and recording information.
I used discourse and assessment EQUIP factors to identify areas in which the six physical science teachers showed growth and experienced challenges (RQ1 and RQ2). I used specific groups of EQUIP factors to rate interactive formative assessment (IFA) and planned formative assessment (PFA) practices, and approaches teachers were using to keep students engaged (ENG) in lessons third-year teachers Carl and Kari taught (RQ3).

Teaching self-efficacy was measured using a validated survey developed by Tschannon-Moran and Hoy (2001). The survey measured teachers’ confidence in their ability to enact specific instructional strategies, promote student engagement, and manage their classroom. The teaching self-efficacy instrument is included in Appendix A, Research Instruments. I used end-of-year participant responses to identify trends in teaching self-efficacy from Year 1 to Year 2, and compare teachers’ self-efficacy in their use of questions to the level of alignment with inquiry questioning practices observed during their lessons and rated with the EQUIP instrument.

I interviewed third-year teachers Carl and Kari using the teacher beliefs interview developed by Luft and Roehrig (2007). The interview questions and protocol are included in Appendix A (Research Instruments). I based follow-up questions on participant responses, and allowed Carl and Kari to provide as much information as they were comfortable sharing.

**Study Participants**

I recruited physical science teachers from three consecutive cohorts of a graduate, master-level science teacher education program (STEP). I selected six physical science or chemistry teachers so first, second, and third year experiences would provide a cross-sectional sample of STEP graduates who taught physical sciences. The second- and third-
year participants taught physical science or chemistry in each year of teaching, although they may have taught other classes as well. Participants did not change employment location during this study.

Participants were a part of an ongoing longitudinal study, and I extracted data for this study from the larger data set. Data sets are composed of six teachers’ first-year practices, four teachers’ second-year practices and two teachers’ third-year practices, as shown in Table 3.2 below.

<table>
<thead>
<tr>
<th>Participant</th>
<th>1st Year</th>
<th>2nd Year</th>
<th>3rd Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kim</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mike</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jena</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Sara</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Carl</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Kari</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Complete data sets by year of experience:</strong></td>
<td>6</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

Second-year teacher Sara was unavailable for follow-up and member-checking interviews, so I used her quantitative (EQUIP and SMK) data only. I constructed deeper case studies of two third-year teachers from classroom observation and interview data.

**Approaching Research Question 1**

As part of a larger investigation (Lewis, et al, 2016) I worked with a calibrated team of researchers to observe and rate teachers’ use of inquiry-aligned instructional practices, including the six teachers’ assessment and discourse practices included in the data set for this investigation. I extracted EQUIP data for the six physical science teachers from the larger study’s data set.
The calibrated investigation team conducted regular observations of lessons, generated field notes, and rated teachers’ use of inquiry-aligned instructional practices using the EQUIP instrument (Marshall, Horton, Smart, & Llewellyn, 2008) and a coding guide. Each teacher was observed at least five times each year; most were observed six times. Teachers were observed, for the most part, teaching lessons within their areas of expertise. Out-of-field lessons (e.g., medical terminology lessons taught by a physics teacher) were excluded from the data set for this investigation.

Data extracted from the larger, longitudinal data set were compiled by multiple observers of each participant, and from multiple observations of each participant at regular intervals for triangulation by data source and researcher (Miles & Huberman, 1994). Each member of the observation team was calibrated collectively each semester using paired observations and inter-rater agreement protocols.

**Data Analysis.** I grouped the six teachers by SMK proficiency, using in-field credit hours, grade point average (GPA), and MOSART tests of misconceptions scores. For this analysis, I used chemistry or physics SMK measures that aligned with the lesson content of the observed lessons during teachers’ second year, and EQUIP scores for these lessons. MOSART developers determined scores above 80% indicate minimal retention of misconceptions, and scores below 80% indicate significant misunderstandings of key concepts within the discipline (Sadler, Coyle, Cook-Smith, & Miller, 2007). Mike and Kim scored the same on the MOSART chemistry test; however, I used Mike’s relatively recent graduate-level chemistry coursework and higher GPA to categorize him with the high SMK group. I relied on Kim’s statements during a member-checking interview to
confirm the categorization; Kim reported she often needed to review chemistry content prior to teaching chemistry lessons.

I analyzed the SMK-related questioning practices observed during second-year physical science lessons (i.e., lessons addressing physics or chemistry topics). Several observed lessons were not physical science, chemistry, or physics lessons, and I excluded these medical terminology and forensics lessons from the analysis. Due to the length of time between my field observations and the completion of this investigation, I had access to Mike’s and Kim’s second year EQUIP ratings.

I compared the fraction of lessons in which the EQUIP ratings for questioning level, complexity of questions, and conceptual development were rated as “proficient” and “pre-inquiry” for both high and low SMK groups. I then compared these teachers’ teaching self-efficacy in instructional practices, which included items addressing teaching self-efficacy in creating and using questions, to the high and low SMK teachers’ alignment with inquiry-based questioning practices.

I selected discourse and assessment practices that showed strengths and challenges to investigate RQ2: to what extent, and how, did induction-phase physical science teachers employ inquiry-aligned discourse practices, and to what extent, and how, they adapted to obstacles in implementing inquiry-aligned assessment practices?

Approaching Research Question 2

I used EQUIP scores to identify areas of growth and challenge in implementing inquiry-aligned teaching techniques. I used these areas of growth and challenge to select focal points for an explanatory phase of investigation, and used field notes to identify how teachers were enacting their decisions within these EQUIP categories (Creswell &
Plano-Clark, 2011). For example, the group of six physical science teachers showed growth in the EQUIP assessment factor *Concept Development*; therefore, I reviewed observation notes for incidences of teachers’ instructional practices that supported students’ conceptual development.

I used teacher self-efficacy data generated from the Teaching Self-Efficacy Survey instrument developed by Tschannon-Moran, Woolfolk-Hoy, and Hoy (1998). Specifically, I used the instructional practices component of the survey that measured teaching self-efficacy in questioning and assessment practices, and differentiating instruction, to explain patterns observed in subject matter knowledge and questioning practices in the EQUIP data analysis.

A schematic of my participants, data sources, and data analysis for Research Questions 1 and 2 is shown in Figure 3.3 below.
Constructing lesson cameos. Researcher memos of lesson observations, post-observation conversations, cognitive interviews about teaching beliefs and practices, and post-study member-checking interviews were used to infer teacher intent and goals as they made their instructional decisions.

I constructed lesson cameos from teachers’ lessons, using video and audio recordings for the third-year teachers, and observation field notes for the first- and second-year teachers. For the third-year teachers lessons, I used the available transcribed interchanges between teacher and students, and teachers’ explanations of their instructional decisions and understanding of the instructional conditions at the time. The
lesson observations of the first- and second-year teachers did not include video recording; therefore this level of detail was unavailable for all six teachers.

I generated lesson cameos by combining results from different methods of questioning (i.e., interpreting quantitative ratings of inquiry-aligned teaching practices over time, in-person observations of lessons as taught, and teachers’ explanations of their decisions and adaptations to their instructional environment, and stimulated recall-cognitive interviews with third-year teachers) to create an “authentic portrait” of teachers’ assessment and discourse practices during their first three years teaching physical science (Miles & Huberman, 1994, p. 278). Table 3.3 (below) summarizes how I used data sources and analysis methods in constructing lesson cameos.

<table>
<thead>
<tr>
<th>Data source</th>
<th>Data produced</th>
<th>Revealing...</th>
<th>Used in cameos...</th>
</tr>
</thead>
<tbody>
<tr>
<td>EQUIP Discourse and Assessment Factors</td>
<td>Inquiry-aligned assessment and discourse practices</td>
<td>Instructional practices that became more inquiry-aligned, and instructional practices that did not, with teacher experience.</td>
<td>To identify specific instructional practices for further investigation.</td>
</tr>
<tr>
<td>Teaching Self-Efficacy Survey</td>
<td>Responses to questions about teaching asking “how much can you do” to enact specific instructional decisions</td>
<td>Teacher confidence in ability to enact instructional decisions</td>
<td>To determine changes in teachers’ confidence in their ability to enact effective assessment and discourse practices from year to year.</td>
</tr>
<tr>
<td>Lesson observation field notes</td>
<td>Specific instructional practices</td>
<td>Examples of individual teachers’ specific discourse and/or assessment practices showing growth or challenge.</td>
<td>To describe lesson events in which the teachers’ discourse or assessment decisions were enacted.</td>
</tr>
<tr>
<td>Post-lesson cognitive interview memos</td>
<td>Teacher statements about their instructional decisions at specific points in the lesson</td>
<td>Teacher perceptions of their instructional environment and conditions influencing decisions.</td>
<td>To explain teacher intent and decision-making process during enactment of instructional decision.</td>
</tr>
<tr>
<td>Method</td>
<td>Purpose</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------</td>
<td>-------------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Video cognitive interviews</td>
<td>To explain teacher intent during transcribed interchanges with students.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-study member-checking</td>
<td>To confirm teacher intent, connect teachers’ experience to growth.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMK measures</td>
<td>Connections between teaching self-efficacy in and enactment of discourse and assessment practices.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

I included measures of subject matter knowledge (i.e., semester hours and GPA by subject) in cameos only if the teacher specifically mentioned SMK as a factor in a specific instructional decision.

I constructed lesson cameos using these data to explain teachers’ instructional decisions. Lesson cameos serve as examples of how individual teachers made and enacted specific assessment and discourse decisions in their own instructional environment.

**Approaching Research Question 3: Teacher Case Studies**

Two third-year physical science teachers comprised the in-depth investigation of assessment and discourse practices. I selected these two teachers, Carl and Kari, based on their similar subject matter and pre-service teacher education preparation, the widely different communities and instructional environments in which they taught, and the different populations of students in Carl’s physical science and Kari’s chemistry classes. I obtained school-level data from public records available from the state educational agency’s website for the public school, and from school promotional materials available.
on-line, confirmed by personal correspondence with school officials for the private school. A comparison of Carl’s and Kari’s school communities is summarized in Table 3.4 below.

<table>
<thead>
<tr>
<th>Kari’s and Carl’s pre-service preparation and school communities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Kari</strong></td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td><strong>Pre-service preparation</strong></td>
</tr>
<tr>
<td>Graduate assistant, laboratory and recitation TA</td>
</tr>
<tr>
<td>Scholarship athlete</td>
</tr>
<tr>
<td><strong>Classes taught</strong></td>
</tr>
<tr>
<td>AP chemistry</td>
</tr>
<tr>
<td>Forensics</td>
</tr>
<tr>
<td><strong>Private, Catholic, single-gender (male) boarding school</strong></td>
</tr>
<tr>
<td>Suburban/rural setting</td>
</tr>
<tr>
<td>Most students are from high SES families</td>
</tr>
<tr>
<td>College-preparatory</td>
</tr>
<tr>
<td>235 student school enrollment, about 16 students per classroom</td>
</tr>
<tr>
<td>Student population is about 80% Caucasian, 20% visiting foreign students (from South Korea, China)</td>
</tr>
<tr>
<td><strong>About 10% of student population are refugees</strong></td>
</tr>
</tbody>
</table>

I describe my lesson observation protocols in the section describing the data sources and analysis in more detail in the following sections. In brief, I observed fifteen
lessons in total. After I had observed about three lessons from each participant, I met with Carl and Kari individually to determine what lessons I should observe in order to ensure I captured a representative sampling of their teaching in the data set.

I video recorded each lesson I observed, and Carl and Kari wore a small microphone and recorder as they taught. I wrote field notes during my observation, and noted instances when Carl or Kari appeared to make instructional decisions, or at roughly five-minute intervals. I used the points of interest for post observation cognitive interviews. I rated each observed lesson for inquiry-aligned teaching practices using the EQUIP instrument.

**Classifying science lessons.** As part of the iterative analysis of lessons, I asked “what are teachers doing in their lessons?” as I viewed the recorded lessons and transcriptions of classroom talk. I used this perspective to ask: how are teachers initiating and sustaining classroom discourse, and how do they use discourse for formative assessment?

To classify the set of fifteen lessons, I coded teacher actions during lessons as teacher modeling (e. g. gradual release of responsibility, or “I do, we do, you do.”) or as providing examples or counter-examples of common misconceptions. I coded lessons that included misconceptions listed in the MOSART instrument (Sadler, Coyle, Cook-Smith, & Miller, 2007), or explicit statements by the teacher during instruction (e. g. “this is where you get confused”) as “M” and lessons that did not include misconceptions as “m.” Similarly, I coded lessons that included a phenomenon or a physical “thing” students could manipulate or that the teacher used as part of a demonstration as “P”, and lessons that did not include a phenomenon or manipulative as “p”. I sorted lessons with a
2x2 combination table, and tabulated EQUIP assessment and discourse scores for each type of lesson. A schematic diagram of my data sources and analysis is shown in Figure 3.4 below.

![Diagram](image)

Figure 3.4. Data sources and analysis of Carl’s and Kari’s lessons for RQ3. Lessons were classified by presence or absence of a phenomenon or science artifact, and whether the lesson addressed a misconception explicitly. Alignment with inquiry-centered interactive formative assessment, planned formative assessment, and engagement factors were tabulated for each lesson type. A representative lesson cameo for each lesson type was selected to illustrate teacher assessment and discourse decisions.

**Triangulation of data.** I described lesson types using data from multiple sources, as shown in Table 3.5 below.

Table 3.5.
<table>
<thead>
<tr>
<th>Data source</th>
<th>Analysis of...</th>
<th>Revealing...</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lesson observation field notes (Carl and Kari)</td>
<td>Presence or absence of misconception or skill; presence or absence of phenomenon or equipment related to lesson objective</td>
<td>How lessons taught by Carl and Kari during the observation period included phenomenon or misconceptions, or demonstrations of science-specific skills.</td>
<td>Lessons were categorized into four types using a 2x2 combination table</td>
</tr>
<tr>
<td>EQUIP discourse and assessment factor ratings for observed lessons</td>
<td>Extent to which inquiry-aligned discourse and assessment practices were used within each lesson type</td>
<td>Patterns of teachers’ inquiry-aligned discourse and assessment practices</td>
<td>Each type of lesson was described by the extent to which interactive formative assessment and planned formative assessment practices, and student engagement practices were aligned with inquiry principles.</td>
</tr>
<tr>
<td>Video recordings of teacher-student interactions</td>
<td>Teacher-student talk, teacher and student actions during lesson segment</td>
<td>How teachers assessed and responded to student learning needs in the context of the lesson</td>
<td>Teacher-student interactions were transcribed, analyzed for teacher intent. Participants used transcripts during VCI.</td>
</tr>
<tr>
<td>Video clip cognitive interview (VCI)</td>
<td>Teacher explanation of intent in discourse or assessment practice or specific utterance</td>
<td>Teacher perception of students’ needs and their decision-making process</td>
<td>To explain teacher intent during transcribed interchanges with students</td>
</tr>
</tbody>
</table>

I describe typical lessons from each category in Part 4 of Chapter 4. I summarized lesson excerpts, teacher-student interactions, and teachers’ explanation of their decision-making process for each of the four types of lessons. As much as possible, I used teachers’ direct statements about their assessment and discourse instructional decisions as stated, with minimal paraphrasing, in order to minimize my interpretation of Carl’s and Kari’s decisions. I used EQUIP ratings of inquiry-aligned assessment and discourse practices for each of the four types of lessons.

**Interactive and planned formative assessment, and engagement clusters.** I used EQUIP assessment and discourse factors, and selected instructional and curriculum
factors, to construct three groups of teacher actions. The EQUIP factors that describe assessment and discourse practices form the interactive formative assessment (IFA) and planned formative assessment (PFA) “clusters” following Bell and Cowie’s (2001) model. During my initial analysis of lessons and teacher statements, I noticed Carl and Kari were actively attentive to student engagement, and I selected EQUIP factors related to student engagement to form the “engage” (ENG) cluster to represent these practices. Analyzing the lesson types by IFA and PFA practices, and instructional decisions intended to engage students, allowed me to integrate teachers’ actions with their explicit statements about their instructional decisions.

I analyzed EQUIP factors, grouped into IFA, PFA, and ENG clusters for each type of lesson, for frequency of ratings. For example, I counted the number of MP lessons (i.e., lessons in which both a misconception and a phenomenon were included) and tabulated inquiry proficiency ratings for IFA, PFA, and ENG clusters.

I used lesson cameos from the two most common lesson types, and the ENG, PFA, and IFA clusters scores to describe how Carl and Kari were initiating and sustaining science talk in their classrooms (ENG), and direct teacher statements from the post-lesson cognitive interviews and stimulated recall interviews to explain their planned and spontaneous assessment decisions as they taught.

Two in-depth case studies of the two third-year teachers, Carl and Kari, are included in Appendix D and Appendix E. I describe the interview data collection and analysis in greater detail in Appendix D (Carl’s Case).

Limitations
The small sample size, as well as the cross-sectional sample restricts generalization of quantitative data beyond these six physical science teachers’ instructional practices. Additionally, five or six observed lessons per year per participant may not adequately capture a representative sampling of instructional practices. At the time of this study, the observation protocol used by the research team did not include information about lessons immediately preceding or following the observed lesson (Lewis, et al, 2016). Teacher self-efficacy survey data was self-reported, and may have been exaggerated or overly affected by respondents’ personal or situational factors at the time of the survey.

The qualitative aspects of this study were undertaken to develop a better understanding of the highly situated and contextualized decisions and perspectives of the two case study science teachers. Qualitative data was generated largely from participants’ self-reported statements, and participants, Kari in particular, may have exaggerated negative or self-critical statements.

**Researcher Statement**

At the time of the study, my experiences in science education included seventeen years teaching mostly high school chemistry or university chemistry labs, high school physics, and three years as a graduate student studying how science teachers learn to teach.

I viewed this study from the perspective of teacher development, and with an understanding that a teacher’s ability, technique, and awareness grow over time. I relied on my own development as a teacher as one “lens” through which to observe Carl’s and
Kari’s teaching, analyze their statements, and construct explanations of their teaching decisions.

My pre-service teacher preparation was in both biology and chemistry, but I gravitated toward chemistry because many of the key concepts in introductory chemistry can be demonstrated with observable events, and the microscopic actions explained theoretically with fundamental principles such as “opposite charges attract”. Earlier in my career, I tended to think of chemistry education as inputs and outputs; students arrived with the requisite skills, encountered meaningful but largely homogenous experiences within the course curriculum, and exited as products.

Over time, I refined by beliefs about teaching and learning. Learning doesn’t happen through symbols or through language alone; there needs to be an experience associated with the words or symbols for learners to generate meaning. Likewise, experiencing a phenomenon is insufficient to fully understand it; learners need to talk to others with a similar level of understanding in order to generate ideas and rehearse their developing understanding. Effective teaching includes providing actual phenomena and opportunities for learners to develop possible understandings, and moderating our students’ developing views as “more knowledgeable others”. I concurrently hold a more utilitarian belief that effective teaching is doing what works for the students.

As the investigator, I made every attempt to be on-site for extended periods, to be unobtrusive and as much like “wallpaper” as possible. I interviewed Carl and Kari in private and quiet locations away from colleagues. I informed Carl and Kari, my two in-depth case study participants, I was investigating how science teachers used questions, a reasonable approximation of what the research questions evolved into over the course of
the study. I was, however, closely associated with Kari’s site; I had taught in the school, and in Kari’s classroom, for twelve years. Kari did not directly succeed me when I left St. Sebastian; however, I strongly encouraged her to apply for the position that I once held, based on my belief in her capability as a chemistry teacher. Additionally, during the year after the study, I taught in the classroom next to Carl after accepting a brief appointment at “Honeydew.”

Miles and Huberman (1994) caution researchers to avoid “going native” and to “keep thinking conceptually” by “translating sentimental thoughts into more theoretical ones” (p. 266). Prior to the study, I was about as “native” to St. Sebastian as was possible; and my time at Honeydew provided the bookend to both this study and Miles and Huberman’s admonition. Describing my participants, who are now also my colleagues, was a difficult task at times. However, I took to heart Miles and Huberman’s advice to translate these interpersonal thoughts to answers, or, at least to deeper understandings, of how new teachers develop their discourse and assessment skills as they navigate their new profession.

In order to mitigate the effect my existing beliefs had on my observations and analysis, I relied on direct statements by Carl and Kari, and focused on their explanations of the teaching actions I observed. I generated low-inference explanations of their teaching decisions using direct statements from multiple interviews (initial beliefs, post-lesson cognitive, and stimulated recall video clip interviews), and confirmed my conclusions using a post-observation member-checking interview. I directly observed Carl’s and Kari’s instruction, and used a validated instrument to rate the alignment of the lesson with inquiry principles (EQUIP). I was working with a calibrated team of
researchers at the time, and we calibrated our ratings regularly and frequently (Lewis, et al, 2016). Teacher self-efficacy was measured with a validated instrument (Tschannon-Moran & Wollfolk-Hoy, & Hoy, 2001) and teacher self-efficacy survey (TSES) data were collected from Carl and Kari at multiple and regularly-spaced intervals. I used direct statements from both participants’ multiple interviews to triangulate the self-efficacy data. My description and interpretation of observed lesson events were supplemented with direct statements from participants immediately after the lesson, and with their explanations of their teaching decisions shown in the six video clips I selected for the stimulated recall interview.
Chapter 4: Results

This chapter contains the results of investigating the three research questions of this study. Part 1 is an introduction to the six physical science teachers in the study, their teaching environments, and the science teacher education program (STEP) they completed. Part 2 identifies these six teachers’ areas of developing strengths and consistent challenges in inquiry-oriented assessment and discourse practices, and in their teaching self-efficacy related to these practices. Part 3 explores and describes specific modifications and adaptations these teachers used in their assessment practices, and relates these adaptations to specific components of their practice and pre-service pedagogical preparation. Part 4 presents the two case study (third-year) science teachers’ interactive and planned formative assessment practices, adaptations to their disparate learning environments, and strategies they use to support and maintain science talk and student engagement. Extensions of the two case studies are presented in separate appendices.

Research questions:

RQ1: In what areas do these purposefully selected teachers show developing strengths, and in what areas do they encounter challenges, in enacting inquiry-aligned discourse and assessment practices?

RQ2: To what extent, and how, did induction-phase physical science teachers employ inquiry-aligned discourse practices, and adapt to obstacles in implementing inquiry-aligned assessment practices?

RQ3: How do third year teachers initiate and sustain classroom discourse, and how do they use discourse and formative assessment to support student learning and engagement?
Part 1: Participants’ Background and Characteristics

All six participants are graduates of a 14-month master-level science teacher education program, and each was awarded a NSF Noyce Teacher scholarship that paid for their STEP program based on their demonstrated academic ability. The scholarship required awardees to teach in a high-needs school district. Masters-level STEP candidature required a BS degree in a science field (i.e., biology, chemistry, geology, or physics). Teachers’ educational and career histories are summarized in Table 4-1.

Table 4-1

<table>
<thead>
<tr>
<th>Participant</th>
<th>Degree(s), major</th>
<th>Endorsement area</th>
<th>Career changer?</th>
<th>Previous career(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Year</td>
<td>Mike</td>
<td>BS, chemistry</td>
<td>Chemistry</td>
<td>no</td>
</tr>
<tr>
<td></td>
<td>Kim</td>
<td>BS</td>
<td>Chemistry</td>
<td>yes</td>
</tr>
<tr>
<td>2nd Year</td>
<td>Jena</td>
<td>BS, Biochem</td>
<td>Biology, Chemistry, and Science (field)</td>
<td>no</td>
</tr>
<tr>
<td></td>
<td>Sara</td>
<td>BS, Biochem</td>
<td>Biology, chemistry</td>
<td>no</td>
</tr>
<tr>
<td>3rd Year</td>
<td>Carl</td>
<td>BS, physics</td>
<td>Physics</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td>Kari</td>
<td>BS &amp; MS, chemistry</td>
<td>Chemistry</td>
<td>yes</td>
</tr>
</tbody>
</table>

At the time of the study Mike and Kim were first-year chemistry and physical science teachers in different high schools in a large district, Urban Public Schools (UPS). Mike completed a bachelor’s degree in chemistry and one year of graduate school before entering the STEP program. Kim completed her bachelor degree with credits from several post-secondary institutions over the course of ten years while she worked in the health field.
Like Mike and Kim, second-year science teachers Jena and Sara also taught in different public schools within a large district, Washington School District. Both Jena and Sara began the STEP shortly after completing their undergraduate degree programs, and were not considered career changers.

Third year teachers Carl and Kari taught in widely different schools. Carl, like Mike and Kim, taught in UPS; however, his school was the smallest high school in the district and had a higher student poverty rate than the other high schools in the district. Kari was the only participant to teach in a private school; she taught in a college-prep, all-boys religious boarding school located along the suburban edge of Urban School District.

Admission to the STEP program required completion of a BS degree in a science field. All participants in this study applied for and were awarded a grant-funded stipend from the NSF based on their academic preparation and professional experience in science. These STEP graduates were considered highly qualified due to their BS degree in their endorsed field.

First-year teachers Mike and Kim, and third year teachers Carl and Kari were observed teaching within their major field. Second-year teachers Jena and Sara were endorsed to teach chemistry; however, both had completed more coursework in biology than in chemistry as they completed their biochemistry majors. Teachers who were endorsed in a single subject (Carl, Kari, Mike, and Kim) met and exceeded the minimum course hours and GPA requirements set by the state education agency and their university; Carl, Kari, and Mike either completed a graduate degree in their field (Kari,
MS in chemistry) or had progressed in a graduate program when they decided to change careers (Carl, astronomy; Mike, chemistry).

**Part 2: Strengths in Discourse and Challenges in Assessment**

This section addresses Research Question #1: In what areas do these purposefully selected teachers show developing strengths, and in what areas do they encounter challenges, in enacting inquiry-aligned discourse and assessment practices? As a group, these six beginning physical science teachers showed developing strength in inquiry-aligned questioning practices, and persistent challenges in planned assessment practices. The cross-sectional sampling of these science teachers precludes any descriptions of their growth from year to year. Data analysis is intended to reveal specific discourse and assessment practices these teachers are successfully employing, whether subject matter knowledge influences specific questioning practices, and identify any practices that appear to be consistently absent in these teachers’ lessons.

**Organization.** This section begins with an overview of teacher SMK data and a grouping of the six physical science teachers into high and low SMK groups. An analysis of high and low SMK teachers’ questioning practices and their alignment with inquiry practices follows this initial analysis of teacher SMK. Next, observed strengths in questioning practices, and persistent challenges in assessment practices, are connected to teaching self-efficacy in instructional practices. This section concludes with the identification of specific assessment practices that were consistently challenging for these teachers.

In brief, this section addresses:

- Teacher SMK measures and grouping into high and low SMK
• Questioning practices related to SMK and their alignment with inquiry practices

• Teaching self-efficacy in instructional practices related to developing strengths in questioning practices, and challenges in assessment practices

• Specific areas of consistent challenges in assessment revealed by EQUIP data analysis

**Teachers with well-developed SMK ask few low-level questions.** The frequency of lessons featuring proficient inquiry level questioning practices is generally constant between groups of teachers with high and low subject matter knowledge; however, the high SMK group’s use of recall-level, one answer questions that did not require explanation or connections to other ideas, was minimal compared to the low SMK groups pre-inquiry questioning practices.

I grouped the six teachers by SMK proficiency, using in-field credit hours, GPA, and MOSART scores. For this analysis, I used chemistry or physics SMK measures that aligned with the lesson content of the observed lessons during teachers’ second year, and EQUIP scores for these lessons. MOSART developers determined scores above 80% indicate minimal retention of misconceptions, and scores below 80% indicate significant misunderstandings of key concepts within the discipline (Sadler, Coyle, Cook-Smith, & Miller, 2007). Mike and Kim scored the same on the MOSART chemistry test; however, I used Mike’s relatively recent graduate-level chemistry coursework and higher GPA to categorize him with the high SMK group. I relied on Kim’s statements during a member-checking interview to confirm the categorization; Kim reported she often needed to
review chemistry content prior to teaching chemistry lessons. The six teachers’ SMK measures separated into two groups as shown in Table 4.2.

Table 4.2

<table>
<thead>
<tr>
<th>SMK Level</th>
<th>Teacher</th>
<th>MOSART%</th>
<th>Credit Hours</th>
<th>GPA</th>
<th>Second-year lessons’ topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Carl</td>
<td>100</td>
<td>66</td>
<td>3.68</td>
<td>Physical science (physics)</td>
</tr>
<tr>
<td></td>
<td>Kari</td>
<td>95</td>
<td>42</td>
<td>3.38</td>
<td>Chemistry</td>
</tr>
<tr>
<td></td>
<td>Mike</td>
<td>82</td>
<td>52</td>
<td>3.42</td>
<td>Chemistry</td>
</tr>
<tr>
<td>Low</td>
<td>Kim</td>
<td>82</td>
<td>24</td>
<td>3.08</td>
<td>Chemistry</td>
</tr>
<tr>
<td></td>
<td>Jena</td>
<td>72</td>
<td>10</td>
<td>3.00</td>
<td>Physical science (physics)</td>
</tr>
<tr>
<td></td>
<td>Sara</td>
<td>64</td>
<td>22</td>
<td>2.68</td>
<td>Chemistry</td>
</tr>
</tbody>
</table>

I analyzed the SMK-related questioning practices observed during second-year physical science lessons (i.e., lessons addressing physics or chemistry topics). Several observed lessons were not physical science, chemistry, or physics lessons, and I excluded these medical terminology and forensics lessons from the analysis. Due to the length of time between my field observations and the completion of this investigation, I had access to Mike’s and Kim’s second year EQUIP ratings. The analysis indicated teachers in the low SMK group used inquiry-aligned questioning practices at an apparently greater frequency than their high-SMK colleagues in their second year of teaching. However, during their second year, the low SMK group more frequently used low-level questions, with single and predetermined answers, that did not require connections to other content or critical thinking or explanation of reasoning. Such low-level questions were rare among the high-SMK group; only one of the fourteen observed lessons featured learning by memorization or repetition. Table 4.3 shows inquiry proficiencies for questioning level, question complexity, and conceptual development EQUIP categories.
Among both groups, about one in five observed lessons featured teacher questions that required analysis of concepts or data, making connections between ideas, and explaining reasoning in both low SMK and high SMK groups. This observed frequency of proficient questioning practices is consistent with these teachers’ reported teaching self-efficacy in crafting and using good questions, discussed in the next section. The lack of teacher-centered, single answer questions among the high-SMK group suggests this group is growing more rapidly in their use of inquiry-aligned questioning than their lower SMK colleagues.

Teacher intent and lesson topic may influence the level of questioning observed in these lessons. For example, Kari’s use of simple, single-answer questions to guide students to connections between ideas and deeper conceptual complexity is explored in a lesson cameo in Part 3 of this chapter.

**Teachers report high teaching self-efficacy in using instructional strategies.**

These six physical science teachers reported generally high self-efficacy in using instructional strategies (Table 4.4 below). The instructional strategy section of the teaching self-efficacy survey (TSES) included questions about teaching self-efficacy in using discourse and assessment strategies, and differentiating instruction to meet student needs. Teachers broadly reported being able to do “some,” “quite a bit”, or “a great deal”
in all questions in this category at the end of their second year. As with the EQUIP data in the previous section, I had access to Kim’s and Mike’s second year survey responses, and these data are included in the analysis of first-to-second year teaching self-efficacy.

At the end of their first and second years, these six teachers consistently responded they could do “quite a bit” or “a great deal” in responding to student questions, crafting good questions for their students, gauging comprehension of what they taught, and providing alternative examples. At the end of their first and second years, these six teachers consistently reported they could do “a great deal” or “some” to provide appropriate challenges for capable students, use a variety of assessment strategies, and implement a variety of instructional strategies in their lessons (Table 4.4). The only question to which these six teachers’ responses showed a decline from Year 1 to Year 2 was “to what extent can you adjust lessons to the proper level for individual students.”

Table 4.4.

*Teaching self-efficacy in instructional practices between first and second years*

<table>
<thead>
<tr>
<th>Trend Y1-Y2</th>
<th>Teacher self-efficacy survey question: To what extent can you…</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong &amp; Stable</td>
<td>…respond to difficult questions?</td>
</tr>
<tr>
<td></td>
<td>…craft good questions for your students?</td>
</tr>
<tr>
<td></td>
<td>…gauge comprehension of what you taught?</td>
</tr>
<tr>
<td></td>
<td>…provide alternative examples when students are confused?</td>
</tr>
<tr>
<td>Generally positive</td>
<td>…provide appropriate challenges for capable students?</td>
</tr>
<tr>
<td></td>
<td>…use a variety of assessment strategies?</td>
</tr>
<tr>
<td></td>
<td>…implement a variety of strategies in your classroom?</td>
</tr>
<tr>
<td>Declined</td>
<td>…adjust lessons to proper level for individual students?</td>
</tr>
</tbody>
</table>

Teachers’ self-efficacy in these instructional strategies is largely reflected in observations of their discourse and assessment practices, and echo areas of instructional practices emphasized in the STEP. Their overall high teaching self-efficacy in instructional practices and their observed use of inquiry-aligned questioning practices in
about 20% of observed lessons indicate their pedagogical knowledge was sufficient to support SMK-dependent questioning practices, even when teacher SMK may have been minimally adequate for the lesson.

These teachers reported lower teaching self-efficacy in adjusting lessons to meet the needs of individual students. This relatively lower teaching self-efficacy is also evident in their observed teaching practices. Participants reported lower, but stable and still positive, teaching self-efficacy in responding to formative assessments, applying alternative teaching strategies and using a variety of assessments, and declining teaching self-efficacy in differentiating instruction, which connect directly to the EQUIP Assessment “Role of Assessment” factor, where these teachers’ observed inquiry-aligned practices revealed challenges.

Teach er s ommited specific assessment practices. In contrast to the areas of developing strengths in inquiry-aligned questioning practices in the group revealed in the EQUIP ratings and self-efficacy survey results discussed above, an analysis of second-year EQUIP ratings show these six teachers typically did not assess prior knowledge (PK), or provide opportunities for students to reflect on or plan for their learning (SR), or use formative assessment data to modify lessons (RA).

Prior knowledge. Teachers, regardless of experience, rarely assessed student prior knowledge (i.e. pre-inquiry), and when they did, they did not modify lessons in response to what they learned (i.e. developing inquiry). Across experience levels, teachers were observed partially modifying instruction in response to students’ prior knowledge (i.e. proficient inquiry) in less than ten percent of lessons.
**Role of assessment.** Teachers’ primary challenge in enacting assessment practices was a lack of an immediate response to assessment information. Teachers were very rarely observed adapting their planned lesson in response to assessment data, the indicator of proficiency in inquiry-aligned use of assessments. Rather, teachers nearly exclusively either asked questions requiring little or no justification or explanation (i.e. pre-inquiry), or used the answer only to gauge student understanding across experience levels, with no apparent alteration of their lesson plan (i.e. developing inquiry).

**Student reflection.** In nearly all observed lessons, teachers either did not prompt students to reflect on their learning. Year 1 teachers did not include any opportunities for student reflection in 82% of observed lessons, Year 2 teachers did not include opportunities for student reflection in 71% of observed lessons, and Year 3 teachers did not include opportunities for student reflection in 80% of observed lessons. When teachers included student reflection, they asked students to reflect on their learning at a minimal knowledge level: 18% of observed lessons for Year 1 teachers, 19% of observed lessons for Year 2 teachers, and 20% of observed lessons for Year 3 teachers. In only 3% (2 of 64) of all observed lessons were teachers observed prompting students to substantially reflect on their learning.

The next major subsection of this chapter, Part 3, explains how these teachers recognize and adapt to these three specific challenges in their assessment practices.

**Part 3: Teachers identify and adapt to limitations in enacting assessment practices**

Part 3 of this chapter addresses Research Question #2: To what extent, and how, did induction-phase physical science teachers employ inquiry-aligned discourse practices, and adapt to obstacles in implementing inquiry-aligned assessment practices?
These beginning physical science teachers show developing strength in inquiry-aligned discourse practices and in some components of their assessment practices during their first three years teaching; however, they consistently omitted assessment of prior knowledge and opportunities for student reflection, and rarely modified planned lessons in response to formative assessments during lessons.

At first glance, these omissions may suggest a deficiency in these teachers’ pedagogical knowledge (PK) deriving from either gaps in their preparation program or from their schools’ or districts’ policies. However, participants appeared to recognize the omissions, and reported or were observed adapting their practices to meet the conditions of their instructional environment. For example, teachers consistently reported using assessment information to modify their plans, and explained they did so by making modifications to the next day’s lesson rather than attempting to modify an ongoing lesson.

How these teachers recognized their own areas of challenge, how they addressed them, and how they built on their own expanding successes are explored in this section. This section uses observed and reported teacher actions, and explanations of their teaching decisions during interviews to explore and reveal obstacles to enacting inquiry-aligned assessment practices identified as challenges by the analysis of EQUIP data in the previous section, and participants’ adaptations to these challenges. Specific instances of well-developed and successfully enacted pedagogy are included and discussed as illustrations of *PK strengths*. Specific omission or pre-inquiry application of discourse or assessment methods are included and discussed as *PK in development*. 
**Organization.** This section begins with an overview of the areas of consistent challenge identified by the EQUIP data. Following the overview, the challenges and teacher adaptations are summarized in table form. Each challenge and teacher adaptation is then described using lesson excerpts and summaries of teacher statements explaining how they identified deficiencies and adapted, or how they used their strengths to compensate for challenges.

- Areas of developing strength and persistent challenges revealed in EQUIP data analysis
- Summary of challenges, strengths, and teacher adaptation to deficiencies
- Lesson excerpts and teacher explanations of specific adaptations

**Strengths and challenges.** As described in Part 2, these teachers showed developing strengths in alignment of questioning practices with inquiry-based practices. These strengths were apparent for teachers with high and relatively lower SMK measures, and high SMK teachers appeared to use fewer low-level questions. These teachers also encountered persistent challenges in assessing prior knowledge, responding to assessment data, and providing opportunities for students to reflect on their learning.

These challenges and teacher adaptations are summarized in Table 4.5 below.

<table>
<thead>
<tr>
<th>EQUIP Discourse or Assessment Factor</th>
<th>PK Strength or Challenge</th>
<th>Teaching event illustrating obstacle &amp; adaptation or Teaching event illustrating PK strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Questioning level</td>
<td>Strength</td>
<td>Kari used a series of low-level, student-accessible questions as a cognitive ladder to develop a complex idea.</td>
</tr>
<tr>
<td>Question complexity</td>
<td>Strength</td>
<td></td>
</tr>
<tr>
<td>Concept development</td>
<td>Strength</td>
<td></td>
</tr>
<tr>
<td>Role of assessment</td>
<td>Challenge</td>
<td>Kari used assessment data in her decision to change lesson plans.</td>
</tr>
<tr>
<td>Prior knowledge</td>
<td>Challenge</td>
<td>Mike selected questions from a set of district-provided test review questions to match lesson content and use as prior knowledge or retained knowledge assessment.</td>
</tr>
</tbody>
</table>
Carl provided a physical thing to manipulate and a challenge for students to meet so he could listen to student conversations while providing a needed common experience for his class.

<table>
<thead>
<tr>
<th>Role of assessment</th>
<th>Challenge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kim modified next days’ lessons to address student needs revealed through planned formative assessment opportunities.</td>
</tr>
<tr>
<td></td>
<td>Jena’s low confidence in her physical science SMK restricted her development of proficiency descriptions for learning objectives. Jena reviewed samples of student work to generate proficiency indicators either as students were working, or once student work was turned in.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Student reflection</th>
<th>Minimal or absent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carl’s in-class quiz correction routine required students to identify why questions were missed; assessment data for informal individual academic coaching.</td>
</tr>
</tbody>
</table>

**Lesson cameos.** This sub-section uses lesson cameos to illustrate teacher adaptations to the deficiencies in assessment practices revealed by the EQUIP data analysis. Lesson cameos include descriptions of teachers’ actions during lessons that changed the direction of the lesson, with explanations of these decisions extracted from post-lesson cognitive interviews, stimulated recall interviews, and post-study member checking interviews. In this analysis, I use these teachers’ statements and assessments of their own teaching practices as evidence of their applied pedagogical knowledge. Each lesson cameo concludes with an overview of the pedagogical strengths and their developing pedagogy evident during the lesson. The lesson cameos will be developed in the same order as they are presented in Table 4.5 above.

**Kari’s lesson: Teachers build on their strengths.** Kari applied strong subject matter knowledge, positive relationships with students, and shared expectations about learning chemistry in a college-prep school, and a series of related low-level questions to develop complex and abstract concepts. Kari’s teaching decisions are explored in depth in Appendix D, and detailed descriptions of Kari’s class and her students are included there.
Most of Kari’s observed lessons were teacher-centered, and the lessons I observed during her third year often involved abstract concepts that were difficult to demonstrate. In particular, developing a connection between covalent theory and nomenclature rules requires expert guidance, and Kari used direct instruction as she taught these two concepts. Here, Kari used a series of recall-level and convergent questions to guide a student to an understanding of patterns in chemical nomenclature and making connections to periodic trends. This cameo shows how low-level questioning can be applied for complex conceptual development.

### Table 4.6.

*Kari’s PK strengths and adaptive teaching practices.*

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Questioning Level &amp; Complexity, Conceptual Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kari (Y3) Strength</td>
<td>Kari used a series of low-level, student-accessible questions as a cognitive ladder to support students’ development of complex and related ideas.</td>
</tr>
<tr>
<td>Pedagogical principle</td>
<td>Interactive formative assessment: Kari noticed her student’s difficulties, recognized how her student was misunderstanding the idea, and reacted by providing guidance and feedback.</td>
</tr>
<tr>
<td>Result</td>
<td>Kari provided adaptive conceptual support as the “more knowledgeable other.”</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Role of Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kari (Y3) Strength</td>
<td>Periodic informal assessment of student understanding using brief interviews between classes or during study periods, and quick scans of in-progress homework provided Kari with sufficient assessment data to inform her decisions about lesson content.</td>
</tr>
<tr>
<td>Pedagogical Principle</td>
<td>Using assessment data for short-term planning.</td>
</tr>
<tr>
<td>Result</td>
<td>Kari demonstrated adaptive teaching practices to meet students’ learning needs.</td>
</tr>
</tbody>
</table>
Conceptual development through interactive formative assessment. For about two weeks prior to a lesson on 05 December 2014, Kari’s students had been learning naming conventions for ionic and covalent compounds. Kari was concerned about her students’ understanding, based on student contributions during prior lessons and her experience with the subject from the prior two years. Kari initially planned to give a quiz during this lesson; however, after a quick review of student homework before class revealed too many mistakes, she decided to make the quiz “formative” and use it as a review for the next day’s “real” quiz.

Kari began the class with the announcement the quiz was delayed one day, a statement reviewing what had been covered during the last class, and asked for student questions. After a long and silent pause, Kari asked again for questions from the class. A student asked about naming compounds composed of transition metals and polyatomic ions. In response, Kari wrote three chemical formulas from the “quiz” on the board, and instructed the class to name the compounds. Students began work in their notebooks, and Kari circulated the room, monitoring student progress and answering individual questions. After about ten minutes of sustained work, Kari and a student interact to name a compound from its formula. Kari quickly assessed her student’s low confidence, asked a less demanding question to gauge his understanding, and then used a series of questions that prompted the student to actively recall and apply information to a new process. In this way she scaffolded his cognitive processes.

<table>
<thead>
<tr>
<th>Turn</th>
<th>Speaker</th>
<th>Utterance</th>
<th>Teacher intent</th>
</tr>
</thead>
<tbody>
<tr>
<td>[1]</td>
<td>Student:</td>
<td>I’m really confused about how to start this…</td>
<td></td>
</tr>
</tbody>
</table>
Kari: For this?

Student: Yeah.

Kari: Alright, what we need to do…

Student: I’m really sorry…

Kari: …any time we’re looking, first, is this an ionic compound or a covalent compound? (pause)

Student: Um, covalent?

Kari: How would I know? (Build confidence: Explain reasoning)

Student: Um, well, it’s between two metals, so it’s…

Kari: These are both metals? (Scaffolding: Encouraging self-assessment)

Student: Wait a minute. [Pause] I don’t think so.

Kari: Where is calcium? What group is this? (Scaffolding: Focusing question)

Student: Um, metal.

Kari: Alright, where’s nitrogen? Where’s that? (Evaluation)

Kari: OK. Specifically, do you know what this is?

Student: Um, no.

Kari: I would probably make sure we know that.

Student: Well a blue element symbol means gas…

Kari: umm hmmm (positive affirmation of correct idea) (Evaluation)

Student: so…

Kari: So most of my gasses are what, metals, metalloids or nonmetals? (Promote problem solving: Access learned content)

Student: Nonmetals.

Kari: Nonmetals. We’ve got a metal and a (Scaffolding: )
nonmetal…what type of compound is that?

[24] **Student:** ummm, molecular…oh..

[25] **Kari:** Is there a metal?

[26] **Student:** …so it’s an ion.

[27] **Kari:** Ionic. So, what makes an ionic bond?

After recognizing her student’s confusion and low confidence (turns 4-6), Kari used a series of low-level and interconnected questions to lead her student to deeper conceptual understanding. Kari applied interactive formative assessment with her student to develop the underlying conceptual understanding required for naming ionic compounds. In turns 7-10, Kari asked a convergent question (“Is this ionic or covalent?”), and followed up with questions that provided her student with an opportunity to self-assess and self-correct, while maintaining engagement with a challenging problem. The connection between determining the type of bond and how to name the compound was just beyond the student’s understanding; however, Kari used a sequence of answerable questions to help her student weave the ideas together. Kari controlled the pattern of communication, type (i.e., convergent) and level (i.e., recall or understanding) of question, evaluated the student’s answers, and provided a follow-up question. Kari’s series of questions scaffolded her student’s critical thinking; she used questions to suggest the connections her student needed to understand the deeper idea and to see the underlying pattern. While the communication pattern was teacher-question-
student-answer and highly teacher-controlled, the interaction had a conversational tone, suggesting a trusting and collaborative relationship between student and teacher.

Kari and her student continued their conversation and developed the connection between valence electrons, ionic charge, and the ionic compound’s formula.

<table>
<thead>
<tr>
<th>Turn</th>
<th>Speaker</th>
<th>Utterance</th>
<th>Teacher intent</th>
</tr>
</thead>
<tbody>
<tr>
<td>[28]</td>
<td>Student:</td>
<td>…so it’s an ion.</td>
<td></td>
</tr>
<tr>
<td>[30]</td>
<td>Student:</td>
<td>ummm</td>
<td></td>
</tr>
<tr>
<td>[31]</td>
<td>Kari:</td>
<td>It has nothing to do with [the formula]. What makes an ionic bond?</td>
<td></td>
</tr>
<tr>
<td>[32]</td>
<td>Student:</td>
<td>ummm…don’t know…</td>
<td></td>
</tr>
<tr>
<td>[34]</td>
<td>Student:</td>
<td>It must have ions.</td>
<td>Build confidence: Explain reasoning</td>
</tr>
<tr>
<td>[35]</td>
<td>Kari:</td>
<td>What is an ion?</td>
<td></td>
</tr>
<tr>
<td>[36]</td>
<td>Student:</td>
<td>It’s uh, like, electrons…</td>
<td></td>
</tr>
<tr>
<td>[38]</td>
<td>Student:</td>
<td>it’s like…are they shared?</td>
<td>Evaluation</td>
</tr>
<tr>
<td>[39]</td>
<td>Kari:</td>
<td>mmh hmmm (indicating “no”)</td>
<td></td>
</tr>
<tr>
<td>[40]</td>
<td>Student:</td>
<td>It’s…they’re losing…</td>
<td>Evaluation</td>
</tr>
<tr>
<td>[41]</td>
<td>Kari:</td>
<td>Yep. Losing or gaining, so we’re going to have charged atoms. So, what is the charge of calcium as an ion?</td>
<td>Extending concept</td>
</tr>
<tr>
<td>[42]</td>
<td>Student:</td>
<td>It’s going to lose…two?</td>
<td></td>
</tr>
<tr>
<td>[43]</td>
<td>Kari:</td>
<td>uh huh (yes), which would give it a charge of what?</td>
<td>Scaffolding: Focusing question</td>
</tr>
<tr>
<td>[44]</td>
<td>Student:</td>
<td>Positive two. (with more confidence)</td>
<td></td>
</tr>
<tr>
<td>[45]</td>
<td>Kari:</td>
<td>Positive two. (brief pause) So we know</td>
<td>Evaluation</td>
</tr>
</tbody>
</table>
that. (waits for student to attempt the next step) And what about nitride?

[46] Student: It’s going to be…three.

[47] Kari: Three. Good. So we know these two charges. Now I have to come up with ratios of calcium and nitrogen so that I can make them stable. Their charges added up together will equal zero.

[48] Student: Six.

[49] Kari: Umm hmm [indicates yes]. So how many of these will you need to get to six?

[50] Student: [Immediately and with confidence] Three.

[51] Kari: So that will be a three…how many of these do you need to get to six?

[52] Student: [immediately] Two.

[53] Kari: There you go.

PK strengths: Supporting cognitive development with a cognitive ladder. Writing chemical formulas is an algorithmic exercise; however, Kari used her student’s disequilibrium to review prior content and apply it to the newly learned skill. Kari was attentive to her student’s initial emotional state, and used questions he could answer to build his confidence, as well as provide a series of connected ideas with which he could begin constructing the idea of ionic bonding.

Kari’s approach to conceptual development relies on student engagement and cooperation. The science content of the lesson was learning the skill of chemical nomenclature, and involved bonding theory. Neither topic lends itself easily to demonstration or inquiry; both ideas are very abstract. Kari used student homework to
assess understanding, and responded to assessment data by delaying the quiz in favor of a review lesson. During the lesson, Kari supported a student’s persistence with carefully chosen and answerable questions; the questions and their answers, in turn, helped the student understand the step-by-step process, make connections between naming conventions and bonding theory, and expand his conceptual understanding. In this lesson cameo, Kari used an improvised and responsive series of recall-level questions to develop a deeper conceptual understanding with her student.

By changing her plan to administer a quiz during the lesson, Kari adapted to students’ needs. Kari’s choice was expedient and practical, as providing time for practice and responding to individual students was more manageable than restructuring a lesson as she taught.

*PK in development: Student reflection.* Kari did not direct her students to reflect upon the learning strategies (e.g., observing patterns), or build academic dispositions (e.g., identifying questions, showing productive persistence), although she actively supported these during the lesson. Kari’s students were generally cooperative and may have actively participated in a reflective writing concluding routine. A “one minute essay” where students identify an idea they struggled with, how they solved the problem, and a brief self-assessment of their persistence, would have provided a simple, low effort way for students to reflect on their learning.

*Mike and Carl: Teachers adapt to obstacles in assessing prior knowledge.* First-year chemistry teacher Mike struggled to fit lab activities and district-required practices into a short class period. Third-year physical science teacher Carl adapted to low student
participation in start-of-the-unit assessments of prior knowledge by providing a toy and a challenge.

Table 4.7.

*Teacher-identified obstacles and adaptations to assessing prior knowledge*

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Obstacle</th>
<th>Assessing Prior Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mike (Y1)</td>
<td>Obstacle</td>
<td>Mike relied upon district-provided and scripted content that required specific test review questions at the start of the class. Short class periods limited the time available to assess prior knowledge.</td>
</tr>
<tr>
<td></td>
<td>Adaptation</td>
<td>Mike searched the district-provided document for specific test-preparation questions that matched daily lesson topics as a way to assess students’ prior and retained knowledge, and arranged the review questions to align with lesson content.</td>
</tr>
<tr>
<td></td>
<td>Result</td>
<td>Introductory questions were aligned with lesson content, and allowed Mike to gauge students’ retained knowledge or diagnose their current understanding.</td>
</tr>
<tr>
<td>Carl (Y3)</td>
<td>Obstacle</td>
<td>Low student participation. Carl: “I’ve tried using KWL charts, but I get no student buy in. Everyone just writes ‘I don’t know.’”</td>
</tr>
<tr>
<td></td>
<td>Adaptation</td>
<td>Carl’s students created a code and used Slinkys to communicate simple messages to each other. More generally, Carl included activities involving science phenomena and physical objects to introduce new content.</td>
</tr>
<tr>
<td></td>
<td>Result</td>
<td>Planned formative assessment: Carl monitored student interactions with phenomenon to determine existing understandings of waves. Students developed a common experience that Carl used throughout the wave unit.</td>
</tr>
</tbody>
</table>

*Limiting assessment and inquiry to save time.* Mike’s chemistry lesson was almost entirely an investigation of reaction rate of Alka-Seltzer™ and water, a lab activity provided to teachers through UPS science teacher resources. When I arrived to observe, Mike was already resetting the lab for the incoming class, making sure he had enough materials and the lab stations were more-or-less tidy. Once the bell rang, Mike skipped
the test-preparation bell work and began preparing the class for the lab activity immediately. Mike delivered verbal instructions, distributed lab directions and pre-made data tables, and demonstrated the procedure using the equipment and diagrams. He instructed students to vary the conditions of the reaction (e.g., water temperature, particle size), contain the reaction mixture in a sealed film canister, and record the time required for the canister to “pop.” The lab handout contained instructions and space for observations and data. During the investigation, Mike circulated around the room, kept students on task, and answered procedural questions. Mike reminded students to clean up their stations, record data, and turn in the lab report sheets. Mike indicated the class would review the data during the next class period. During the 40-minute period (12:30 PM to 1:10 PM), Mike was focused on keeping students on task, helping students understand directions, maintaining order, and finishing the lab activity.

Mike prioritized content over assessment and inquiry. Most of Mike’s lessons included bell work for test review; however, he sometimes skipped introductory content when the lesson involved lab work. Mike reported he often felt rushed, especially during lab days. In our post-lesson interview, he explained he decided to eliminate the day’s bell work questions to provide more time for the lab activity. The short 40-minute periods were dictated by the school’s alignment with the International Baccalaureate curriculum, which requires nine class periods per day. Mike’s school provides double periods for advanced and IB classes, and allows only one period for the school’s “standard” classes. During an interview after his second year of teaching, Mike explained “inquiry or discovery learning are the ways students learn more, but it’s also more resource intensive.
It’s a shame—standard classes get a single period, and honors kids get a double period. It’s the opposite [of what it should be].”

Mike’s teaching decisions centered upon efficient use of time. For example, Mike showed diagrams of varying particle size for crushed Alka-Seltzer™, and provided pre-prepared constant temperature baths. Mike’s students could have developed a way of changing reaction rate by varying particle size or water temperature; however, Mike made the decision to address the chemistry content rather than student inquiry. That is, his students investigated what factors affect reaction rate and how by completing a scripted lab activity, rather than developing and conducting an investigation of “what makes a reaction go faster?”

**PK Strengths:** Mike modified required lesson events to assess prior knowledge. Mike omitted un-related test review questions from the lesson to save time for the lab activity; however, modifying the district-provided questions to better match the lab activity would have allowed Mike to better understand his students’ developing ideas about factors affecting reaction rates. Later in his first year, Mike’s included bell work questions more closely related to the topic of the lesson. Mike explained he searched the district-provided document for specific test-preparation questions that matched daily lesson topics, suggesting he was actively finding ways to incorporate assessment of prior knowledge in his lessons.

**PK in development:** Student inquiry. Mike carefully timed his lesson plan; each event had a pre-determined time for completion, and Mike kept his lesson and his students on schedule. The laboratory activity used the entire 40-minute period, with only a few minutes at the end for clean up. Using bell work questions connected to the lab
activity, such as a question about cooking temperatures and cooking times, or a similar question about how long it would take to fry an entire potato compared to a French fry, may have provided Mike with some measure of student prior knowledge. Mike could have asked students to use their answers to suggest ways to make the Alka Seltzer™ react faster, then directed them to investigate their suggestions as they completed the scripted activity.

Alternatively, Mike might have used the previous class period for students to identify variables affecting reaction rate, then plan investigations to conduct during the next class period. However, as a first-year teacher, Mike was still learning the UPS scope and sequence, which allowed little flexibility in the schedule.

Carl’s students addressed a teacher-provided challenge. During an informal interview, I asked Carl why he did not use much prior knowledge assessment in the other science classes I observed. Carl told me “I’ve tried using KWL charts, but I get no student buy in. Everyone just writes ‘I don’t know.’” Instead of explicitly assessing student prior knowledge with something like a KWL chart, Carl structures introductory activities for his units to allow him to observe them directly. Therefore, students had something to manipulate and a partner to interact with, while Carl could watch and listen to assess his students’ understandings of the new content.

Carl assessed his students’ prior knowledge in a way that provided him with a more detailed view of each student’s understanding than directly asking questions his students were hesitant to answer. I observed one of Carl’s introductory exercises for his unit on waves. Carl developed the waves unit during a methods class in the STEP program, and he used the unit, adjusted for grade level, in physical science with mostly
9th graders and in physics with mostly 11th and 12th graders. He used the unit in both classes each year, with minor modifications. During my visit, his physics students were playing with Slinkys™. Carl told me students were creating a code to use to transmit a simple message, analogous to how radio waves are used to transmit information. Students assigned letters of the alphabet a type and number of waves. For example, the letter “a” might be represented with one compression wave and two transverse waves. Students would use the code and the Slinkys™ to send messages to each other. The written component of the exercise required students to sketch and describe the different kinds of waves they observed. Carl used student responses to gauge individual students’ prior knowledge of waves, rather than creating a KWL chart with the entire class. “We could make a chart to see what the whole class knows, but with the range of students we have, we’d never know who knew what.” Carl’s attentive interaction during the wave activity provided him with information about his students’ prior knowledge and his students with foundational experiences they can build upon during the rest of the unit.

**PK strengths: Planned formative assessment.** Carl retained this lesson from his pre-service internship because it successfully engaged students, included materials and opportunities to manipulate materials, and had multiple access points for students of different academic and language abilities. Carl’s use of the activity and student interactions as an assessment opportunity illustrates how he used planned formative assessment to elicit student responses, interpret student understanding, and plan future lessons to respond to student needs.

**PK in development: Student reflection.** I did not observe, nor did Carl report, student self-reporting prior knowledge, with or without prompts, during the time period...
of the study. Including a reflective discussion, which asked students to connect their experiences with the waves in class to times they may have seen or interacted with waves outside of class, may have prepared or conditioned Carl’s students to start thinking about their outside experiences, and perhaps sharing these experiences with the class.

**Kim: Providing active learning opportunities while building SMK.** Kim’s multi-faceted lesson included several adaptations to challenges revealed in the EQUIP analysis in part 2, specifically, assessing prior knowledge and student reflection. Additionally, Kim’s lesson illustrates successful implementation of active learning principles by a first-year teacher. In a post-study member-checking interview, Kim identified several adaptations she used to make existing curricular materials more student-centered. Additionally, she described how her focus on reviewing her content knowledge supported her discourse and assessment practices in her first year of teaching chemistry.

<table>
<thead>
<tr>
<th>Table 4.8</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Teacher-identified obstacles and adaptations of formative assessment practices</strong></td>
<td></td>
</tr>
<tr>
<td>Teacher</td>
<td>Ensuring Subject Matter Knowledge</td>
</tr>
<tr>
<td>Kim (Y1) Obstacle</td>
<td>Kim worked for ten years as a surgical tech, and felt her chemistry content knowledge was a little rusty.</td>
</tr>
<tr>
<td>Adaptation</td>
<td>Kim invested significant time reviewing lesson content from numerous sources to ensure she understood each lessons’ material well enough to teach.</td>
</tr>
<tr>
<td>Result</td>
<td>The time invested in content review left her little time to prepare alternative instruction when students misunderstood; however, Kim identified difficult concepts and planned learning experiences so students could work collaboratively, and so she would have opportunities to monitor and support student understanding.</td>
</tr>
<tr>
<td>Kim (Y1) Obstacle</td>
<td>Kim reported feeling pressure to keep on pace with the district scope and sequence document, while also needing to ensure student understanding of key concepts in the curriculum.</td>
</tr>
</tbody>
</table>

Assessing Prior Knowledge and Role of Assessment.
Adaptation  Kim explicitly elicited student prior knowledge; however, she did not modify the lesson in response to what she learned.

Result  Kim noted students’ level of understanding during the interactive components of the lesson, and planned the next days’ lesson to address misunderstandings.

**Providing Active Learning Opportunities**

Kim  **Strengths**  Paired demonstration with direct instruction, students paired for peer instruction, students made and tested predictions, multiple modes of learning used in the lesson, opportunities for self-assessment with learning journals.

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**Modifying existing materials.** Kim’s first period chemistry class began with bell work, a required practice in UPS schools, and the block-scheduled class period provided time for multiple lesson events. Kim’s students answered the projected test review questions, math skills and vocabulary practice, and a review of previous content. Another chemistry teacher had provided Kim with the bell work questions, as well as the rest of the slides she used during the lecture part of the class. This was the first time Kim had taught this lesson, and she was visibly uncomfortable with some of the factual inaccuracies on the slides. During the lecture, Kim used a conductivity demonstrator to show varying conductivity of ionic and non-ionic solutions. The demonstration led to a worksheet-centered formula and nomenclature activity, and Kim included small-group collaboration to provide opportunities for peer-to-peer talk and support. Kim circulated the room, and asked questions to check student understanding. Kim usually provided just enough support to prompt students to focus on the assignment; students would sometimes get stuck on a name or formula and disengage from the activity.

The lesson also addressed atomic emissions, and students used spectrosopes to view different light sources. During their observations, students recorded data on lab
sheets they later included in a learning journal. During the investigation, Kim asked students to make predictions and compare them to their observations. During this part of the lesson, Kim assessed students’ prior knowledge by asking her class if they had seen chemical reactions before; however, Kim did not modify her lesson plan. Kim explained, and then showed, the different colors of light produced from adding a salt to a flame. During her explanation, Kim connected the flame test demonstration to the previous nomenclature activity concept, and asked her students if any of the salts she used were used for other purposes. She projected an American Chemical Society-produced video showing and explaining how ionic compounds provide color to fireworks while students completed their journal entries or nomenclature reports, and finished the lesson with a guided writing assignment where students summarized the lesson content.

Obstacle and adaptation: Just-in-time SMK development. In a post-study member-checking interview, Kim told me that during her first year her lesson planning focused mostly on ensuring her complete understanding of the lesson content, and keeping on pace with the district’s scope and sequence plan. During the interview, Kim told me she prepared for lessons several hours per week, especially on the weekends. Kim prepared to teach the lessons by reviewing textbooks and “watching lots of [online] videos.”

In preparation to teach the content, Kim invested significant time ensuring she understood the underlying concepts. In addition to building her confidence in the content, Kim’s preparation helped her support student discourse during the lesson. For this lesson, she identified difficult content students would work cooperatively to understand, crafted opportunities for students to make and test predictions, made connections to outside
content, and planned points in the lesson where she would interact with students as they struggled to master the content of the lesson.

**PK Strengths: Providing opportunities for active learning.** During this lesson, Kim demonstrated many active learning assessment, discourse, and student engagement practices. She assessed prior knowledge, although she did not modify the prepared lesson. Her planned lesson included opportunities for students to engage in cooperative learning with a nomenclature exercise, conduct a scripted activity as they observed spectra, and included an interactive, teacher-led discussion during a demonstration of the conductivity of solutions. The lesson also included a video of fireworks to help her students make connections between common experiences and chemistry content. While nearly entirely teacher-controlled, students in Kim’s chemistry class had opportunities to be active, make predictions, and write summaries of their learning. Kim used journal entries as a part of a portfolio assessment, which provided students an opportunity to control part of their own assessments, and may have provided opportunities to reflect on their learning.

**PK in development: Role of assessment.** During the lessons I observed, Kim did not substantially modify her lesson plans as she taught. In prioritizing her own mastery of content in support of teaching a lesson, Kim did not always anticipate where students would misunderstand a concept; however, Kim told me she regularly assessed their developing understanding, and would modify her next day’s lesson plan to address specific misunderstandings. Kim used formative assessment data to inform her teaching, but she only felt comfortable in applying her decisions during the next lesson. Like Mike,
Kim also re-arranged the district’s test review questions to better align with lesson content.

**Jena’s assessment plan hindered by low SMK.** Jena’s low confidence in her physical science SMK restricted her development of proficiency descriptions for learning objectives. Jena developed her assessment criteria by reviewing samples of student work to generate proficiency indicators either as students were working, or once student work was turned in.

**Low confidence in SMK delays responses.** During our post-study member-checking interview, Jena reported her assessment practices were limited by her low confidence in her SMK during her first- and second-year physical science classes. Like first-year teachers Mike and Kim, Jena used borrowed material for her Physical Science lessons, and was initially limited to the assessment practices included in these borrowed lesson plans. Jena explained her assessments and her response to assessment information was delayed by using other teachers’ lesson plans, and more so due to her diminished confidence in the physics and chemistry concepts in physical science.

<table>
<thead>
<tr>
<th>Table 4.9</th>
</tr>
</thead>
</table>

**Teacher-identified obstacles and adaptations to role of assessment**

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Obstacle</th>
<th>Role of Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jena (Y2)</td>
<td>Jena connected her limited SMK in physical sciences to her low confidence in assessing student understanding.</td>
<td>To compensate, Jena developed assessment criteria by listening to student discussions during the lesson, rather than identifying and constructing assessment indicators prior to the lesson.</td>
</tr>
<tr>
<td>Adaptation</td>
<td>Development of, and response to, formative assessments were delayed as Jena determined what students should know as she taught the lesson, monitored the class to determine the overall level of understanding, and adapted the next day’s lesson to address any poorly-learned objectives.</td>
<td></td>
</tr>
</tbody>
</table>
According to Jena, her first year assessment development, application, and response practices followed a regular pattern. Rather than identifying indicators of student understanding as she planned the lesson, Jena identified students who understood the content well, and listened to their conversations during activities in order to construct an understanding of “where her students should be” in their conceptual development. Using what she learned, Jena would then gauge other students’ understanding, and identify and plan specific interventions for the next day’s lesson. Jena reported “knowing the content” of the physical science course, but not confidently or well enough to predict students’ responses or misconceptions.

In comparison to her physical science classes, Jena noted her experience with university-level instruction as a teaching assistant provided familiarity and comfort with the high school health science content, and helped her to develop and implement formative assessments in her anatomy and medical science classes. She reported much lower confidence in using formative assessment instructional strategies in her first- and second-year physical science classes.

*PK strengths and SMK deficits:* Jena recognized the purposes of formative assessment and the general application of assessment practices. Development of, and response to, formative assessments were delayed as Jena determined what students should know as she taught the lesson, monitored the class to determine the overall level of understanding, and adapted the next day’s lesson to address any poorly-learned objectives.

**Development in active learning and assessment, deficits in reflection.** These teachers successfully applied their pedagogical knowledge to provide active learning
opportunities, use assessment data in planning future lessons, and interactively adapt individual instruction to build conceptual understanding. These six teachers were aware of, and employed, different ways to address gaps in their assessment practices, specifically in assessing student prior knowledge and using formative assessment information to modify lessons. However, as a group, using student reflection as an assessment practice was noticeably absent across instructional settings and years of experience.

**Active learning and interactive assessment were strengths.** Lesson cameos illustrate the strengths of these teachers’ application of active learning pedagogical principles in specific instances. Carl and Kim provided multiple modes for student learning, and provided opportunities for students to interact with peers as they learned. Carl consistently monitored student talk during planned activities to assess students’ prior knowledge and their developing understanding. Kari used assessment data for short-term planning, and interactively supported her students’ conceptual development with cognitively appropriate questions. Generally, the teachers in this study understood the general principles of educative assessment, and were developing in their application of these principles as they gained experience.

**Responses to formative assessments were in development.** The teachers in this study inconsistently assessed prior knowledge, and rarely modified instruction during lesson. However, teachers reported planning lesson content in response to assessment data for the next day’s lesson.

**Teachers consistently omitted opportunities for reflection.** Only two of the six teachers were observed or reported including student reflection in their lessons. Kim
reported assigning chemistry students to small groups so they could review sample problems and work through stoichiometry problems as peer-teachers, but also noted she reserved this practice for difficult content. I observed Carl using a class routine for quiz grading where students would complete a quiz, then self-evaluate and make note of what content was missed and why; the quizzes were kept in a student portfolio for later study. Carl also used his detailed accounting of student performance by learning standard to coach students individually. Carl’s use of assessment data is detailed in Appendix D.

Lesson cameos provide a more detailed, yet brief, view of developing discourse and assessment practices among this group of teachers. Part 4 of this chapter explores more deeply how two third year teachers initiated and supported classroom discourse, and how they used discourse and formative assessment to maintain student engagement and conceptual development.

**Part 4: Teacher Case Studies**

This section explores how two third year teachers, Carl and Kari, supported and sustained student discourse and engagement in their lessons, and how they used planned and interactive formative assessment to guide conceptual development. Students had opportunities to “talk science” in lessons that included a phenomenon that was clearly connected to a central learning objective for the lesson, for them to observe, manipulate, and discuss. During conceptual change lessons, where a misconception and a phenomenon were both present, student discussion provided teachers opportunities to monitor and guide student conceptual development. Teachers were more effective in facilitating student science talk when they had both identified misconceptions and
developed assessment criteria prior to the lesson. In skills lessons, students took an active role in their learning as they manipulated the equipment.

**A typology of science lessons.** As described in the methods chapter, I categorized Carl’s and Kari’s lessons by presence or absence of a science artifact or phenomenon, and by inclusion or omission of an explicitly indexed misconception. More of Carl’s lessons involved both misconceptions and science artifacts or phenomena than did Kari’s. Carl’s lesson topics (i.e., heat, forces and motion) provided many opportunities for Carl and his students to confront common misconceptions and manipulate objects or observe events. Not every discussion of misconceptions was accompanied by physical events or manipulated objects; Carl’s classes were long, and each observed lesson included a physical or manipulated object, even if each individual topic addressed during the lesson did not. Conversely, Kari’s lesson topics were more process-oriented (e.g., stoichiometry calculations) or abstract (e.g., covalent bonding), were presented in a 45-minute period, and did not provide as many opportunities to use science artifacts or phenomena.

<table>
<thead>
<tr>
<th>Artifacts or Phenomena</th>
<th>M (yes)</th>
<th>M (no)</th>
<th>Misconception</th>
<th>m (yes)</th>
<th>m (no)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P (yes)</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>p (no)</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Description of lesson types.** I labeled the four types of lessons based on the lesson objectives identified by the teacher or that were apparent in the lesson. For example, Kari did not explicitly tell her students the objective of one lesson was an introduction to
titration, but I was able to determine her intent from observation. Lesson types and their characteristics are summarized in Table 4.11 below.

<table>
<thead>
<tr>
<th>Code</th>
<th>Lesson type</th>
<th>Lesson description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>MP</td>
<td>Conceptual change</td>
<td>Teacher demonstrates a phenomenon or provides an object to manipulate to elicit initial student statements and set up a contradiction between current understanding and scientific understanding.</td>
<td>Carl provided spring scales and an impossible challenge to introduce Newton’s Third Law.</td>
</tr>
<tr>
<td>mP</td>
<td>Skills acquisition</td>
<td>Teacher demonstration and student practice of a skill.</td>
<td>Kari demonstrated and explained how to deliver solution with a burette, read volume, and determine titration equivalence point</td>
</tr>
<tr>
<td>Mp</td>
<td>Lecture: science concept</td>
<td>Teacher-centered whole-class discussion; mostly teacher talk with some student contributions.</td>
<td>Teacher asks students to recall or imagine a common situation related to a science misconception</td>
</tr>
<tr>
<td>mp</td>
<td>Process practice</td>
<td>Practice of an algorithmic process, or gradual release lesson focusing on computation or process.</td>
<td>Teacher modeled stoichiometry calculations, students independently practice, teacher monitors.</td>
</tr>
</tbody>
</table>

*Conceptual change lessons.* Conceptual change lessons included a science artifact or phenomenon and addressed a misconception related to a science concept. During these lessons, the teacher demonstrated a phenomenon or provided an object to manipulate to elicit initial student statements and set up a contradiction between current understanding and scientific understanding.

*Skills acquisition lessons.* Skills acquisition lessons included a teacher demonstration of a specific skill, and student practice of the skill. For example, Kari
demonstrated and explained how to deliver solution with a burette, read volume using starting and ending volume readings, determine titration equivalence point using an indicator’s color change, and perform an end point check. Her students then practiced the titration procedure. Skills also include algorithmic processes, such as balancing equations or stoichiometric calculations, if the skills are presented without connection to their underlying concepts. For example, balancing equations is a skill if it is taught as a step-by-step process, but it is a concept if the underlying idea of conservation of mass is included in the lesson.

Lecture on concepts or misconceptions. These lessons, or lesson segments, featured lectures or teacher-centered whole-class discussion that were mostly teacher talk with some student contributions. Teachers asked students to recall an event from a previous lesson, or imagine or recall a commonly experienced event to support the lecture content.

Teacher modeling and independent practice. During these lessons, teachers used a gradual release of instruction, or an “I do, we do, you do” modeling of a calculation or step-by-step written process. For example, Kari demonstrated a stoichiometric calculation for her class, then provided another example for her students to complete and then check as Kari worked the problem on the board. Kari then directed students to work independently or in small groups to practice with additional problems.

Physics concepts provide opportunities to manipulate and predict. At the time of this study, Carl was teaching forces and motion, and energy and heat transfer, topics that can easily include demonstrations of physical events. Kari was teaching patterns of reactions, molecular geometry, and introductory stoichiometry. Kari frequently included
laboratory activities in her instruction, and several of her lessons included demonstrations of proper laboratory equipment use. Table 4.12 (below) shows Carl’s and Kari’s use of science artifacts or phenomenon and misconceptions in lessons.

Table 4.12

Classification of Carl’s and Kari’s lessons

<table>
<thead>
<tr>
<th>Artifact or phenomenon</th>
<th>M (yes)</th>
<th>Misconception</th>
<th>m (no)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carl: 5</td>
<td></td>
<td>Carl: 1</td>
</tr>
<tr>
<td></td>
<td>Kari: 1</td>
<td></td>
<td>Kari: 5</td>
</tr>
<tr>
<td>p (no)</td>
<td>Carl: 0*</td>
<td></td>
<td>Carl: 0</td>
</tr>
<tr>
<td></td>
<td>Kari: 2</td>
<td></td>
<td>Kari: 1</td>
</tr>
</tbody>
</table>

n = 15 lessons

*One of Carl’s lessons included a whole-class discussion of energy types without use of demonstrations or manipulated objects; however, the lesson did include a simulation of energy exchanges earlier in the lesson, but a quiz and review between the simulation and discussion essentially isolated the lesson components. The lesson cameo illustrating mp lessons was extracted from this lesson.

Most of Carl’s and Kari’s lessons were either MP or mP; that is, 80% of the fifteen lessons I observed were either conceptual change lessons (i.e., involved a misconception and a phenomenon), or a skill acquisition lesson (i.e., teacher demonstration and student practice of a specific skill). Conceptual change lessons involved a misconception and phenomenon, and featured complex, high cognitive level, open-ended teacher questions, and multiple opportunities for teachers and students to interact and discuss the science content. Lessons involving a science skill were engaging for students, and the teacher and student role in the lesson was more aligned with inquiry practices than in lessons where students took a more passive part in developing skills or understandings.

I used the EQUIIP factors related to interactive formative assessment (IFA) to compare the two most common lesson types Carl and Kari used. As described in the
conceptual frame for this study and in the methods chapter, IFA is a cycle of teacher noticing, recognizing, and reacting to student progress in understanding a concept or developing a skill.

IFA EQUIP cluster scores for skills lessons (mP) were typically rated as “developing inquiry,” and the one skills lesson rated higher in IFA embedded the skill instruction within a student investigation. Conceptual change (MP) lessons were consistently more aligned with inquiry practices in questioning level, concept development, and question complexity. Table 4.13 summarizes the IFA cluster scores for the two lesson types.

Table 4.13

<table>
<thead>
<tr>
<th></th>
<th>MP Lessons (science concepts)*</th>
<th>mP Lessons (skills)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Questioning Level</td>
<td>Pre</td>
<td>Dev</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Concept Development</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Question Complexity</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Assessment Type</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Role of Assessment</td>
<td>0</td>
<td>6</td>
</tr>
</tbody>
</table>

*n = 6 for both MP lessons and mP lessons

Conceptual change, or MP lessons, featured complex, high cognitive level, and open-ended teacher questions, and multiple opportunities for teachers and students to interact and discuss the science content. In contrast, teacher questioning in skill acquisition lessons was less focused on conceptual development and more focused on students’
understanding of the step-by-step process of the demonstrated skill. However, students were consistently engaged and active during skill acquisition lessons.

**Skills-centered demonstrations increased student engagement.** Teachers took a more central role during skills lessons, and teachers were more likely to repeat the same demonstration without modification if students did not initially grasp the procedure than in lessons designed to foster conceptual change. Teachers seemed more likely to adapt their questioning or modify their demonstration in response to student answers or participation during the conceptual change lessons (role of assessment). However, in comparison to conceptual change demonstrations and discussions, students were more involved during skills lessons, as they usually performed the skills individually after the demonstration (role of student). Table 4.14 shows ENG Equip cluster ratings for skills and concept demonstrations.

<table>
<thead>
<tr>
<th>Role of Teacher</th>
<th>MP Lessons (science concepts)*</th>
<th>mP Lessons (skills)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Dev</td>
</tr>
<tr>
<td>Role of Teacher</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learner Centrality</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Role of Assessment</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Role of Student</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Prior Knowledge</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

*Table 4.14 Engagement in conceptual change (MP) and skills acquisition (mP) lessons*

* n = 6 for both MP lessons and mP lessons

**Conceptual change, skill lessons lack prior knowledge assessment and reflection.** Carl and Kari more often elicited statements of student prior knowledge or
understanding when using demonstrations for conceptual development or conceptual change than when they used demonstrations for skill building; however, neither Carl nor Kari explicitly encouraged students to reflect on their learning (Student Reflection) in either lesson type.

<table>
<thead>
<tr>
<th></th>
<th>MP Lessons (science concepts)</th>
<th>mP Lessons (skills)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior Knowledge</td>
<td>Pre</td>
<td>Dev</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Student Reflection</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Role of Assessment</td>
<td>0</td>
<td>6</td>
</tr>
</tbody>
</table>

Twelve of the fifteen (80%) lessons I observed involved a physical phenomenon or a representation or simulation of a physical phenomenon, or manipulated object. Of those twelve lessons, 50% addressed a misconception, and 50% developed a skill. The next sections use lesson cameos to illustrate how Carl and Kari connected their planned formative assessment (PFA) and their interactive formative assessment (IFA) practices with demonstrations for skill development and conceptual development.

The lesson cameos that follow illustrate typical teaching practices I observed in skill acquisition lessons (i.e., mP lessons) and conceptual change lessons (i.e., MP lessons). During our stimulated recall interviews, both Carl and Kari indicated they were generally satisfied with the outcome of these lessons. Carl, however, noted the lesson segment where he attempted to address a misconception without a related phenomenon did not meet his expectations, and identified several modifications to the lesson he planned to use in the future.
Students are active during skills acquisition lessons. Skills acquisition lessons included a teacher demonstration of a specific skill, and student practice of the skill. Kari’s laboratory-based lesson included opportunities for students to develop an understanding of reaction types and patterns; however, Kari’s focus during the lab was on procedures and skills, and obtaining data to use during the next day’s discussion of step-wise stoichiometry calculations rather than underlying concepts such as patterns of reactions or conservation of matter.

Kari began this lesson with a reminder of safety concerns, a brief summary of the laboratory procedure, and the eventual goal of the activity. As she usually would in preparation for a lab, Kari had detailed the directions during the previous day’s class meeting in order to reserve class time for the lab activities. She reminded the class what equipment was needed, where the reagents were located, and directed the class to begin the lab activity shortly after the class period had started.

Kari worked with the pair of students as they heated a sample, observed changes, and constructed explanations. I asked Kari to narrate her decisions as we watched the video of the interaction:

<table>
<thead>
<tr>
<th>Turn</th>
<th>Speaker</th>
<th>Classroom dialogue</th>
<th>Kari’s comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>[1]</td>
<td>Kari:</td>
<td>A little further away…what are you seeing?</td>
<td>“I’m trying to ensure they’re noticing everything, making the observations they’re supposed to, without saying ‘do you see this and this?’”</td>
</tr>
<tr>
<td>[6]</td>
<td>Student:</td>
<td>A little smoke from the top?</td>
<td></td>
</tr>
</tbody>
</table>
“Alright. Is it smoke?”

“Well, it’s not smoke. If they see steam, they immediately think it’s smoke because it’s hot.”

“Maybe steam?”

“Probably steam. Why?”

“Uhh, probably water?”

“Probably water, indubitably. So, as soon as you notice water, you want to move it further away, because I think you’re burning it just a little bit.”

Kari provided “opportunities and then [helped students] when they get overly frustrated.”

As we watched the video of this interaction, Kari told me her question, “what are you seeing?” (Turn 1), was intended to direct attention to the reaction. Prior to Kari’s question, the student pair was carefully attending to heating the sample, but not looking for evidence of a reaction. Kari used the follow-up question “what else?” (Turn 3) and guided the pair to notice the condensation of water in the test tube. Kari stated she expected her students to conclude the vapor coming off the solid was smoke, based on her prior experience with this lab. Kari asked “is it smoke?” (Turn 7) to direct students to consider what else the “smoke” could be. Kari confirmed the student’s conclusion (Turn 11) and redirected the student’s attention back to the lab procedure. Kari focused on the lab procedure at the end of Turn 11 without asking about the source of the steam. Since students were thermally decomposing a hydrate, noting the steam as a product of the reaction may have established a connection between the visible evidence of decomposition and the chemical equation of the reaction they would later write in their lab reports.

While many of Kari’s interactions with her students during lab activities focused on “doing” the lab, she also made a point to elicit statements in order to reveal how her
students were interpreting their observations. Kari used the lab environment, and the many rich opportunities for teacher-student interactions, to assess and refine her students’ understanding of the event as they observed the event. Kari’s statement “If they see steam, they immediately think it’s smoke because it’s hot” indicates she was aware her students tended to mischaracterize steam as smoke. During this interaction, she did not explicitly identify the mischaracterization as a misconception. She pressed her student to reconsider his conclusion, and guided him to conclude the “smoke” was water vapor. In this instance, it appeared Kari was guiding her student to a correct characterization rather than helping her student identify and address a misconception. While this was a stoichiometry investigation, the observed reaction was a thermal decomposition of a hydrate; the correct identification of water vapor as a product was essential to the student’s understanding of a larger, generalizable pattern of decomposition reactions.

**Analysis of lesson cameo.** Formative assessment in this lesson was largely unplanned; while Kari planned and intentionally included this lab activity itself, and anticipated student misunderstandings, formative assessment as an instructional practice was largely tacit. Kari expects to interact with students to assist their understanding. Based on Kari’s explicit statement about being hurried during lab days, it is likely Kari did not identify specific learning outcomes for the lab, other than for students to generate data to analyze in the next day’s lesson.

Like the other skills acquisition lessons, this lab activity provides opportunities for students to be active, and was rated “proficient” in the EQUIP factor student role. Teachers’ use of formative assessment in skills acquisition lessons are usually limited to on-the-spot correction of mistakes and student repetition until a pre-determined outcome
is achieved; these types of lessons are usually rated low in role of assessment since the teacher does not change strategy or adjust content. In this lesson, Kari noted a misconception (“Well, it’s not smoke. If they see steam, they immediately think ‘smoke’ because it’s hot.”), but did not explicitly address the misconception. The lesson would have been more effective, rated higher in role of assessment, and have been classified as a conceptual change lesson had Kari responded to the student’s statement as a misconception. In this lesson, students had many opportunities to manipulate things, but limited opportunities to manipulate ideas. Student learning outcomes, such as “correctly identifies product and supports with observations,” as part of a clearly articulated assessment plan, would have helped Kari focus her interactive formative assessments on concepts as well as skills.

**Connecting skill development to problem solving provided context and applications.** The one skills lesson that rated proficient in questioning level, concept development and assessment type used a central question for students to investigate. In this lesson, Carl asked his students to determine which of two constant-velocity cars were faster without directly comparing them (i.e., racing), and to explain how they determined their answer. The investigation required students to interpret data and communicate relevant results, determine velocity by measuring and graphing time and displacement, and apply their learning to larger ideas, while developing their skills in measurement, data management, and data representation. Critical thinking and authentic practices were a central component of this lesson.

During my interview with Carl about his beliefs about reformed-based teaching and learning, Carl reported that in his experience, his students learn best from
“hands-on activities, with the concrete thinking questions does a pretty good job. But the moment I start asking them an abstract question, like ‘where did the bubbles come from?’ and I get a lot of ‘IDK’ written on there—‘I don’t know.’”

Carl told me “taking notes doesn’t do them any good. Abstract discussions usually don’t go over very well.” Carl preferred to “get them moving and then ask them the hard questions. That’s the most fun I have and I think it’s when they learn best.” During this investigation of the relationship of speed, time, and distance, Carl provided his students with an initial task they could perform. Once students were investigating their question, Carl asked the “hard questions,” that is, the application and analysis questions Carl developed for the project’s assessment rubric.

As I observed this lesson, I noted Carl’s interaction with a student as an “inflection point” where Carl made a decision that changed the direction of his student’s thinking. Immediately after the lesson, Carl and I discussed the interaction, his decisions, and his evaluation of the success of the interchange. Carl told me the student had created an accurate graph in a non-standard style, and that he took time to see if the graph made sense.

If they had accurately plotted the data, I didn’t want to undermine the work they had done. It was a perfectly fine stacked bar graph, it just wasn’t what I was looking for. I’m not going to say it was wrong, because it’s not. We’ve got a different way.

I selected a short video clip of this specific interaction for a more in-depth discussion of Carl’s teaching choices and decisions, and asked him to narrate his decision-making process. We were unable to discern the student’s contribution to the exchange; however, Carl was able to recall most of the interaction.

<table>
<thead>
<tr>
<th>In-Class Dialogue</th>
<th>Carl’s Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Carl:</strong></td>
<td>What I need you to do for me</td>
</tr>
</tbody>
</table>
is to make a graph. Do you remember how to make a line graph? [Carl walks with the student to her lab station.] Do you have a pen? So you’re going to… [Carl explains the graphing procedure]…then you draw a straight line. It’s not hard! Alright, so this is my time, and you did time at zero, and at two, and four… making sure the math wasn’t the challenge.

Because she was getting stuck on how to graph, and if you don’t have that, it’s hard to see the relationship [between distance, time, and rate]. That’s what a lot of this help was on, how do you set up a graph, how high do you need to go, what’s the scale? It’s one of those things a lot of our students struggle with.

[2] Carl: It’s like counting quarters. At two seconds, it’s at one hundred. Wow, that guy’s fast. At four seconds, geeze, he’s going to be way up here! Even when she has the right answers, she’s one that wants that “OK, you got that right” and off she goes. Even when she’s doing it right, she can’t see when she’s doing it right. It’s kind of hard to tell if [she’s] needing affirmation or really doesn’t, [or] can’t evaluate her work.

I wondered why Carl did not say “graphing is something science students struggle with” or something more general about the difficulties of teaching graphing skills to ninth-graders. During a follow-up interview, Carl explained his own experience as a science student and his more recent experience as a student teacher contrasted with his current experience at Honeydew. Carl told me he was a quick study in math and physics as a student, and the students at the affluent and suburban school where he completed his teaching internship were more worried about the “details of graphing, not the actual
process.” Carl told me his current physical science students, like their peers at Honeydew, had difficulty with many math concepts, and graphing was one of the more difficult skills for them to master. Carl might have pressed his student to consider whether a bar graph or a line graph were more appropriate for the type of data being graphed; however, Carl indicated he thought making the distinction would have distracted his student from seeing the overall relationships in distance, velocity, and time.

**Variations of skill lessons.** Carl’s distance, rate, and time lesson was similar to a smaller group of skills lessons, where two dimensions of skill building were evident in the lesson structure; students used observation or laboratory skills to either passively or directly gather data, which teachers used for instruction of step-wise calculations. In these lessons, student activity appeared to fall into two categories: (1) students observing an event and recording data but not making direct measurements themselves; (2) students performing scripted lab activities and making measurements, and gathering data in teams or individually. In each case, teachers used data to show students another skill, specifically how to conduct step-by-step calculations (stoichiometry, D=RT). Connections to “the big picture” were often overshadowed by the emphasis on the calculation procedure or problem-solving strategy.

In addition to Carl’s distance, rate, and time investigation, I observed two similar lessons in Kari’s classroom. In the first lesson, Kari provided real mass data from a real burning candle so students could calculate the number of moles of wax and the number of wax molecules involved in the reaction. In the second instance, Kari’s students followed a scripted lab procedure to generate data they later used to illustrate a stoichiometric
concept. In all three examples, data were used to work through calculations, which were more skill-based and algorithmic than conceptual.

**Concept and phenomenon: Greater alignment with inquiry.** Carl’s lessons usually included a “science thing” to support conceptual development and student engagement. This lesson’s topic was Newton’s third law, a topic Carl considered “more counterintuitive than most people realize” and difficult for students to understand beyond reciting ‘for every action there is an equal and opposite reaction.’ Carl challenged his students to achieve an “impossible task,” to connect two spring scales and pull so each scale showed a different force. Students worked in pairs to manipulate the scales, and Carl moved around the room to check student progress, maintain student focus, and prompt small group discussion. Carl’s interactions with one group, an excerpt from the whole-class discussion, and Carl’s comments are shown below.

<table>
<thead>
<tr>
<th>Classroom dialogue</th>
<th>Carl’s comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Carl: Okay, who’s going to pull 5? Okay, you’re going to pull 5 and you’re going to pull 15.</td>
</tr>
<tr>
<td>2</td>
<td><strong>Student 1 and 2:</strong> [Pairs of students pull on spring scales.]</td>
</tr>
<tr>
<td>3</td>
<td>Carl: [To Student 1] Look at yours. Get it down to five.</td>
</tr>
<tr>
<td>4</td>
<td><strong>Student 1:</strong> [Adjusts spring scale]</td>
</tr>
<tr>
<td>5</td>
<td>Carl: [To Student 2] Okay, look at yours. Get it up to fifteen. When you get it figured out let me know. [Carl leaves the group to manipulate the spring scales, and moves to another group.]</td>
</tr>
<tr>
<td>6</td>
<td><strong>Student 2:</strong> [Starts to pull on spring scale]</td>
</tr>
<tr>
<td>7</td>
<td>Carl: [Asks for attention of the class] How many people could do [that]? Raise your hand if you could pull the same? [Waits for response; there “I need to get better at identifying the response I’m looking for…I was getting a lot of visual nods or [hand</td>
</tr>
</tbody>
</table>
gestures] meaning ‘yes, no, kinda.’"

“A lot of times I stick Kyle next to people who are fairly social but do need the help.” Carl explains he uses peer-to-peer talk and considers student ability level, social tendencies, and individual student interactions when he assigns seats.

In an initial interview about his beliefs about reformed-based teaching, Carl told me he emphasized and kept returning to a few key principles throughout the physical science curriculum. Carl identified energy as one principle, and Newton’s laws of motion as another. In addition to their centrality within physics, Carl noted the many misconceptions associated with the concepts.

During the post-study member-checking interview, Carl told me he “focuses on the big core ideas” in the physical science curriculum, and develops meaningful and student-active lessons because “it’s gotta stick.” Carl based his decision to invest the creative energy and class time to this specific core idea (i.e., Newton’s Third Law) based on both his understanding of the idea within the discipline and the district’s requirements.
As I observed this lesson, I noticed Carl was working to include one student’s contributions while limiting his participation so other students would have a chance to talk. For the student Kyle, figuring out the impossible task, and needing to explain why it was impossible was interesting and compelling, and Kyle wanted to share his understanding. Carl’s interaction with Kyle reveals a dilemma: Carl wants to encourage all his students to participate, not just one enthusiastic student.

During our initial teacher beliefs interview, Carl told me “on the good days, I’m an agitator.” Carl expressed a sense of enjoyment in providing mysteries for his students to figure out: “It’s the most fun I have, and I think it’s when they learn best.” During this lesson, Carl used his evaluation rubric for the Newton’s third law learning standard to both assess student understanding and to prompt deeper discussion within the small groups. As we watched the video segment of this lesson, Carl told me he planned the lesson because “the hands on activities [that include] the [application] thinking questions seem to do a lot” to promote deeper conceptual development.

Student engagement is a priority for Carl, and he sees student-to-student interaction as a way to better understand his students’ learning: “What I like to see is the students start to ask each other questions, with or without prompting. That’s when I know [the content] is really starting to take hold.” Carl structured the lesson intentionally, using the initial impossible task as the mystery for students to solve and discuss, including opportunities to make and test predictions, and having ready-made prompts and learning objectives in mind.

**Concept through discussion only.** In the lessons I observed, Kari often discussed concepts without providing a physical phenomenon to support discussion. In two of the
eight lessons I observed Kari teach, as summarized in Table 4.12, Kari’s in-class discussions about misconceptions or common misunderstandings required students to recall an observation from a prior lab experience. Kari’s whole-class discussion connecting the reactivity of metals to ionization energy is the focus of Kari’s Case in Appendix D, and illustrates how Kari relied her students to recall events they experienced in labs. In short, Kari relied on student input and their ability to recall the previous day’s lab work to support the whole class discussion and development of conceptual understanding.

Similar to Kari’s Part 3 lesson cameo in which she modified her lesson plan in response to a quick survey of student homework, Carl’s discussion of energy types and transformations was an impromptu reaction to his students’ quiz answers. In this 20-minute section of a larger lesson that did include a simulation of potential and kinetic energy, Carl quickly noticed and responded to student misunderstandings of the quiz material, and improvised a discussion to address the misunderstandings.

The interchange described below happened after Carl’s class took and graded a short quiz. As students made corrections and study notes on their quizzes with colored pencils, Carl quickly scanned student work to identify trends in student responses. Carl noticed a pattern: many students were having trouble correctly categorizing types of energy. Carl projected images from the quiz that showed stylized line drawings of a campfire, a rubber band, objects in motion, and objects at different vertical heights. He referred to the images as he talked to his students about energy types:

<table>
<thead>
<tr>
<th>Classroom dialogue</th>
<th>Carl’s comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carl: You’re looking at motion. For [gravitational potential energy].</td>
<td></td>
</tr>
</tbody>
</table>
what are you looking for?

[2] **Student 1:** If it can fall…

[3] **Carl:** If it can fall…Here’s [inaud] if it’s higher than something, anything, it just has to be higher than something else in the picture. [Pauses to indicate new idea, motions to image on screen] Elastic. You’re looking for something bent, or squished, or stretched. Any of those. And for thermal, what are you looking for?

This is one of the lessons I need to revamp, because I’m doing too much of the talking.

[4] **Student 1:** You’re looking for heat, and light.

[5] **Carl:** [To Student 1] Heat or friction. [Pauses] So we have some examples of what to look for, for those. [gestures to the screen] and these are examples of things that have energy. They do not fit neatly into a single category. Fire shows up in two [categories], the sun shows up in three, because it has more than one kind of energy. So we need to, I want to remind you guys, of the unusual energy types. So food, fire and gasoline. What kind of energy is in food, fire and gasoline?

What I’d like to do is shift it around a bit more so they’re trying to categorize it themselves, and tell me why it’s in that category.

[6] **Students:** [Some beginnings of answers, with hesitation]

[7] **Carl:** Here’s what I’m looking for guys, food doesn’t have to have heat, does it? So this is one of the rare types, not rare, but unusual, because it’s hard to tell how much is in there. Do you guys know how much chemical energy is in soap? Do you know if it has more or less than the soda?

Chemistry is a lot of telling, not a lot of doing… I want [students to ask] “what’s going on” rather than “that’s what he said.”

[8] **Students:** umm, more…

[9] **Carl:** I’m not drinking it, thank you. [Pauses] It’s hard to tell which one has more chemical energy. Now, if I do this [lifts soda over his head] can you tell which one has more
gravitational?

[10] **Students:** yeah

[11] **Carl:** Pretty easy, right? So these are just as powerful and useful as these [points to elastic energy and gravitational energy images on the board] but they’re harder to understand. So we just talk about it in general. It’s kind of like in your English class, you don’t talk about Shakespeare when you’re three years old? You talk about how to spell “cat,” right? I know a lot about these [indicating chemical energy], but right now we’re just talking about these in general, so you know they’re there.

I’m not sure I could even start with [discussion strategies] yet. Part of it is, [how do I] get started? … Teaching them how to teach themselves is my goal. But I’m not really sure how to do that.

The rest of Carl’s interchange with his students was question and answer, and Carl confirmed correct answers to one-answer questions. The impromptu review of quiz material indicates Carl used assessment data to modify this lesson in real time; however, I noticed Carl was visibly dissatisfied, frowning while he watched the video of the lesson, with the lesson. During this lesson, Carl was sustaining the whole-class discussion mostly on his own. Students were not engaged with the lesson, and Carl asked several students to leave the classroom for behavior issues. As we watched video of the interchange, Carl told me:

“This is one of the lessons I need to revamp, because I’m doing too much of the talking. I’m the one saying ‘what’s this do?’ and [confirming answers]. What I’d like to do [is have students] categorize [the energy types] themselves, and tell me why.”

Carl identified modifications to the lesson to provide opportunities for students to talk:

“A card-sorting activity, and having students justify the [categorization] to other people at the table, or to the class as a whole. That would be my goal for reorganizing the lesson for next year. Looking at this, I can’t blame the students for being a bit bored. I am.”
As we discussed the video, Carl told me his revision process is finding “what tool is right” for his mostly ninth-grade physical science class. Carl also told me he had difficulty making the idea of chemical energy as accessible to students as the idea of gravitational and elastic potential energy. During Turn 9, Carl demonstrated differences in gravitational potential energy by elevating a soap dispenser, and his students responded more enthusiastically (Turn 10) than when he attempted to illustrate differences in the chemical energy in the soap and the soda (Turn 7).

**Part 4 summary: Give them something to talk about.** Rich discourse was present in lessons that included a phenomenon, connected to a central learning objective for the lesson, for students to observe, manipulate, and discuss. During conceptual change lessons, where a misconception and a phenomenon were both present, student discussion provided teachers opportunities to monitor and guide student conceptual development. Teachers were more effective in facilitating student science talk when they had both identified misconceptions and developed assessment criteria prior to the lesson. In skills lessons, students took an active role in their learning as they manipulated the equipment.

**Summary of Results and Findings**

In summary, this chapter presented the findings associated with each of the three research questions.

As a group, these six beginning physical science teachers showed developing strength in inquiry-aligned questioning practices, and persistent challenges in planned assessment practices. The frequency of lessons featuring proficient inquiry level questioning practices is generally constant between groups of teachers with high and low subject matter knowledge; however, the high SMK group’s pre-inquiry questioning
practices was minimal compared to the low SMK groups pre-inquiry questioning practices, suggesting teachers with well-developed SMK may be developing their questioning skills more rapidly than the low SMK teachers in the study.

These six teachers were aware of, and employed, different ways to address gaps in their assessment practices, specifically in assessing student prior knowledge and using formative assessment information to modify lessons. However, as a group, using student reflection as an assessment practice was noticeably absent across instructional settings and years of experience.

The two third-year teachers used lessons that included science artifacts, phenomenon, or physical objects to initiate and sustain classroom discourse, conceptual development, and student engagement. Most lessons (80%) taught by the two third-year teachers were one of two types: conceptual change or skill acquisition. Discourse was robust and participatory during conceptual change lessons, and skills lessons were oriented to student engagement.

Extensions of the two case studies are found in “Carl’s Case” and “Kari’s Case” in Appendix D. Carl’s case shows how he enacted the pedagogical and professional principles emphasized during STEP coursework and teaching internships, including a description of his detailed assessment plan. Carl’s beliefs about teaching and learning, and his professional outlook are particularly well-suited for teaching science to under-resourced children, and for his persistence of practice and professional development.

Kari’s case shows how she used positive relationships with her students, and an informal but generally effective approach to interactive formative assessment. Kari reported a general good feeling about her students’ effort and their shared positive and
trusting relationship. However, Kari’s declining teaching self-efficacy in employing instructional strategies was not congruent with her statements of strong student effort and their overall academic achievement. A standards-based approach to assessment, with consistent monitoring of student progress, may have sustained and built Kari’s teaching self-efficacy, helped her refine and more carefully plan to meet learning objectives, and reduced the considerable stress she consistently reported as she strained to keep her curriculum on pace.

Chapter 5 extends the findings of the three research questions presented in this chapter into separate claims, and situates the claims within foundational literature and among current research.
Chapter 5
Discussion

In this chapter, I communicate claims associated with the research questions and findings of this study. Each of these claims extends the findings into larger statements about the interactions between teacher subject matter knowledge, pedagogical practices introduced in teacher education programs and observed in practice, and teachers’ use of feedback as both a teaching tool and as a way to evaluate the effectiveness of their own practice.

Purpose

The purpose of this investigation was to identify how beginning physical science teachers used formative assessment (i.e., assessment for learning) and discourse practices, and in what areas within each they found particularly difficult, and in what areas they showed growth. This study also investigated how two third year physical science teachers supported classroom discourse and student engagement. Finally, this investigation explored how these same two teachers developed and applied formative assessment practices.

As explained in the previous two chapters, the research questions investigated in this study are

Research Question 1: In what areas do these purposefully selected teachers show developing strengths, and in what areas do they encounter challenges, in enacting inquiry-aligned discourse and assessment practices?

Research Question 2: To what extent, and how, did these purposefully selected teachers employ inquiry-aligned discourse practices, and adapt to obstacles in implementing inquiry-aligned assessment practices?

Research Question 3: How do two third year teachers initiate and sustain classroom discourse, and how do they use discourse and formative assessment to support student learning and engagement?
Claim #1 relies on the findings of Research Question 1 and Research Question 2.
Claim #2 relies on the findings of Research Question 2, and Claim #3 relies on the findings of Research Question 2 and Research Question 3.

**Claim #1: Well-developed subject matter knowledge supports adaptability**

Teachers’ domain-specific subject matter knowledge (SMK) appeared to support high teaching self-efficacy in generating and using questions, as well as developing strengths in their questioning practices. Teachers’ confidence in using questions is important because teachers often rely on questioning to determine their students’ conceptual understanding, which they may use to inform their teaching decisions in the moment. Teacher questions, and student answers, are essential components of interactive and planned formative assessment. The use of formative assessment, or “assessment for learning” is one key component of adaptive teaching practice (Wiggins, 1998, p.12).

As developed in the previous chapter on the results from the study, these beginning teachers showed developing strengths in using inquiry-aligned discourse practices and experienced consistent challenges in applying inquiry-aligned assessment practices. Strengths in using inquiry-aligned questioning practices, indicated by EQUIP ratings, are congruent with these teachers’ high and stable teaching self-efficacy in developing and crafting good questions, using questions to assess students’ understandings, and providing alternative explanations and examples when their students were confused (Tschannen-Moran, Woolfolk Hoy, & Hoy, 2001). These beginning teachers also encountered consistent challenges in their assessment practices; this claim
focuses on how teachers adapted to specific challenges in their use of assessment data to support student learning.

The ways in which these teachers were able to use discourse, specifically their use of inquiry-aligned questioning, provided them with information about their students’ learning. Third-year teachers with highly developed subject matter knowledge adapted their questioning practices to support connections between complex ideas (i.e., Kari’s conceptual ladder), and to provide opportunities for students to interact and describe phenomenon based on developing teaching experience (i.e., Carl’s conceptual change lessons). Additionally, in their second year, teachers with well-developed SMK used fewer low-level, single-answer questions than teachers with the same experience level but lower SMK measures. Two teachers with relatively low SMK reported spending most of their lesson preparation time ensuring their own understanding of the lesson content; one reported constructing assessment standards based on high-performing student work and discussions as she taught the lessons. In all, these instances of assessment practices illustrate these teachers adapt their practices; further, teachers with well-developed SMK were able to focus their adaptations on the needs of their students more readily. The organization of evidence, examples, and reasoning that provide support for Claim #1 is diagramed in Figure 5.1 below.
Evidence supporting this claim is drawn from subject matter knowledge measures and EQUIP ratings showing how teachers’ question use aligns with inquiry practices, teaching self-efficacy in developing and using questions, Kari’s use of a cognitive ladder to develop deeper understandings of complex ideas, Jena’s delayed assessment and feedback, and Carl’s adoption of a conceptual change model of instruction. The relationship between SMK and adaptive practices is further supported by Jena’s reported difficulties with her formative assessment plan associated with her low confidence in the
subject she was teaching. Jena’s assessment practices will be discussed in greater detail in support of Claim #2.

Formative assessment practices may begin with, but are not limited to in-class questions and discussions. However, teachers often rely on in-class dialogue to provide information about their students’ understandings. Student answers and contributions, “the interactive exchanges between teacher and students, and between students themselves,” provide teachers with data essential to their instructional decision-making process (Black & Atkin, 2014, p.780). Supporting in-class dialogue with teacher questions, therefore, is an essential component of effective formative assessment, and, by extension, of adaptive teaching. Subject matter knowledge in support of questioning practices, and adaptive teaching, is discussed in the following subclaim.

**Subclaim: Well-developed SMK improves questioning practices.** As discussed in the previous chapter, the discourse and assessment practices that focus on students’ conceptual understanding (i.e., questioning level, question complexity, and conceptual development) are influenced by teachers’ subject matter knowledge. As shown in Table 4.3, teachers with better developed SMK as well as teachers with less developed SMK, used questions that involved higher-level thinking, required explanation, and linked concepts at about the same frequency. However, teachers with better-developed SMK also used fewer recall-level, single answer questions that did not require explanation than teachers with less-well developed SMK, shown in Table 4.3. There was not an apparent relationship between teacher SMK and their use of questions requiring analysis of ideas or connections between ideas, as five of the six teachers’ observed lessons were consistently rated as developing or proficient inquiry in this area.
While the use of open-ended questions that require explanations is one source of formative assessment data for teachers, the use of such questions alone does not make the practice a formative assessment. In order for an assessment to be formative, a teacher must modify their instruction to meet the needs revealed by the assessment (Bell & Cowie, 2001). Teachers in this study used questions and responded to student questions as planned formative assessment (i.e., Carl’s conceptual change lesson) and as interactive formative assessment (i.e. Kari’s cognitive ladder). The argument supporting the subclaim that well-developed SMK supports teachers’ questioning practices is outlined in Figure 5.2 below.

*Figure 5.2. Conceptual development of subclaim. This is a diagrammatic representation of the argument presented to support the subclaim: “Well-developed SMK improves teachers’ questioning practices.”*

**Teachers apply SMK and questioning to formative assessment.** Classroom observations, EQUIP ratings, and teaching self-efficacy in questioning practices indicate using questions for interactive formative assessment is an area of developing strength for these six teachers. However, these strengths in questioning practices are especially
apparent when viewed in contrast to the areas of persistent challenges in these teachers’
assessment practices, which are developed in the discussion of Claim #2.

Specifically, observed depth of conceptual development in lessons taught by the
three teachers with graduate-level course work, high GPA and passing MOSART scores
indicate teacher subject matter knowledge supports teachers’ adaptability by enabling
them to better use formative assessments. Excerpts from two high-SMK teachers’ lessons
illustrate the connections between Carl’s and Kari’s subject matter knowledge and their
adaptability to their learning environments and to their students’ needs.

Kari’s cognitive ladder supports development of related ideas. Strong subject
matter knowledge is foundational to effective questioning practices (Pierson, 2008). For
example, structuring a series of low-level questions to help a student develop deeper
understandings, as Kari did with her students, would not happen without a deep
understanding of the content.

Oversby (2002) identified five levels of increasing conceptual understanding.
Definitional understanding is characterized by stating a concept with no details, and
descriptive understanding is characterized by the inclusion of details such as providing
physical examples of the concept. Interpretative understanding is evidenced when a
theoretical explanation is included in the explanation, and causal understanding is
evidenced by the identification of the mechanism driving the phenomenon. Predictive
understanding requires producing a generalizable statement about the phenomenon (ibid).
Kari’s stated goal of “getting to the why” revealed her intention to develop at least an
interpretive understanding of chemical concepts. Kari’s questioning practices during
skills acquisition and conceptual development lessons (see Tables 4.12 and 4.13) indicate
conceptual development aligned with developing or proficient inquiry practices; however, she used a series of low-level questions to scaffold her student’s understanding of and connections between the related concepts.

During an individual interaction with a student, Kari used a cognitive ladder (Chin, 2007) to support developing understanding of ionic charges, classify a bond by type, and correctly predict a formula. In another example, described in Appendix D, Kari used a cognitive ladder and a whole class discussion of reaction predictions to connect patterns of reactivity to ionization energy. Kari intended to connect her students’ descriptions of observable phenomenon, a definitional and emerging descriptive understanding of the concept, to a more sophisticated interpretive understanding and identification of the cause of the observed phenomenon.

*Teacher knowledge about misconceptions supported planned formative assessments.* Like Kari, Carl’s subject matter knowledge was developed in undergraduate and graduate-level coursework, as well as with research work in his field. In addition, Carl also understood students’ misconceptions about the content he taught. As shown in the conceptual change lesson cameo in the previous chapter, and explored in greater detail in Appendix D, Carl planned lessons to help students identify and modify their naïve conceptions of specific physics ideas. Carl’s assessment, planning, and instructional strategies interact with his subject matter knowledge and his knowledge of student misconceptions to support conceptual change lessons, which also generate rich in-class discussions and support student engagement.

Carl and Kari’s science teaching methods instructor explicitly used the conceptual change model, and included a brief description of the approach in the course syllabus.
The conceptual change teaching approach requires initial assessment of student understanding. Teachers who use the conceptual change model elicit student statements in order to reveal understandings, provide a test of the understandings, and mediate the developing new conception (Posner, Strike, Hewson, & Gertzog, 1982). Teachers using conceptual change must apply both planned formative assessment and interactive formative assessments during lessons (Bell & Cowie, 2001; Mortimer & Scott, 2003). A major assignment in the second science teaching methods course was a lesson study that required the teachers to analyze the success of the lessons based on assessment data (e.g., artifacts and observations), and redesign and reteach the lessons with modifications (Hurd & Lewis, 2011). Carl’s exposure to conceptual change and lesson study in his methods courses parallel his use of conceptual change in his lessons, and his consistent analysis and modification of his own teaching.

*Carl’s subject matter knowledge enhances his assessments.* Carl’s understanding of common student misconceptions, and how specific misconceptions about one topic can affect understandings of other physical science concepts helped him plan his integrated curriculum and assessment program. Carl identified the most important ideas in physical science, and how these key ideas were usually misunderstood, and used conceptual change lessons to address these ideas. Carl returned to these key topics at multiple points in his curriculum, and used assessment data to track student learning and modify his instruction.

For example, Carl modified his lessons on heat transfer based on assessment data he collected during his first two years of teaching. He found that his students’ misconceptions and over-simplifications (e.g., “heat rises”) were particularly resistant to
change using his initial approach to the subject, and he adopted a conceptual change approach to better address these misunderstandings. Carl’s lesson on heat transfer is detailed in Appendix D. The following argument details how Carl applied his SMK to his assessment and instructional decisions. Figure 5.3 represents the evidence offered in support of this finding.

![Diagram](image)

**Figure 5.3.** Conceptual development of Claim #1. This is a diagrammatic representation of *Carl’s subject matter knowledge enhances his assessment practices.*

For another conceptual change lesson, described in the results chapter, Carl identified common misconceptions about Newton’s third law and developed an “impossible challenge” based on common misconceptions for his students to attempt to solve. Carl developed mastery indicators for his lessons, and he used these indicators to guide his interactive formative assessment questions as his students struggled to solve the impossible challenge.
Carl intentionally constructed conceptual change science lessons in order to evoke the “uncertainty, judgments, values, and interests” of his students, and in doing so, involved his students in the process of understanding science (Lemke, 1990, p. 130). He was careful to support his students’ developing understandings, as “science teaching also tends to pit science against common sense and undermine students’ confidence in their own judgment” (Lemke, 1990, p. 129).

By significantly altering his instructional approach to better fit a conceptual change model, Carl demonstrated his application of assessment data in planning for improving his instruction. By adopting a conceptual change approach, Carl also demonstrated his understanding of key pedagogical principles: student cognition, the importance of students’ prior experiences, and effective instructional strategies. Carl’s explicit belief statements about how students learn science align with the tenets of a conceptual change approach; in addition, the intentional and explicit use of conceptual change during his methods courses provided Carl with the pedagogical knowledge he needed to enact the practice, and his deep understanding of physics principles supported his pedagogical decisions.

Carl’s decision to emphasize foundational ideas in physics such as laws of motion indicate he thinks of his curriculum holistically, and that he planned instruction so that important concepts are introduced, revisited, and revised over the course of the year. Lederman and Gess-Newsome (1999) reported that experienced teachers in their study used a coherent subject matter structure to plan long-term instruction. Carl’s development and use of long-term planning that focused on key understandings suggests that he uses SMK and pedagogical knowledge in ways that a more experienced teacher would.
Chan and Yung (2015) investigated teachers’ “on-site” instructional decisions, and similarly concluded that strong subject matter knowledge and well-developed pedagogical knowledge interact when teachers have time to reflect on decisions they made while teaching challenging content (p. 1267). In Carl’s case, the habits of reflection and lesson modification established during his methods course, in concert with his existing dispositions and reflective practices, amplified the interactions between his pedagogical knowledge and subject matter knowledge. The well-developed subject matter knowledge Carl brought to the STEP provided the content to which Carl applied his pedagogical practices.

Settlage and Meadows (2002) examined how standards-based reforms influenced science instruction in urban schools. Settlage and Meadows (2002) focused on the unintended detrimental effects of standard-based reform, and identified ways teachers could resist these negative effects. Specifically, Settlage and Meadows (2002) described the efforts of one teacher, Diane, who, without supporting resources from her district or state Department of Education, restructured her district’s science curriculum to meet the tested objectives determined by the state. “Diane’s story of resistance” parallels Carl’s adaptations (Settlage & Meadows, 2002, p. 121). Carl, like Diane, brought their “classroom activities inline with the objectives and the assessment,” and applied their pedagogical knowledge of assessment and alignment as adaptive teachers (Settlage & Meadows, 2002, p. 122).

In contrast to the examples offered in support of Claim #1, two teachers, Kim and Jena, reported their low confidence in their subject matter knowledge hindered their effective use of assessment practices. The next section discusses another trend apparent
Teachers were aware of and attended to deficiencies in their own subject matter knowledge.

**Teachers are aware of and attend to deficits in SMK.** Teachers reported identifying gaps in their subject matter knowledge, and reported taking specific actions to address these gaps to improve their instructional practices. One teacher, Jena, reported that her limited SMK hindered her ability to develop and use formative assessments. This section discusses how Jena adapted her assessment practices to mediate the effects of her developing subject matter knowledge. Figure 5.4 shows the conceptual diagram of the argument supporting this claim.

**Limited SMK also limits formative assessment.** Teachers noted where their SMK was lacking and the effects it had on their teaching and preparation for teaching. For example, first-year teacher Kim felt she needed to refresh or develop her SMK, and second-year teacher Jena reported that her limited SMK in physical science restricted her ability to effectively administer a formative assessment plan and offer timely feedback. Additionally, as described in Appendix D, Carl indicated his limited understanding of
chemistry content resulted in his reliance upon confirmatory, rather than exploratory, chemistry lessons and activities.

In summary, teachers in this study applied their SMK to questioning practices to support classroom dialogue, elicit statements of student understanding, and develop their students’ ability to apply concepts and analyze statements. Teachers with well-developed SMK used questions to scaffold students’ developing understanding of complex ideas, and relied on their SMK to help them identify the essential ideas their students commonly misunderstood. Additionally, teachers with well-developed SMK were able to design assessment programs, and effectively use planned and interactive formative assessments.

Claim #2 explores the specific areas in which these six teachers demonstrated adequate pedagogical knowledge about formative assessment and adaptive teaching, and the areas in which they encountered persistent challenges. The discussion of Claim #2 follows.

Claim #2: Teachers Are Generally Knowledgeable About Formative Assessment, But Assessing Prior Knowledge and Student Reflection Practices Need Support.

As discussed in the previous chapter, the teachers in this study understood the pedagogical principles of formative assessment developed in their STEP, and attempted to modify their teaching in response to assessment data. However, their limited experience restricted more immediate responses to student learning needs. As developed in the discussion of the previous claim, teachers were observed and they reported teaching practices that revealed areas of developing strengths in discourse practices associated with subject matter knowledge, specifically in their use of complex questions to support conceptual development. Conversely, teachers did not often assess student
prior knowledge, and when they did, they rarely modified their instruction in response. Additionally, opportunities for students to reflect on their learning were almost entirely absent from their lessons.

The research questions and findings within this study are closely interrelated. Most of the evidence used in support of Claim #2 developed from findings of Research Question 2; however, several examples from Research Question 3 and its associated claim are used here to illustrate how teachers apply pedagogical knowledge in formative assessment. Research Question 2 and Research Question 3 are duplicated below.

Research Question 2: To what extent, and how, did induction-phase physical science teachers employ inquiry-aligned discourse practices, and adapt to obstacles in implementing inquiry-aligned assessment practices?

Research Question 3: How do two third year teachers initiate and sustain classroom discourse, and how do they use discourse and formative assessment to support student learning and engagement?

These teachers demonstrated sufficient pedagogical knowledge in understanding formative assessment, but encountered obstacles to assessing prior knowledge, and in developing and applying an educative formative assessment plan. The consistent lack of opportunities for student reflection in lessons indicated either a profound deficiency in pedagogical knowledge, or insurmountable systematic obstacles to implementing reflective practices in their lessons. Figure 5.5, shown below, show the conceptual diagram of the argument for Claim #2.
Evidence: (1) The teachers in this study understood the pedagogical principles of formative assessment and attempted to implement a responsive assessment plan. (2) Teachers reported making modifications in the next-days’ lessons in response to formative assessment data. (3) Two teachers modified required practices in response to their district’s requirement to use test review questions as a start-of-class routine; another modified a prior knowledge structure to better elicit useful student statements. (4) Opportunities for students to reflect on their learning were absent from nearly all lessons.
Table 5.1 shows evidence in support of this claim in context with findings related to Research Question 2 and Research Question 3.

Table 5.1: Claims and evidence summary for Claim #2

<table>
<thead>
<tr>
<th>Findings</th>
<th>Claims</th>
<th>Evidence</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginning teachers encountered consistent challenges in using formative assessment to adjust lessons, assessing student prior knowledge, and providing opportunities for students to reflect on what they learned</td>
<td>Claim 2: The formative assessment practices of these six teachers indicate sufficient pedagogical knowledge of assessment practices.</td>
<td>Teachers attempted to implement a responsive assessment plan.</td>
<td>Jena developed an assessment plan as she taught, in response to her limited SMK in an out-of-field course.</td>
</tr>
<tr>
<td>Beginning teachers understood the principles of formative assessment, and adapted required practices to make their assessments educative.</td>
<td></td>
<td>Teachers planned lessons in response to student needs revealed in prior lessons.</td>
<td>. Kim applied FA practices, but was also limited by SMK.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Three teachers modified a district-required practice for better alignment of content, or a commonly used FA strategy to better elicit student statements</td>
<td>Mike and Kim re-arranged test review questions to better align with lesson content and used the questions as an approximation of PriorK assessment.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Student reflection is almost never included in lessons.</td>
<td>Carl applied active learning principles to his PriorK assessment.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Two teachers reported their short class periods limited assessment opportunities in general.</td>
<td></td>
</tr>
</tbody>
</table>

**Discussion of evidence: Teacher PK supports, and developing SMK limits**

effectiveness of formative assessment practices. Figure 5.6 places this discussion within the larger argument in support of Claim #2.
Second-year teacher Jena recognized the need for and generally understood the principles of formative assessment; however, in her case, her lack of confidence in her subject matter knowledge hindered her ability to develop and enact an educative assessment plan. Jena was unable to define levels of mastery prior to teaching the lesson, and she intentionally developed indicators of mastery based on student responses during the lessons. Jena used assessment data to inform subsequent lesson planning, which indicated she understood the pedagogical principles of formative assessment. While her subject matter knowledge in physical science was inadequate to develop an assessment routine that met her expectations, the STEP program and her internship experiences were sufficient to develop her pedagogical knowledge of assessment. Jena responded to her students’ needs, but later than she would have liked.

Similarly, first year teacher Kim reported using most of her out-of-school preparation time reviewing the chemistry content for upcoming lessons. Kim ensured she conveyed accurate information, but potentially at the expense of her own professional

![Figure 5.6: Conceptual development of Claim #2. This is a diagrammatic representation of evidence, teacher PK supports, and developing SMK limits effectiveness of formative assessment practices, in support of the claim Assessing prior knowledge and student reflection practices need support, but teachers are generally knowledgeable in formative assessment.](image-url)
growth. Sanders, Borko, & Lockard (1993) reported when teaching unfamiliar content, even with teaching experience and well-developed pedagogical knowledge, teachers used more novice-like teaching practices. The authors (ibid) report experienced teachers relied on their pedagogical knowledge to buoy inadequate subject matter knowledge. For Kim and Jena, their subject matter knowledge and teaching experience were developing at the same time, and this reduced their ability to use formative assessments to adapt to their student’s needs. Further, the time they spent building subject matter knowledge could have been invested in deeper reflection on their teaching decisions that may have provided opportunities for growth in their pedagogical knowledge.

Kim and Jena both recognized the limits of their subject matter knowledge and adapted as needed to present their students accurate science content, and to use assessment to support student learning. It is likely a next-day response to assessment data is the practical limit for any novice teacher, and Kim’s and Jena’s attentiveness to the practice of formative assessment indicates pedagogical knowledge of assessment practices was well-established in their STEP and well-maintained by their districts.

*Discussion of evidence: Modifying provided curriculum indicates adequate pedagogical knowledge of assessment.* Figure 5.7 places this discussion within the larger argument in support of Claim #2.
First year teachers Mike and Kim intentionally modified the “bell work” test review content their district provided to more closely align the review questions with the lesson content, and used student responses to gauge understanding. Both teachers understood the importance of assessing students’ current understanding. While they did not report immediately modifying lessons based on the bell work responses through interactive formative assessment, they did report modifying their next lessons to respond to student needs. Kim and Mike were not unique; as shown in the EQUIP prior knowledge and role of assessment factors, few teachers in this study were observed modifying lessons in response to both planned and unplanned formative assessments.

Third-year teacher Carl encountered limited student participation when he used a formal assessment of student prior knowledge. In response, he changed his approach to assessing prior knowledge by including a phenomenon and opportunities for his students to interact with each other.
Example: Bell work in service of formative assessment. Mike and Kim recognized the ineffectiveness of their district’s test review routine, and modified the required procedure so the introductory questions were better aligned with the lesson topic and could be used to measure student prior knowledge. These two first year teachers demonstrated their understanding of alignment of instruction and assessment, and were moving toward the application of assessment data to lesson planning and modification.

Mike’s and Kim’s decision to modify bell work questions to better align with lesson content was supported by their understanding of the content; which questions to choose, and at what cognitive level, were informed by their understanding of physical science and chemistry concepts. Their attention to the substance of the assessment and to the alignment of content with lesson objectives (Wiggins, 1998) illustrates the positive interactions of well-developed subject matter knowledge and pedagogical knowledge in their teaching practice.

Example: Responding to limited participation. Carl’s use of constructivist and phenomenon-based instruction is detailed in support of the next claim. However, Carl’s use of phenomenon with structured activities in which students can manipulate physical objects, and his practice of using small group discussions with structured investigative activities was a direct response to limited student participation in a traditional “KWL” prior knowledge strategy (Ogle, 1986). Carl reported attempting to use the KWL approach, with little student participation. The structured activities, small group discussion, and a physical object to observe or manipulate stimulated student talk, and this student talk provided Carl with insight to their thinking. By shifting his assessment method, Carl demonstrated he was attentive to what his students were thinking. Carl was
willing to reconsider the structure and strategy, and he kept in mind, as Coffey, et al (2011) maintain, that the formative assessment strategies teachers learn and are sometimes required to use must provide the teacher with an “awareness and understanding of the students’ understandings and progress” (p. 1128).

**Discussion of evidence: Absence of student reflection indicates a gap in pedagogical knowledge and institutional policies.** Figure 5.8 places this discussion within the larger argument in support of Claim #2.

![Figure 5.8: Conceptual development of Claim #2](image)

Opportunities for students to reflect on their own learning were largely absent in observed lessons across all experience levels. Only three percent of observed lessons included any explicit reflective components. Further, only two of the six teachers in the study mentioned student reflective practices, and these mentions were in context of student self-assessment and peer instruction, rather than in goal setting, planning, or identifying learning strategies. Both Kim and Carl used notebooks or folders as an
organizational tool for their students, and it is possible they used these for student reflection, planning, or as evidence of growth over time. I observed one of Carl interact with a student during an impromptu academic coaching session; Carl relied on his assessment data to determine student needs, and to provide the student with evidence of his progress. Other than these examples, student reflection was not included in teachers’ instructional practices.

Teachers did not explicitly identify obstacles to including student reflection in their teaching. Based on teacher statements about limited time for instruction in general during 40- or 45-minute class periods, it is likely the teachers perceive there is limited time for assessment or student reflection. Importantly, Kim and Carl, the two teachers who used rudimentary or developing reflective practices, taught in schools that used much longer class periods.

While student reflection was largely absent in the lessons taught by teachers in this study, they used bell work as an introductory practice nearly universally if their schools required the practice. Institutional decisions, such as the length of class period and which assessment practices are used, likely exert a strong influence on teachers’ use of student reflection in their teaching.

**Summary of Claim #1 and Claim #2: Formative Assessment is the Foundation of Responsive Practice**

Teachers in this study demonstrated adaptability in their assessment practices to their unique instructional environments, and adequate pedagogical knowledge about assessment practices. As discussed in support of Claim #1, teachers in this study relied on their subject matter knowledge to support their questioning practices. Further, as
discussed in Claim #2, teachers with limited subject matter knowledge recognized deficiencies in their subject matter knowledge, the effect these deficiencies had on their instruction, and adapted the implementation of an assessments that adequately met the needs of their students. Overall, the teachers in this study are knowledgeable about formative assessment, but assessing prior knowledge and student reflection practices need support.

**Student reflection supports learning inquiry.** The National Research Council (2000) identified conceptual understanding, performance of scientific inquiry, and an understanding of inquiry as primary outcomes of inquiry-based teaching. Metacognitive reflection as a part of an integrated assessment plan is a reliable way to support each of the three outcomes identified by the NRC. Peters and Kitsantas (2010) reported learning gains in science content and scientific practices among students who were prompted to reflect on their developing understanding during learning activities. However, as reported by Zimmerman and Martinez-Pons (1990), reflective practices are linked to language and cognitive developmental level. It is possible teachers in this study hold a belief that 7-12 students are not developmentally ready to meaningfully reflect on their own learning. If so, instruction on using scaffolded reflective activities with high school students should be incorporated into the teaching methods and adolescent psychology courses of the STEP. A more likely reason for the lack of student reflection is a lack of time during a class period. Mike and Kari both taught in schools with 45-minute class periods, and both reported feeling rushed to complete their lessons.

**Assessing prior knowledge is foundational to differentiated instruction.** Assessing student prior and retained knowledge is the first step in differentiating
instruction for individual students. Teachers need to know what students understand and at what level in order to modify lesson content for students who are struggling, as well as for students who may be accessing the content easily or who have learned the content in prior classes (Fisher, Grant, Frey, & Johnson, 2010). Teacher assessment of existing knowledge, coupled with a change in instructional strategy in response to the assessment, defines *formative assessment* (Black, 1993). However, assessing during one day, and generating lesson content to respond to the learning needs of the class as a whole for the next lesson may be the extent of what beginning science teachers are able do at this stage in their professional development.

The importance of quality feedback to student learning, which Wiggins (1998, p. 46) defined as “highly specific, highly descriptive…clear to the performer, and available...in terms of specific targets and standards” has been affirmed in numerous studies (e.g. Hattie & Timperley, 2007). For teachers, providing effective feedback depends on their accurate and deep understanding of the subject matter, and their ability to ask questions to elicit statements and assess understanding. How two third year teachers, both experts in their subject areas, use different formative assessments to help them provide useful feedback for their students, and how they used assessment data as feedback on the effectiveness of their teaching, is explored in the support of Claim #3.

**Claim #3: Adaptive and Responsive Teaching Was Achieved by Using Assessment Information as Feedback.**

As I described in the methods chapter, I selected two third-year teachers for the in-depth case studies because of their similar academic preparation within their fields, and their nearly identical teacher preparation. Both teachers were graduates from the
same cohort of the teacher preparation program, and both completed their student
teaching in the same high school. Upon graduation, Carl and Kari accepted teaching
positions in vastly different schools. Honeydew’s student population is culturally,
ethnically, and linguistically diverse, and a large majority of its students are from under-
resourced families. In contrast, Kari’s school, St. Sebastian, is a religious, all-boys
college-preparatory boarding school. Although St. Sebastian serves a larger proportion of
under-resourced students than its nearest public school, enrollment is largely limited to
students whose families can afford its tuition. Honeydew’s and St. Sebastian’s student
demographics and characteristics are detailed in the results chapter.

This section expands on the previous descriptions of Carl’s and Kari’s adaptive
assessment practices, and explains how teacher dispositions, aligned with teacher
preparation standards, support teacher adaptability in practice. Specifically, Carl adopted
a constructivist approach in planning his lessons, and included ongoing assessment and
opportunities for students to engage in the assessments. Kari adapted her teaching to
include more wait time and ask more questions, a professional development goal that
allowed her to involve more students in the interactive formative assessment process, and
which provided her with the flexibility she needed to guide student thinking.

Adaptive and responsive teaching varies by instructional setting. Many of
Carl’s assessments were planned and often centered on phenomenon; his discourse
practices focused on establishing student engagement. Most of Kari’s assessments were
spontaneous; her discourse practices relied on student engagement. These two teachers
purposefully used student assessment data as feedback, and modified their teaching in
response. Additionally, both teachers provided feedback to students during their
interactions in class to support conceptual development. Carl and Kari, however, approached their planned formative assessment very differently. Both teachers identified different components of assessment as professional development goals, and modified their instruction to meet these goals. Carl focused on developing a standards-based assessment program, and Kari focused on asking more questions and using more wait time. Evidence and argument in support of this claim is diagrammed in Figure 5.9 below.

**Figure 5.9:** Conceptual development of Claim #3. This is a diagrammatic representation of specific evidence presented to support the claim “Adaptive and responsive teaching was achieved by using assessment information as feedback.”

**Discussion of evidence: Interactive formative assessment.** Both Carl and Kari used “notice, recognize, react” to support conceptual and skill development as they
interactions with their students (Bell & Cowie, 2001, p. 86). Generally, Kari’s in-class discussions, opportunistic and brief student interviews, and periodic homework checks provided information about how her students were learning, and she relied on their cooperation and willingness to ask questions. Kari’s lesson modifications were spontaneous and addressed learning in the short term. Figure 5.10 places this discussion of Carl’s and Kari’s interactive formative assessment practices within the larger argument in support of Claim #3.

**Claim #3:** Adaptive and responsive teaching was achieved using assessment information as feedback.

**Interactive formative assessment**

- Carl & Kari: Consistently used notice-recognize-react to guide student conceptual & skills development
- Kari: Relied on student cooperation & contributions for whole-class discussions and individual support

Figure 5.10. Conceptual development of Claim #3. This is a diagrammatic representation of how adaptive and responsive teaching, in the form of interactive formative assessment, was achieved by using assessment information as feedback.

**Example: Kari adapted discussion with student input.** Kari’s expertise in chemistry allowed her to extemporaneously adjust in-class discussions of lab events and their connection to theoretical explanations. Her attentive experience as a university TA and third-year chemistry teacher provided her with enough familiarity with the curriculum she could anticipate where students would have difficulty. Kari planned opportunities for formative assessments by selecting homework questions or preparing lab activities, but she did not have to modify her normal practices to elicit student contributions in the way Carl did.
In one example of adaptive formative assessment, Kari changed lesson plans based on a quick assessment of student homework. Kari developed an efficient way to check student understanding as a group; she selected a sample of students' work to review as the class began, and used the information to adjust or completely change the lesson.

Kari’s use of student homework revealed her students were misunderstanding classification of reactions, the first step in predicting if a reaction would occur. Students were attempting to apply patterns of reactivity, but were using the same pattern for two different types of reactions. Kari recognized her students’ fundamental mistake, and also recognized the assessment she had planned for the day would not have served her students’ learning. Kari quickly improvised a review session of the content in place of the planned assessment, and used whole-class discussion to help her students develop the initial classification skills they needed to accurately predict reactions. Kari used assessment data from her quick scan of student work, as feedback from her students. She responded to the feedback by altering her lesson plan. During the lesson, she elicited statements of understanding from her student, and provided specific, descriptive feedback her student could understand, and a clear definition of success (Wiggins, 1998).

Discussion of evidence: Planned formative assessment. Carl and Kari used planned formative assessment very differently. Kari assigned homework problems to provide topics for whole-class discussions; Carl used conceptual change lessons, which required identification of student misunderstandings, a teacher demonstration or student activity, and a set of questions to use in response to anticipated but not guaranteed student responses. Figure 5.11 places this discussion of Carl’s and Kari’s planned formative assessment practices within the larger argument in support of Claim #3.
Example: *Carl and Kari apply “assessment for learning.”* Both teachers adapt their instruction to meet their students’ needs; however, they do so very differently. In contrast to Carl’s more constructivist instructional practices, discussed later in support of this claim, Kari’s chemistry instruction was more traditional, yet also responsive. Kari’s planned formative assessments were formal homework assignments. She used the homework in two ways: scanning selected students’ work to gauge how the class comprehended the content, or as a source of student questions for the introductory activity. For challenging concepts, Kari based decisions about individual lessons on her review of student homework. Most of Kari’s formative assessments were interactive; conversations with students were Kari’s way of “getting to the why,” as she told me during an interview, or as Lemke (1990) described it, as “finding the science in the dialogue” (p. 12). Kari relied on a mutual understanding of expected practices of teacher and student in a college-preparatory high school to support the whole class discussions.
Carl and Kari both planned “classroom discussions, questions and learning tasks” to reveal what their students were learning, and provided “feedback that move[d] learners forward” (Wiliam & Thompson, 2007, p. 63). Carl’s formative assessments also incorporated phenomenon associated with identified misconceptions, were strongly aligned with instructional goals, and included pre-prepared “learning intentions and criteria for success” he shared with his students (ibid). Kari provided the criteria for success during instruction, as she modeled skills and calculations to her chemistry students.

**Discussion of evidence: Adapting instructional practices based on data.** Carl and Kari demonstrated adaptability to changing student needs by setting and working toward professional development goals in their assessment practices, providing more time for students to answer questions and provide more complete answers, and, in Carl’s case, extensively modifying and integrating an assessment plan into all components of his teaching. Figure 5.12 shows the conceptual diagram connecting evidence of adaptive practices to the larger claim.
Both Carl and Kari adapted their instructional practice, by setting and working toward professional development goals that involved assessment practices. Carl developed an integrated assessment plan, and Kari incorporated more questions and longer wait times in her lessons. These professional development goals were not adaptations of teaching practices in response to assessment data of themselves; rather, they were Carl’s and Kari’s adaptations of their instructional practices to gather more and higher-quality assessment data.

Kari recognized providing adequate time for her students to respond to her questions was needed in order for her students to think about their answers. More thoughtful answers yielded more meaningful information about students’ understandings, which Kari used to provide more useful feedback.

Carl’s assessment system provided specific information about what and when students were learning, and Carl used the information to modify lessons in the short-term...
and long term. Additionally, Carl defined and described levels of performance as part of his planning process. By explicitly stating what he expected his students to demonstrate as evidence of learning, and by sharing his expectations with his students, Carl established “specific targets or standards” his students understood (Wiggins, 1998, p. 46).

Carl modified his instruction and his teaching practices continually and, over time, extensively, to meet his students’ needs. As discussed in support of the previous claims, Carl included alternative assessments of prior knowledge, adopted lessons that were aligned with a conceptual change model, and used assessment data to select specific science content to revisit at multiple points in the curriculum.

Discussion of evidence: Carl’s constructivist assessment plan. Similar to his adoption of conceptual change lessons, Carl’s adaptations to engage his students in classroom science talk were in response to his evaluation of his students’ low participation in assessment routines that required student input. As discussed previously, Carl included experiences for his students in order to affect conceptual change; however, his lessons also included opportunities for students to generate their own data for analysis. One observed lesson included data generation and analysis, which Carl used to develop specific data analysis skills. The skill building component of the lesson provided opportunities to interact with students and provide informational feedback as they developed their graph making and interpreting abilities.

Wiliam and Thompson’s (2007) framework joins instructional practice and assessment for learning in five steps:

1. “Clarifying and sharing learning intentions and criteria for success
2. Engineering effective classroom discussions, questions, and learning tasks that elicit evidence of learning
3. Providing feedback that moves learners forward
4. Activating students as instructional resources for one another
5. Activating students as the owners of their own learning” (p. xx) (p. 63)

Carl’s conceptual change lessons and skill-building lessons infused several components of constructivist teaching: materials, manipulation, and adult support (Williams & Veomett, 2007). Further, his assessment plan provided information about retained misconceptions and, from the proficiency descriptors for each learning objective, different levels of questions to ask his students. Carl’s “upstream planning of good questions” resulted from identifying learning outcomes, and created options he may have employed as he taught the lesson (Wiliam & Thompson, 2007, p. 66).

As evidenced by his consistent use of materials and equipment for students to manipulate and demonstrations for students to observe, Carl planned lessons to include student experiences. These experiences helped support student engagement and provided opportunities for Carl to interactively assess student learning. Carl explicitly stated he intended to “get them going, and ask them the [hard] questions” as part of the lesson, and indicated “that’s when they learn best.” Carl’s plan allowed him to respond and interact with students’ thinking as they interacted with the phenomenon and talked to their peers (Bell & Cowie, 2001).

As noted in support of the previous claim, Carl reported using a traditional approach to assessing student prior knowledge, the KWL chart, with little success. Carl hoped to generate enough contributions to determine what knowledge his students brought to the lesson; however, Carl’s expectation and his students’ did not align. Carl’s students, nearly all from under-resourced homes, and most belonging to ethnic minorities
under-represented in the science professions, “disaffiliated” from the expected practice (Carlone, Haun-Frank, & Webb, 2011, p. 479).

In their 2011 study, Carlone, Haun-Frank, & Webb report different levels of affiliation with “the smart science person” identity among urban elementary science students. High performing minority students “did not define themselves as smart science people,” and “actively disaffiliated themselves from those they considered smart science people” (p. 479).

Importantly, Carl’s view of his students as problem solvers, and of science as a problem solving process, positioned him to understand the failure of the KWL approach as I used wrong instrument for my students rather than my students don’t know anything. Carl noticed and responded to his students’ hesitance to contribute ideas publically, and modified his approach to assessing prior knowledge. Carl provided experiences for his students as a less threatening way to elicit student ideas.

Carl’s knowledge of specific constructivist teaching methods, such as conceptual change, coupled with beliefs aligned with InTASC core assessment and instructional strategies dispositions, supported his ability to adapt to a challenging instructional setting and maintain a positive teaching self-efficacy. Specific components in Carl’s teaching, detailed in Appendix D, indicate he was willing to use “multiple types of assessment processes to support, verify, and document learning,” respected “learners diverse strengths and needs,” and valued “the variety of ways people communicate” (CCSSO, 1994).
InTASC teacher preparation standards state that teachers should align assessments with learning objectives, use appropriate and varying forms of assessments, including formative assessments, and analyze of data to inform their planning. Further, the InTASC standards identify critical dispositions essential to effective application of assessments. Teachers should also engage students in the assessment process, use different types of assessments to measure learning, and apply assessment data to promote students’ growth (CCSSO, 1992). The two third-year teachers in this study demonstrated their understanding of underlying pedagogical principles of formative assessment, and demonstrated capacity to adapt their practices to meet the changing needs present in their instructional environment.

Implications and applications of these findings, and connections to current and literature related to these claims, are included in the next chapter.
Chapter 6: Implications and Conclusion

The three research questions of this study address two larger ideas. Researching RQ1 and RQ2 identified specific discourse and assessment practices where growth and challenges were encountered by the six participants in the study, and how teachers adapted to the challenges they encountered. The first section of this concluding chapter explains how teacher education programs can adapt to support beginning science teachers during their pre-service professional coursework and internships.

Research Question 1: In what areas do these teachers show developing strengths, and in what areas do they encounter challenges, in enacting inquiry-aligned discourse and assessment practices?

Research Question 2: To what extent, and how, did induction-phase physical science teachers employ inquiry-aligned discourse practices, and adapt to obstacles in implementing inquiry-aligned assessment practices?

The second large idea, addressed by RQ3, is an exploration of specific factors that resulted in exemplary assessment use by an early career teacher.

Research Question 2: How do third year teachers initiate and sustain classroom discourse, and how do they use discourse and formative assessment to support student learning and engagement?

**Key findings**

The key findings that resulted from my investigation of these questions revealed that the six teachers in the study: (a) showed developing strengths in inquiry-aligned discourse practices, specifically in questioning practices relative to the alignment of their assessment practices with inquiry (b) maintained high teaching self-efficacy in developing effective questions (c) faced challenges in responding to assessment data in a timely manner and (d) consistently omitted assessment of prior knowledge and opportunities for student reflection.
The apparent disconnection between the reform-based pedagogical principles developed in teacher education programs and the didactic teaching practices observed in classrooms has been noted by, among many others, Hunter and Markman (2017), Feldon (2007), and Kagan (1992). Hunter and Markman (2017) identified teachers’ goals as a stronger motive for making decisions than pedagogical or subject matter knowledge. Feldon (2007) asserts the highly complex and constantly changing nature of teaching increases teachers’ cognitive load beyond their capacity, and teachers revert to more didactic approaches. Kagan (1992) assigned blame to “inadequate procedural knowledge provided to novices in university courses” (p. 142). Feldon’s (2007) assertion that pre-service educational “approaches that emphasize theory may not emphasize the rehearsal of teaching skills prior to working in the classroom” (Feldon, 2007, p 130). For this reason, I focus the implications of this study on potential solutions that involve both pedagogical theory and in-field practice.

NRC’s *National Science Education Standards* (1996) Teaching Standard A: “Select science content and adapt and design curricula to meet the interests, knowledge, abilities and experiences of students” (p. 30). In order to select science content and responsively design curricula, teachers will need to assess their students’ current understandings. Assessing students’ prior knowledge is part of our national science teaching standards; further, asking students about their own experiences and including them in the lesson is a welcoming, inclusive action that takes little effort.

**Implications**

The implications of the findings of this study are of particular interest to teacher education program designers, university faculty, teacher educators, and district- and
school-level teacher supervisors and science curriculum directors, and secondary science teachers.

**Teacher education programs designers.** Teacher education program directors and faculty should use beginning teachers’ strengths as a starting point when addressing areas of weakness (Davis, Petish, & Smithey, 2006). For example, since teachers in this study felt generally confident in their ability to craft good questions for their students, a pre-service assessment project could require pre-service teachers to write, practice, and refine questions to elicit students’ prior knowledge. The importance of the practice could be developed in both teaching methods and adolescent psychology courses as PSTs explore the effects of prior experience and naive conceptions of understanding science concepts. Similarly, in-service professional development or an early-career mentorship program could focus on using eliciting questions when introducing new content.

**School-level teacher supervisors and district-level curriculum developers.** Five of the six teachers in this study worked in schools that required teachers to use introductory bellwork with every lesson. If districts provide bellwork content as part of their curriculum, prior knowledge questions could be included in the content. Similarly, extending the requirement to use bellwork as a closing activity can add opportunities for reflection questions. Simply requiring the practice is insufficient; teachers, especially new teachers, will need high quality questions that are both aligned and integrated into the content of the lesson, written in “kid friendly” language that is easy to modify to meet specific situations. Teachers will need professional development and collaboration time to plan for the varying levels of students’ understanding.
Bellwork, the start of class routine of asking review questions, can be used for prior knowledge assessment, and include questions more closely aligned with lesson content. If Carl’s experience with low participation in prior knowledge assessment routines is common in other settings, the prior knowledge assessments as part of bellwork must be engaging, constructed to elicit student statements, and placed strategically within the instructional unit in order to provide both assessment data and time for teachers to plan their responses. Further, building student confidence and their understanding of the usefulness of the practice may increase participation. Wang, Chow, Degol, and Eccles (2017) tracked changes in motivation for physics and chemistry in multiple sequential cohorts of 7-12 students. Wang, et al (2017) study did not include a diverse student population, but the authors speculated the group that showed declining motivation and engagement in physical sciences may have felt less competent in physical science and thus were less interested in the subjects. As school districts work to align their instruction with new science standards, they should develop activities that combine phenomenon, and an opportunity to interact with the phenomenon, with the elicitation questions.

Similarly, using bell work at the end of a lesson for reflective writing, for example, may involve non-science related obstacles. Language ability generally, and writing ability or willingness to write specifically, may limit the effectiveness of reflective writing for science students who need the practice the most. Further, reflective thinking is a cognitively advanced action (Loughran, 2002). Teachers who use reflective writing must provide temporary supports for students as they work at the edge of their abilities, such as sentence starters, as they learn to assess their own learning, set goals, and make plans that support their learning.
In-service science teachers. In-service science teachers can apply principles of constructivism in order to increase learning opportunities for students during a lesson. Science lessons should include materials and opportunities to manipulate them, a degree of self-determination and choice in how the materials are manipulated, and appropriately structured discussions to rehearse and refine their developing understandings (Williams & Vehomett, 2007). These opportunities to respond provide students with more a more equitable learning environment, teachers with more and more meaningful assessment data, and make the science lesson more representative of science practices.

Carl’s use of manipulatives and phenomenon promoted more student-to-student talk than when his lessons did not include a manipulative or phenomenon. The presence of a science artifact alone is not a marker of effective science lessons; it must be purposefully connected to the content of the lesson, unit, and overall framework of the course curriculum (NSES Teaching Standard A, 1996). Using an existing, or developing an assessment plan as part of a professional learning community, may provide beginning teachers with a more complete view of the yearlong framework of their curriculum, and help beginning teachers identify specific curricular content that has high explanatory power to emphasize throughout the curriculum.

Integrated assessment supported teacher adaptability

In this section, I identify specific factors which contributed to Carl’s instructional decisions: those decisions that led to constructivist or inquiry-aligned instruction, as well as those decisions that led to more traditional, teacher-centered instruction. Both third year teachers in the study were successful in their first three years, and their success continues as both conclude their sixth year teaching. Specifically, this section of the
concluding chapter identifies components of methods courses and internships experiences that supported Carl’s development of an adaptive and responsive assessment program.

Reflective practice builds on existing pedagogical knowledge and is guided by assessment data. In their synthesis of InSTASC and NSES, Davis, Petish, and Smithey (2006) combine planning, instructional strategies, and assessment into the theme of “understanding instruction” (p. 621). Carl, one of the two third year teachers, provided an important and perhaps singular view of how strong subject matter knowledge, pedagogical knowledge, and teacher dispositions positively interacted. Carl’s third year teaching included, to varying degrees, the four components of “ambitious teaching” (Windchitl & Calabrese-Barton, 2016, p. 1121). Carl consistently planned for “student engagement with important science ideas, elicit[ed] student ideas to shape instruction, support[ed] ongoing changes in student thinking,” and supported “students’ evidence-based explanations” (ibid).

Carl’s choice to use a conceptual change approach was informed by a lack of success in developing his students’ understandings so they aligned with scientific understandings. “How do I get them to see and struggle with contradictions?” Carl indicated without a phenomenon presented to counter their misconceptions, his students “were just memorizing random facts.” Carl’s decision to significantly modify his lesson structure indicates his knowledge of different instructional approaches at the time was sufficiently well-developed.

Based on his understanding of how students learn, Carl constructed these events to induce disequilibrium, and a sense of dissatisfaction with current understandings. “I needed to do something so that [the concept] was ingrained.” Carl recognized his
conceptual change lessons may not have resulted in a permanent alignment of student thought with scientific understanding. “Even now, I think they’re picking ‘heat rises’ [on multiple choice test items] because it’s the familiar answer.”

Not every misconception can be addressed; however, the key misconceptions that hinder understanding of the most important content within a subject need to be identified and addressed by science teachers. Engaging with common misconceptions about the content they teach will help science teachers confront their own misunderstandings, and help them select the most important content to emphasize as they plan. Conceptual change lessons require extensive planning and resources, and usually take more class time than direct instruction. Deep interaction with the science content and assessment data will help teachers prioritize content for conceptual change lessons.

**Integrating assessment and curriculum.** The National Research Council recommended integrating assessment within curriculum in order to improve opportunities for teachers to provide meaningful feedback, teachers and students to measure progress toward shared goals, and promote close alignment between assessments, instruction, and learning objectives (NRC, 2001). Further, a comprehensive, detailed assessment plan that separates ideas into discrete learning objectives, and includes performance descriptors for each, will help teachers develop a more comprehensive, long-term view of their curriculum (NRC, 2001, p. 8). This long-term view will help science teachers identify the most important content, the content that has the greatest explanatory power for content throughout the curriculum, and track student progress in mastering these essential understandings throughout the instructional period. A ‘spiral’ curriculum that introduces essential understandings, and returns to these topics periodically for reinforcement and
extension, in concert with a detailed assessment program, will provide students with opportunities to build their understanding, develop cross-cutting connections, discard novice understandings and develop more scientifically accurate understandings. The detailed assessment plan will allow teachers to track students’ understanding of these essential ideas, and tailor lessons to address misconceptions.

Developing a detailed integrated assessment plan can provide an opportunity for science teachers to think deeply about the organization of their subject. Using specific science learning objectives, and a description of mastery levels for each will provide a consistent method of measuring student learning, and provide teachers with the opportunity to “develop a framework of yearlong and short-term goals” for their students (NRC, 2001, p30).

Interacting with learning objectives, indicators of mastery, and sequence of concepts will advance teachers’ understanding of their curriculum (Loewenberg Ball, 2008) as well as refine and enhance their use of assessment data to adapt to students’ needs (NRC, 2001). The deep interaction with the content of their courses, informed by teachers’ knowledge of student misconceptions (e.g. Sadler & Sonnert, 2016) and current and detailed assessment data, will help teachers select the most important concepts in which to invest the significant time required for conceptual change lessons.

As described in detail in the previous chapters and in Appendix D, Carl’s development and application of his assessment program informed every aspect of his teaching practice. In constructing units “by backward design,” starting with learning outcomes first, and developing learning events to support the outcomes, as directed by Wiggins, Wiggins, and McTighe (2005, p. 13), Carl ensured alignment of standards,
instruction, and evaluation. At the time of the study, Carl’s state had not yet adopted new science standards aligned with NGSS; however, Carl’s identification of the NGSS cross-cutting concepts (e.g. energy) and his intentional inclusion of energy as a central concept in all of the physical science units reveals the strong connection between Carl’s SMK and his understanding of the science curriculum. From another perspective, identifying specific learning outcomes and describing proficiency levels for each ensured each lesson included at least two of Wiliam and Thompson’s (2007) five essential components of formative assessment: “clarifying and sharing learning intentions and criteria for success,” and “providing feedback that moves learners forward” (p. 8).

Carl used assessment data to respond to student needs along multiple time scales. Identifying and describing evidence for different levels of student understanding allowed Carl to quickly adapt to student needs during a lesson; he had a question for students who needed additional challenges, as well as prompts for students who were struggling. In the longer view, Carl used assessment data for specific and commonly misunderstood concepts, to identify teaching practices to modify from year to year. For example, Carl monitored assessment data, and in conjunction with pedagogical knowledge developed through a misconceptions investigation and an emphasis on formative assessment in his science teaching methods courses, he identified and responded to students’ persistent misunderstanding of heat transfer.

**Current Applications of Study’s Findings**

In response to initial data for this study, I modified and extended the assessment component of science teaching methods course to include three lesson studies (Hurd & Lewis, 2011). Each of the three lesson studies focuses on one component of assessment
the participants in this study found particularly challenging. Preservice science teachers are required to plan, teach, critique, revise, and re-teach lessons in clinical settings that focus on assessing prior knowledge, providing opportunities for students to reflect on their learning, and respond to anticipated student misunderstandings about a common misconception related to the lesson topic.

Similarly, I included an analysis of teacher questions in the science teaching methods course and internship. The question analysis project spans two semesters; in the first semester, PSTs select a topic for unit-level planning, and identify common misconceptions associated with the topic. PSTs interview high school students about the misconceptions in order to develop an understanding of how students think and why some misconceptions are so pervasive and resistant to change. Later, PSTs develop a lesson where a phenomenon is used, either as a demonstration or as a student activity, which would “bring out” student misconceptions. PSTs plan questions to elicit student contributions, extend answers with follow-up questions, and direct students to a contradiction in what they observe and in what they stated. PSTs record the lesson, then select between six and eight minutes of the lesson to transcribe. PSTs analyze their questions for question type and intent, and wait time (Rowe, 1986). By integrating the theoretical and potentially abstract practices with in-field applications, PSTs tie the “pedagogy emphasized in teacher education to authentic goal” of a desired instructional practice (Hunter & Markman, 2017, p 728).

**Near Future Extensions of Current Study**

Davis, Petish, and Smithey (2006) suggest “engaging new teachers in effective science teaching while they are still students” may support development of effective
teaching practices (p. 636). Applications of this study’s findings include extending methods and internship experiences into the first and second years of teachers’ early careers by establishing science-specific professional development with the STEP’s partner institutions. For example, beginning teachers, working within a professional learning community, can conduct lesson studies as they did as pre-service teachers, in order to develop and refine specific instructional practices. In addition to highly personalized and self-directed professional development, the lesson study can produce evidence of professional growth that beginning teachers and their administrators can use to identify new professional goals.

Other extensions of the current study can include investigation of how and to what extent do new teachers enact assessment and discourse practices they developed during their lesson study projects in their methods courses. How do new teachers assess prior knowledge and respond to assessment data, and how often do they provide opportunities for their students to reflect, and how do teachers incorporate student reflection into their curriculum?

Limitations

The small sample size, as well as the cross-sectional sample restricts generalization of quantitative data beyond these six physical science teachers’ instructional practices. Additionally, five or six observed lessons per year per participant may not adequately capture a representative sampling of instructional practices. At the time of this study, the observation protocol used by the research team did not include information about lessons immediately preceding or following the observed lesson (Lewis, et al, 2016). Teacher self-efficacy survey data was self-reported, and may have
been exaggerated or overly affected by the mood of the respondent at the time of the survey.

The qualitative aspects of this study were undertaken to develop a better understanding of the highly situated and contextualized decisions and perspectives of the two case study science teachers. Qualitative data was generated largely from participants’ self-reported statements, and participants may have exaggerated negative or self-critical statements.

Conclusion

Using an integrated assessment plan consistently supports teachers’ ability to apply their content knowledge to the changing needs of their students, supports a long-term view of curriculum, which in turn, appears to bolster the effect of teacher experience. Incorporating phenomenon in science lessons, especially in concert with conceptual change, appears to support in-class science talk and provides multiple opportunities for teachers to monitor student learning interactively. Overall, when assessment is integrated into curriculum, students’ potential paths to understanding can be more easily mapped, and used as a choose-your-own adventure version of science class, based on students’ needs and developing understandings.


Council of Chief State School Officers (2017). InTASC Model Core Teaching Standards and Learning Progressions for Teachers 1.0.


Duit, R. (2016). The constructivist view in science education—what it has to offer and what should not be expected from it. *Investigações em ensino de ciências*, 1(1), 40-75.


Rowe, M. B. (1986). Wait time: slowing down may be a way of speeding up!. *Journal of teacher education, 37*(1), 43-50.


Appendix A: IRB Approval Letter

October 6, 2014

Elizabeth Lewis
Teaching, Learning and Teacher Education
212 HENZ, UNL, 68588-0355

Aaron Musson
Teaching, Learning and Teacher Education
18906 BENTON BLVD ELKHORN, NE 68022

IRB Number: 20141014446 EX
Project ID: 14446
Project Title: Physical Science Teachers Discourse Decisions

Dear Elizabeth:

This letter is to officially notify you of the certification of exemption of your project by the Institutional Review Board (IRB) for the Protection of Human Subjects. It is the Board's opinion that you have provided adequate safeguards for the rights and welfare of the participants in this study based on the information provided. Your proposal is in compliance with this institution's Federal Wide Assurance 00002258 and the DHHS Regulations for the Protection of Human Subjects (45 CFR 46) and has been classified as Exempt Category 1 and 2.

You are authorized to implement this study as of the Date of Exemption Determination: 10/06/2014.

1. Your stamped and approved informed consent documents have been uploaded to NUgrant (file with “Approved.pdf in the form files). Please use these documents to distribute to participants. If you need to make changes to the informed consent documents, please submit the revised documents to the IRB for review and approval prior to using them.

We wish to remind you that the principal investigator is responsible for reporting to this Board any of the following events within 48 hours of the event:
* Any serious event (including on-site and off-site adverse events, injuries, side effects, deaths, or other problems) which in the opinion of the local investigator was unanticipated, involved risk to subjects or others, and was possibly related to the research procedures;
* Any serious accidental or unintentional change to the IRB-approved protocol that involves risk or has the potential to recur;
* Any publication in the literature, safety monitoring report, interim result or other
finding that indicates an unexpected change to the risk/benefit ratio of the research;  
* Any breach in confidentiality or compromise in data privacy related to the subject or others; or
* Any complaint of a subject that indicates an unanticipated risk or that cannot be resolved by the research staff.

This project should be conducted in full accordance with all applicable sections of the IRB Guidelines and you should notify the IRB immediately of any proposed changes that may affect the exempt status of your research project. You should report any unanticipated problems involving risks to the participants or others to the Board.

If you have any questions, please contact the IRB office at 472-6965.

Sincerely,

Becky R. Freeman, CIP
for the IRB
Appendix B: Participant Consent Forms

TEACHER INFORMED CONSENT FORM

Introduction

The purposes of this form are to provide you, as a prospective research study participant, information that may affect your decision as to whether or not to participate in this research and to record the consent of those who agree to be involved in the study.

Purpose of the Research

The purpose of this research is to investigate the ways teachers plan for and use questions in their teaching practices and the effect these questions have on patterns of student talk in the classroom. Data will be gathered from scripted and semi-scripted interviews, teacher-generated lesson plans, classroom observations that include audio recording of teacher talk and brief follow-up interviews, and observations of student communication patterns during instruction.

Description of Research Study

If you decide to participate, then you will join a study of science teachers’ use of questions in their teaching. You may elect to skip any questions during the interviews. If you say YES, then your participation will involve approximately six hours of interviews (three hour-long interviews and short follow-up interviews after observed lessons) and allowing the researcher access to your classroom for observation and to your lesson plans and instructional materials such as presentation slides and handouts used in class. By agreeing to be a part of this study, you give permission to the researcher, Aaron Musson, to interview you, collect artifacts that inform the teaching methods you use during your work, and to visit your classroom to observe you teach. The research procedures you will participate in are described below.

Procedures

Participation in this study will include the following:

* three interviews lasting approximately an hour each. The first interview will focus on your thoughts about education. Two later interviews will focus on how you plan lessons, and your perceptions of your teaching environment.
* coordinating with the researcher to select units and lessons for observations
* providing the researcher with electronic copies of your lesson plans and access to other instructional materials for each observed class
* allowing observations of at most thirty class periods, during which you will wear a microphone for audio recording of your speech during class
* allowing the researcher to observe and video record lessons
* allowing the researcher to photograph your empty classroom, lab equipment or demonstration materials you use during observed lessons
* answering brief follow-up questions about each lesson’s intended instructional goals and providing insight to your decision making during your instruction. These follow-up interviews will occur at the conclusion of the observed lessons or at a convenient time for you after the lesson during the day the class is observed.

118 Hentzlik Hall / P.O. Box 803565 / Lincoln, NE 68588-0356 / (402) 472-2231 / FAX (402) 472-2837
Risks and/or Discomforts

There are no known risks or discomforts associated with this research.

Benefits

Participating in this research/evaluation will inform an understanding of teacher educational beliefs, planning for instruction and implementing instructional practices. At the conclusion of the investigation and at your request the researcher will make the transcripts of your talk during the observed lessons available to you.

Confidentiality

All information obtained in this study is strictly confidential. The results of this research study may be used in reports, presentations, and publications, but the researcher will not identify you. In order to maintain confidentiality of your responses, the researcher will use pseudonyms for individuals and associated institutions in any presentations and/or publications. Any audio recordings of the interviews will be kept in a secured location along with transcriptions of the data. The audio files will be destroyed a year after the last paper has been published using the data.

Compensation

There is no compensation for participation in this research study.

Opportunity to ask Questions

You may ask any questions concerning this research/evaluation and have those questions answered before agreeing to participate in or during the study. Or you may call the investigator at any time: Aaron Musson (402-516-8814). Dr. Beth Lewis is supervising this study, and you may contact her through email (btlewis@nml.edu) or her office phone (402-472-2251). You may also contact the University of Nebraska-Lincoln’s Institutional Review Board at (402) 472-6965 if you have any questions about your rights as a research participant.

Freedom to Withdraw

Participation in this study is completely voluntary. It is okay for you to say NO. Even if you say YES now, you are free to say NO later, and withdraw from the study at any time. Your decision will not affect your relationship with the researcher or the University of Nebraska-Lincoln or your school district or otherwise cause a loss of benefits to which you might otherwise be entitled. If you withdraw from the study, any interview data that has been collected from you will be destroyed at that time and will not be used in any presentations or reports generated from the data.

Consent, Right to Receive a Copy

This form explains the nature, demands, benefits and any risk of the project. By signing this form you agree knowingly to assume any risks involved. Remember, your participation is voluntary. You may choose not to participate or to withdraw your consent and discontinue participation at any time without penalty or loss of benefit. In signing this consent form, you are not waiving any legal claims, rights, or remedies. A copy of this consent form will be given to you.
Signature of Participant

Initial if you agree to be audio recorded, video recorded and photographed during the interviews. Your signature below indicates that you consent to participate in the above study.

Participant's printed name: Andrew J. Becker

Participant's signature: [Signature]

Date: 10/21/14

Signature of Participant

Initial if you agree to be audio recorded, video recorded and photographed during the interviews. Your signature below indicates that you consent to participate in the above study.

Participant's printed name: Leah Zohner

Participant's signature: [Signature]

Date: 10/23/2014
Dear Parent or Guardian:

My name is Aaron Musson, and I am a graduate student at the University of Nebraska-Lincoln. Over the past three years I have worked with your student’s science teacher, Andrew Benker. I am currently working on my own research exploring the decisions science teachers make about classroom discussions as they teach, and Mr. Benker has agreed to help me.

I plan to use video recording in Mr. Benker's class. The video camera will always be focused on Mr. Benker. I will place the video camera at the back of the room to keep students from appearing in the video. However, it is possible that your student might appear in the video recordings. I will use the video only to study the conversations in the classroom, and your student will not be identified.

I will show Mr. Benker short clips of his teaching and verbal interactions with students so I can better understand his decisions as he teaches. Mr. Benker will be the focus of the short clips, but your student may briefly appear in the video or your student’s voice may be audible in the video. I will carefully choose video clips so students are shown as little as possible. The video will only be used to show Mr. Benker the brief video clips, and to confirm my notes from observing the science lesson.

There are no known risks or discomforts associated with this research. I do want you to be aware of the research and its low-level of risk, but there is nothing recorded other than the usual activities in the classroom. I will keep all video recordings in a secure location, and the files will be password protected. The video recordings will only be used for research purposes. If you do not want your child to appear in the video, Mr. Benker and I will make sure your child is seated off camera.

I will send an official consent form home with your student. Please review the form, and feel free to contact me (aaronmusson@gmail.com, 402-516-8814) if you have any questions about the procedures. Dr. Beth Lewis is supervising the study, and you may contact her via email (elewis3@unl.edu) or at her office phone (402-472-2251).

Thank you for your consideration.

Sincerely,

Aaron Musson

Program, Research and Teaching Assistant
Department of Teaching, Learning and Teacher Education
University of Nebraska-Lincoln
Project Title: Physical Science Teachers Discourse Decisions

Sponsoring Organization: University of Nebraska-Lincoln, Department of Teaching, Learning and Teacher Education.

Principal Researcher: Aaron Musson, under the supervision of Dr. Elizabeth Lewis (elewis3@unl.edu, 402-472-2251)

Project Location: Benson Magnet High School

Introduction: The purpose of this form is to provide you, as the parent or legal guardian of a student at Benson Magnet High School, information that may affect your decision whether or not to allow your child’s participation in a research study. The purpose of this research is to investigate how physical science teachers use in-class discussion and questions as they teach science. Your child/legal ward is invited to participate in this study because his/her teacher is a former UNL student and is currently teaching physical science. The study has been approved by Omaha Public Schools Division of Research, but is not sponsored or conducted by Omaha Public Schools.

Procedure: The researcher, a UNL graduate student, will visit your child’s science classroom during the 2014-2015 school year, and will audio and video record the teacher during science lessons. The video will focus on the teacher and not on individual students in the classroom. The researcher will share short video clips of the participating teacher’s interactions with students as part of short interviews about his/her decisions about teaching. Only these short clips will be shared with the participating teacher. The rest of the video will not be shared with the teacher or with other school personnel. The video will only be used for the purpose of observing the teacher’s science lesson. The video camera will be placed so students are not identifiable. Children whose parents do not want their child to appear in the video of their teacher’s classroom instruction will be seated off camera during those lessons that are being videotaped.

Benefits: There are no direct benefits to your child/legal ward as a research participant. However, the results of these science lesson observations will help the researchers understand how science teachers use classroom discussions and questions to help students learn science.

Risks and/or Discomforts: There are no known risks or discomforts associated with this research. We do want parents to be aware of the research and its low-level of risk, but there is nothing recorded other than the usual activities in the classroom.

Confidentiality: Any information obtained during this study that could identify your child/legal ward will be kept strictly confidential by the researcher. Students will not be identified by name.
University of Nebraska at Lincoln
Department of Teaching, Learning and Teacher Education
Attn: Aaron Musson
118 Hendricks Hall
Lincoln NE 68588-0355

Re: Beginning physical science teachers’ use of and decisions about discourse practices during chemistry lessons

Dear Aaron Musson:

The Research Review Committee has reviewed your research proposal that involves the collection of data from students, teachers, and administrators through processes such as the examination and/or collection of information from files or records, direct observation, focus groups, surveys, or individual interviews.

We believe your study has merit and permission is granted for you to proceed under the following conditions:

- The Principal of Benson High School agrees to your study.
- Participating teacher agrees to your study.
- Parents of students in the study will complete a passive consent form if they are uncomfortable with the possibility of their child being videotaped. You will submit this form to Lindsey Bandow, in the Research Division.
- You, the researcher, will be responsible for distributing and collecting parent consent forms. This will not be the responsibility of the schools.
- In the reporting of the data/results, teachers, students, schools, and district will not be personally identifiable.
- You will be willing to share results of your study with OPS.
- The findings of the study must be shared with the Research Review Committee for review before being presented or released for publication.
- The collected data will be destroyed after the project has been completed.

Please note: The research proposal is preliminarily approved pending background checks and completion of necessary adherence of steps provided by Erin Perry (402-557-2323), Human Resources, regarding observing in the classroom.

Thank you for your interest and support in meeting the needs of our students.

Best wishes.

Sincerely,

Janet Zahm
Instructional Research Administrator
IZM

pc: Anita Harkins-Baldwin
Erin Perry
Appendix D

Methods for Case Construction

The case studies of the two third-year teachers is included in this appendix. Tables and figures are noted as if they were included in Chapters 3 and 4.

Constructing teacher case studies

The data sources and conceptual framework I used to construct Carl’s and Kari’s cases is shown in Figure 3.5. Subject matter knowledge was approximated using in-field credit hours and GPA, and scores on the MOSART chemistry and physics exams. Teaching self-efficacy was measured using TSES data collected at the conclusion of Carl’s and Kari’s first, second, and third years of teaching. I conducted an initial teacher beliefs interview, and explored Carl’s and Kari’s beliefs about teaching and learning science during the post-lesson cognitive interviews, stimulated recall interviews, and during the post-study member-checking interview. I relied on teacher statements about their perceptions of curricular factors that influenced their teaching decisions, and supplemented these statements using district curricular maps when available. I used publically available school-level data from the state’s department of education website to describe Honeydew’s student demographics, size, and test performance, and statements from personal communication with St. Sebastian’s principal to describe Kari’s learning community. My own experience as a science teacher at St. Sebastian and Honeydew provided information, and more generally, an understanding of the instructional environments in which Carl and Kari worked.
Teacher beliefs interview. The initial teaching beliefs interview with third-year physical science teachers Carl and Kari was semi-structured (questions found in Appendix X) and adapted from the Teacher Beliefs Interview (TBI) developed by Rohrig and Luft (2007). The TBI focused on Carl’s and Kari’s views of assessment, factors affecting their curricular decisions, their understanding of their learning environment, and how they view themselves as teachers. The questions were intentionally open-ended, and participants provided as much information about what they considered the important aspects of their teaching as time allowed (Kvale, 1983). Kari’s answers were direct, and her TBI generated 365 statements. In contrast, Carl had more time available to talk at the
end of the school day, and his TBI generated about 1100 statements. I wrote initial memos immediately after the interviews, and refined the memos during the transcription process.

**Observations of lessons.** I observed seven of Carl’s lessons, and eight of Kari’s. After I had observed about three lessons from each participant, I met with Carl and Kari individually to determine what lessons I should observe in order to ensure I captured a representative sample of their teaching in the data set.

I video recorded each lesson I observed, and Carl and Kari wore a small microphone and recorder as they taught. I wrote field notes during my observation, and noted instances when Carl or Kari appeared to make instructional decisions, or at roughly five-minute intervals. I used the points of interest for post observation cognitive interviews.

**Post-observation cognitive interviews.** As I observed each lesson, I noted specific points of interest. Points of interest were usually moments in the lesson where the teacher appeared to make an instructional decision that resulted in a change during the lesson. During the short post-observation interview, I reminded teachers of the event (Lyle, 2003). For example, I asked teachers “you were here, about half-way into the period, and you noticed Student X had problems with…what were you watching for or listening for at that moment?” Carl and Kari kept their audio recorders on during these interviews, and I later transcribed their responses into my observation notes for the lesson.

**Video clip cognitive interviews.** I selected six lesson events from Carl’s and Kari’s video recorded lessons for a stimulated-recall interview, a “video clip interview”
(VCI) (Dempsey, 2010). I selected the short video clips after the observation period, and used my observation notes and memos, and teacher statements during the post observation cognitive interviews to identify important “inflection points” where the direction of instruction seemed to change in response to a teacher action. I selected the video clips purposefully to ensure I had a representative sampling of each teacher’s instructional practices. For example, I included video clips of Kari’s interactions with students during lab activities, as she responded to student questions, and interactions she had with students during in-class work time or during demonstrations. I included instances where teachers successfully implemented their decisions, as well as instances where the lesson event did not appear to happen as planned. I decided to use six video clips in order to keep the interview to an hour. Carl and Kari confirmed in a follow-up member-checking interview the six video clips represented their typical teaching habits.

Prior to the VCI, I transcribed teacher-student dialogue. I provided teachers with the transcription as they watched the video clip showing their interactions with students. Carl and Kari described their decisions, what they considered before and during the interchanges, and their intended outcome from the interchange. I video recorded both VCIs to capture teacher responses and descriptions of the lesson events.

Analysis of teacher belief statements about teaching and learning. I began analysis of the TBI recordings as I transcribed audio while I concurrently re-viewed the video recordings of each lesson. During this initial analysis, I made initial memos, which informed axial coding categories (Miles & Huberman, 1994). Based on two years of observations and a pilot study prior to this investigation with these two teachers, I anticipated Carl and Kari would discuss their teaching experiences, and their perceptions
of obstacles to and support for their intended teaching practices. I identified “Experience” and “Teacher Self Efficacy” as *a priori* codes.

Based on my familiarity with the two participants, and the memos recorded during transcription, I identified subject matter knowledge, pedagogical knowledge, classroom management, and reflection as the *a priori* codes for “Experience.” My initial codes for Teacher Self Efficacy were “obstacles” and “supports,” and after I reviewed the interview transcription memos, I added “opportunities” and “beliefs” to the *a priori* codes for initial analysis.

I separately analyzed Carl’s and Kari’s transcribed interviews. I divided interview transcriptions into 5-word phrase, and transferred these into a spreadsheet, where I assigned each phrase an *a priori* category. I grouped phrases within each a priori category, and copied the phrases to a separate spreadsheet for axial coding. A deeper description of the coding categorization and thematic analysis is found in the results chapter.

I extracted explicit statements about teachers’ instructional decisions, their intent as they enacted their decisions, and the factors they were considering as they made and enacted their decisions from multiple interviews (TBI, post-observation cognitive interviews, video cognitive interviews, and post-study member checking interviews) and I used excerpts from lessons to construct plausible explanations of each teacher’s instructional decisions.
Carl’s Case

Carl was one of fourteen teacher candidates awarded an NSF Robert Noyce Teacher Scholarship, and a member of the initial cohort of science teachers graduated from the university’s STEP program. The STEP program was designed to answer Noyce program’s charter to recruit practicing scientists, provide them with state-of-practice pedagogy in preparation to teach in high-need schools, with an emphasis on constructivist teaching principles. At Honeydew, Carl demonstrated the use of the pedagogical and professional principles emphasized during STEP coursework and teaching internships. Further, Carl’s growth in his teaching self-efficacy can be attributed, in part, to his application of constructivist principles and assessment practices. Carl’s beliefs about teaching and learning, and his professional outlook are particularly well-suited for teaching science to under-resourced children, and for his persistence of practice and professional development.

Carl uses an integrated standards-based formative assessment program to promote concept development, sustain student engagement and build student self-efficacy and positive academic dispositions. Carl’s assessment program provides him with evidence his teaching decisions result in learning gains for his students, and supports his own teaching self-efficacy and persistence in a challenging instructional environment by providing him with evidence of his own effectiveness. The following case study reveals, explores, and explains the key factors he considers in his practice.

“On a good day, I’m an agitator.” Carl’s preferred teaching approach closely matches his stated belief about how students learn science. According to Carl, students learn science in a more-or-less sequential process when their learning is mediated by a teacher.
The student (1) is exposed to a phenomenon, (2) asked how it works, and to explicitly state a prediction (3) tests the prediction (4) compares prediction to observations (5) repeats test and refines prediction many times, and refines the explanation. I observed seven of Carl’s lessons, and in six of the seven lessons, Carl included a physical phenomenon he used to challenge pre- or mis-conceptions, or to provide students with a mystery to understand.

The events in the lesson excerpt used in this case study occurred after Carl and a student needed a moment in the hallway to review Honeydew’s cell phone policy; Carl had asked his student several times to put away the phone. Carl paused his instruction, directed the rest of the class to another task, then returned and tried to get the rest of the lesson back on track. During our post-observation conversation, Carl told me the interruption

“definitely made me think about how to get things together, because at that point, I’m also trying to figure out how much of [the lesson] I can keep going, and what I have to cut out. I want to get the point across, but now I have to make up some time. Now my brain has two or three things going; it’s deciding ‘how much slack am I going to cut him?’ The front of my brain is the one doing the monologue. It puts an interesting burden on what I’m doing.”

During the lesson, I noticed the “cell phone student” was actively attentive to the demonstration and involved in the discussion. I asked Carl about the turn around as we viewed the video recording of the lesson together:

“he’s one of those students…if I could convince him that academics is what he wants to focus on, he’d be fine, a “B” or “C” student with minimal effort. But he wants to be social; that’s what his world is now. The moment I can get that [hook], or I can convince him ‘this is in your best interest’ I can get some work from him. So today, apparently, I caught his [attention].”

Carl’s hallway conversations end with an invitation to return to class when he and his student agree upon acceptable behavior. Carl explained to me he believes any student
can understand and learn science once the student decides to care about the question and focus on finding an answer.

In the initial teacher beliefs interview, Carl told me he was thankful he felt confident in his content area, and was able to consider classroom and behavior management without needing to concentrate much on getting the physics right.

The lesson excerpt below typifies Carl’s use of pedagogy, subject matter knowledge, and his understanding of his students’ specific learning needs on “a good day.”

<table>
<thead>
<tr>
<th>Turn</th>
<th>Speaker</th>
<th>Utterance</th>
<th>Teacher intent</th>
</tr>
</thead>
<tbody>
<tr>
<td>[1]</td>
<td>Carl:</td>
<td>Raise your hand. Does heat rise?</td>
<td></td>
</tr>
<tr>
<td>[2]</td>
<td>Carl:</td>
<td>OK, this is one of the biggest areas where you will make mistakes. Everybody says heat rises, right? Now let’s think about that. [Waits.] Which has more heat, the dry ice or my hand?</td>
<td>Indexes the misconception, provides thinking time, asks for student predictions</td>
</tr>
<tr>
<td>[4]</td>
<td>Carl:</td>
<td>OK, so heat rises, right? [Holds dry ice in palm, so hand is under the dry ice.] So the heat goes from my hand into the dry ice and it does what?</td>
<td>Carl re-states the misconception, and provides a situation where the misconception may be valid.</td>
</tr>
<tr>
<td>[6]</td>
<td>Carl:</td>
<td>It melts. And as the heat starts to leave my hand, it starts to feel cold. So heat rises. So if I put my hand on top, it doesn’t get cold, right? Cause heat rises.</td>
<td>Carl told me he accepted “it melts” as a reasonable answer; he did not expect students to use “sublimate.”</td>
</tr>
<tr>
<td>[8]</td>
<td>Carl:</td>
<td>Hold on a second, you guys just said</td>
<td>Carl is re-voicing</td>
</tr>
</tbody>
</table>
heat rises. The heat is in my hand, my hand is above the dry ice, the heat goes up, so it stays in my hand.

[9] Several students: It’ll still be cold.

[10] Carl: [Changes holding position so he’s gripping the dry ice with his hand over it.] So my hand won’t get cold?

[11] Student B: Oh my god. When you’re holding it your hand will still get cold. ‘Cause the dry ice is cold.


[13] Student B: Heat rises, but ...

[14] Carl: So the heat in my body can go down, but .... You guys see this? We’re starting to have a problem here.

I identified a chain of factors that provide a plausible explanation of Carl’s enacted decisions about teaching heat transfer. Carl’s classes required more behavior management than his student teaching classes, and the “hallway conversations” he used to redirect inappropriate behavior were not uncommon during the lessons I observed. Carl told me (1) his understanding of physics allowed him to focus on managing the classroom and student behavior. He also identified (2) energy as a central idea in all areas of science, and understanding energy make it easier for students to understand other content. Carl was particularly attentive to his (3) assessment plan, and carefully constructed lessons to address required curricular content with developmentally appropriate and challenging learning events. Carl explained he aligned assessments with
the required curricular content, (4) spiraled the curriculum by using assessment data and the district’s scope and sequence document to identify content to re-address in later lessons. In this particular lesson, Carl developed understanding of heat as energy, in support of energy as a continuing theme used throughout semester.

Carl (13) planned the demonstration and teacher questions in order to generate student statements, which he used to (5) assess their understanding of heat and heat transfer. Carl justified his use of instructional time for the lengthy demonstration and discussion based on (6) consistent monitoring of student performance on specific learning objectives and (7) his prior experience with persistent student misconceptions and ineffectiveness of simply explaining the concept.

During the lesson, Carl provided (10) a physical event for his students (11) to observe and describe. Carl (12) prompted his students to make explicit statements of their understanding, then used his (9) understanding of common misconceptions about heat and heat transfer to induce (8) disequilibrium between the observed events and his students’ understandings.

| Table 4L2x: SMK and PK interactions with Carl’s enacted assessment and discourse decisions |
|---------------------------------|---------------------------------|---------------------------------|
| **Internal factors** | **Teacher decisions** | **Observed practices** |
| **SMK** | | |
| Content area expertise | | |
| 1 allowed Carl to focus on class management | | |
| | | **Assessment** |
| | | IFA as assessment conversation in developing conceptual change |
| | | PFA to evaluate persistence of misconception, success of lesson, need to revisit the concept later in curriculum |
| | | **5** |
| | | **6** |
Energy as central idea across content areas

Structured required content into a spiral curriculum in order to emphasize and revisit essential content

Reflective practice: evaluated approaches and identified what to modify from year to year

PK
Assessment practices: alignment of learning objectives, instructional practices, and assessments

Learning theory: Disequilibrium and transferability

Provided an interesting physical event to support student engagement with the concept

Prompted students to observe and describe phenomenon

Conceptual change: Identified common misconceptions about heat, Methods 1 course emphasized conceptual change teaching model

Prompted students to state a position or make a statement of their understanding

Used pre-planned whole-class discussion questions based on assessment criteria

Carl’s pedagogy and views of science align with constructivism. Carl’s beliefs about teaching and learning science align strongly with constructivism. According to Carl, students need to “go through the motions of doing science” by identifying a problem, developing a process to address the problem, and applying the process consistently and repetitively in order to construct meaning from the experience. Carl told me he strongly believed anyone can learn science, provided they make the decision to do so. “If they care and focus on a problem, they can work through the process of problem solving.” In Carl’s perspective, students choose to be curious and engaged; once students are curious about and engaged with a question, they systematically work through ways to answer the question. For Carl, as he stated in his end-of-program teaching philosophy statement, learning through inquiry was more than “just an idea to be aspired to” and
perhaps applied in “best case scenarios.” At the conclusion of his teacher preparation, Carl viewed the constructivist approach as “essential in even the most challenged schools,” and considered inquiry learning as “a means to narrow the gap for minority, SPED, and ELL students and even aids traditionally strong students.”

Carl’s approach to learning science parallels his view of how science works; Carl sees science is the best “tool” to solve problems. Learning science helps students build a common understanding of reality, and provides a problem-solving approach that can be applied to different questions in all areas. Carl offered an example of “common understanding” by explaining the importance of hand washing using the germ theory. Without a basic understanding the germ theory, washing hands to prevent disease transmission is “just a ritual. It has no [deeper] meaning.”

For Carl, laboratory events should be investigations, rather than verification of teacher-presented material: “Discovery is probably better than proving concepts,” students should develop methods, and the teacher should “let [students] be wrong” to provide opportunities to evaluate and refine their approach. From Carl’s perspective, the science content he teaches needs to be relevant to a problem students recognize. As their teacher, Carl feels he needs to keep ideas concrete, allow his students to “ask why,” and prompt them to develop an answer.

Carl believes the social component of learning is important in developing curiosity and a “learner mentality.” Students should interact with respected adults who are working out problems in non-school contexts. According to Carl, limited interactions with problem solving may lead a student to believe if s/he doesn’t understand an idea initially, then s/he cannot learn the idea at all. Carl believes students may not have been
conditioned to ask “how things work,” perhaps because their parents also have limited experience asking “why?” Additionally, Carl emphasizes peer support and peer instruction in his lessons, because he wants students to “feel valued for what they know, and feel it’s OK to do well. Students seem to learn better from peers.”

**Obstacles and supports: “Change takes time.”** Honeydew is one of seven high schools in Urban School District, and, according to the State Educational Agency’s report, had high poverty (81%) and student mobility (33%) rates during the year of the study. Honeydew is a majority minority school (74% minority). In the year of this study, and for two years prior to this study, Honeydew was designated as a “persistently lowest achieving school,” which means it was in the lowest 5% of schools in its state for three consecutive years as ranked by the SEA. Carl and his colleagues were acutely aware of the school’s scores and the scrutiny it receives from the SEA and public. Carl told me “It’s hard, maybe impossible, to take a group of kids…and turn them into crack physical science kids that pass [the state tests] at the end of the year. Especially when you throw in all the other challenges that Honeydew has. Thirty percent mobility rate. We have one of the highest refugee populations, and one of the highest non-English speaking populations, and one of the highest special ed populations. Throw all that in with an eighty percent free and reduced lunch rate; we’ve got everything you can think of to make your job harder, stacked against us.”

In our post-study member-checking interview, Carl stated his goal “is to get the biggest change out of my students,” and identified the previous year’s modest increase in state test scores as a “win.” Carl applies his incremental improvement approach to increasing enrollment in physics and AP physics classes, modifying curriculum from year to year, and building his students’ self efficacy.

As we watched the video of the dry ice lesson excerpt, Carl told me he was generally satisfied with student participation as the class was engaged in the
demonstration and student-to-teacher interactions, but he would like to have more
student-to-student science talk. Carl chose to use the dry ice demonstration to teach heat
transfer because “heat rises” is a common and persistent misconception. As we watched
the video, Carl told me he had addressed the misconception in different ways during the
previous two years, and the assessment data revealed the approaches were not successful
in changing student understanding of the concept.

I tried the year before, “heat doesn’t rise; hot air rises; heat goes from hot to
cold.” I had the whole class repeat that three times. And I got chance odds that
they got that [right] on the multiple-choice questions. So I needed to do
something so [the idea] was engrained…to knock them off balance enough…so
they think “oh, wait a second…”

In contrast to another lesson I observed, where Carl attempted to talk his students through
misconceptions with little student engagement, multiple instances of off-task students
disrupting the class, and little conceptual development (see “Nothing to talk about” in the
previous section), this lesson was successful in engaging students’ preconceptions,
stimulating deep science talk between Carl and his students, and bringing a student who
was more interested in his cellphone back into a conversation about heat transfer.

During many of my observations, I noticed Carl’s interactions with students were
to encourage them to start a task, and then to persist in completing the task. I asked Carl
to explain:

“You get a student who thinks deep down that they can’t learn [a task]. If they
really don’t think they have the capability…and they don’t try, it’s not license for
me to give up on them, but I really can’t get angry with them for not trying. It
turns into “how do I show them they can do it? [rather than] “if you would only
try.” [I have to] show them in other ways where they are making progress.”

Carl’s persistence in engaging his students reflects the growth mindset he espouses in his
classes. There are two posters above his door, one reads “Fail, fail again, fail better.” The
other is a Richard Feynman quote about the nature of science: “We are trying to prove ourselves wrong as quickly as possible, because only in that way can we find progress.”

Carl’s growth mindset, his get-data-use-data approach to teaching, a willingness to investigate and to try new ideas drives him to find ways to keep his students engaged.

**Carl’s SMK drives his constructivist approach.** Most of Carl’s teaching assignments are within his subject area. Carl teaches physics and AP physics primarily; however, each year he teaches multiple sections of a survey of physical science class, which includes Earth and space science (ESS) content as well as introductory chemistry. Carl’s academic preparation in astronomy included solar system and planetary formation, and Carl reported feeling confident in addressing ESS subjects. In contrast, Carl’s chemistry preparation consisted of one introductory course. Table (4L1.x, p. X) summarizes Carl’s SMK measures. Carl’s extensive academic preparation in physics, and his limited exposure to chemistry concepts, are reflected in his misconception scores (100% in both Physics and Astronomy MOSART tests, 77% in Chemistry).

Carl is very comfortable and confident with the physics content in the Physical Science course. As illustrated in the previous section, Carl regularly used physical events to confront student misconceptions about physics. Students struggled to overcome Newton’s third law (spring scales), expressed amazement and disbelief when shown a video of a strongman pulling a jetliner (F = ma), and were perplexed and constructively annoyed when Carl challenged a long-held misconception (heat rises) with a demonstration. In contrast, Carl was dissatisfied with the chemistry portion of the physical science curriculum, and told me the chemistry lessons were

...a lot of telling, not a lot of doing. And they’re all sort of demonstration labs... ‘this is what acids and bases do. Let’s mix acids and bases! See, this is what it
did.’ I want [students] to ask ‘what’s going on’ rather than [restating] ‘that’s what he said.’

Carl identified several goals for the next iteration of chemistry in physical science. His plans echoed his approach in his physics lessons: students would predict a chemical change, make observations of a reaction, and resolve the differences between the predictions and observations. Carl noted the ineffectiveness of the teacher-centered chemistry lessons in generating student interest: “if I tell [students] what’s going on, then they [students are] ‘meh.’”

At the conclusion of the STEP program, Carl wrote in his statement of teaching philosophy “creating an open-ended approach and relinquishing control to the students requires that I be very comfortable with the students, the resources available, and the content itself.” Carl’s emphasis on active learning, constructivist teaching, and student investigation is evident in the physics content of physical science, but not as much in the chemistry content of the class.

**STEP pedagogical preparation.** Carl’s first science teaching methods instructor employed a conceptual change approach to introduce and develop constructivist and inquiry teaching techniques, an approach she explicitly noted in the course syllabus. The conceptual change approach supported a misconceptions interview assignment, where teacher candidates interviewed middle and high school students about their understanding of science concepts that are often misunderstood. Assessment practices were emphasized in the second science teaching methods course. Alignment between instructional goals, teaching practices, and evaluation tools were emphasized. Additionally, teacher candidates completed a “lesson study” assignment during the second methods class; teacher candidates would plan a lesson, teach the lesson, and evaluate evidence of student
learning to assess the effectiveness of the lesson in order to identify components of the lesson to modify for use in a subsequent lesson.

During our post-study member-checking interview, Carl told me he could not identify a specific topic or assignment from the methods courses that directly informed his teaching practice, as he had completed the classes four years earlier. Carl explained the content of the methods classes aligned with his experience training restaurant employees, and I observed many of his teaching practices were aligned with the intended outcomes of the methods classes. For example, Carl regularly addressed student misconceptions in his lessons, used a version of conceptual change in his teaching, and applied a continual cycle of lesson planning, evaluation, and revision used in the lesson study assignment.

Carl completed his teaching internship (student teaching) with a host teacher who used the Modeling Physics (MP) approach, and, in his post-program teaching philosophy statement, Carl identified using the Modeling approach as a professional goal. The Modeling Physics curriculum places emphasis on a few essential topics, and develops student understanding in a modeling cycle. The cycle starts with a demonstration of the phenomenon and a class discussion in which the question is identified and understood. Small groups plan and conduct investigations to develop explanatory or predictive models, then present and justify their conclusions to their peers. Once a model is agreed upon, students test their model in new situations. To refine their new understandings, students work collaboratively on related and challenging problems, and present and defend their answers (cite?). I noted many nascent components of the MP approach during my observations of Carl’s lessons. For example, Carl expected his ninth-grade
physical science students to share predictions and conclusions with the class, and his physics students regularly used the whiteboarding discussion method Carl learned during his student teaching.

Lesson study applied in practice: Carl’s self-guided professional development.

Carl recognized his approach to teaching and learning was helping his students. During a follow-up interview near the conclusion of this study, Carl noted several examples of how his approach to teaching worked well for his Honeydew students. During the four years I observed or worked with Carl (two years prior to this study, the year of this study and a year teaching physical science in an adjacent classroom), I noticed Carl’s commitment to incremental improvement in his teaching practice. Specifically, Carl designed a standards-based assessment and grading plan, identified and addressed obstacles to providing effective and timely feedback, and continuously revised lessons to increase opportunities for students to discuss science ideas in class.

Standards-Based Grading and Mastery Learning. In a post-study member-checking interview, Carl told me he used online resources (discussion boards, professional trade articles) to research standards based grading during the summer prior to UPS implementation. Carl reported he “wanted to see how it’s supposed to work, when it’s done the right way.” Carl applied what he learned as he developed his assessment program: each learning objective was included as a separate entry in his grade book, and each objective had descriptions of student performance for each level of mastery. For each unit, Carl provided his students with a booklet containing the objectives and rubrics so they could individually track his or her own performance and progress.
Characteristics of effective feedback. According to Carl, he should assess his students “whenever I have the opportunity to give feedback with specific notes on what to improve.” Carl explained a long interval between the assessment and the feedback was the most important obstacle confounding his ability to use formative assessment effectively; Honeydew’s alternating block schedule meant he met with his students every other day, and the high student absentee rate meant he might not be able to return quizzes until the next week, even if the quiz were administered on a Tuesday. To compensate, Carl would give a quiz, and have students self-correct selected questions using different colored pencils so they could receive some feedback immediately. Further, Carl often directed students to describe why answers were correct or incorrect as part of the in-class assessment. Carl explained he developed the quiz self-assessment and reflection routine as a way to make feedback more immediate. Carl based this part of his assessment plan on his experience as a fast food restaurant manager. Carl told me when employees were trained for a new job or skill, testing the skill was immediately followed by a conference where trainees and mentors would review performance and set goals for the next training cycle.

Engaging students as measure of teaching success. Carl’s teaching practices were usually aligned with his stated beliefs about teaching and learning; however, as he stated in the video clip interviews, he continually revised lessons and activities so students would be more active participants. Carl regularly provided materials for students to manipulate, and lab activities and investigations were common in his physical science classes. Carl identified increasing opportunities for students to interact and talk as a continuing professional goal.
Curricular development. In addition to an emphasis on assessment and providing opportunities for students to engage in science questions, Carl’s science teaching methods classes included curriculum planning. The unit plan assignment required students to apply the “backwards design” approach described by Wiggins and McTighe in Understanding by Design. Carl used the unit plan he developed in each of his first three years, and continues to use the unit with little modification. In planning a unit by design, teachers start by identifying specific learning outcomes, and design their assessments and instruction to reach these goals. Carl’s instructional planning aligns learning outcome, assessment, and instruction. Carl described how he revised the first semester unit plans for physical science:

What [does] the student need to be able to do by the end of the class? I looked at what I was teaching…[and recognized] I had to rewrite the curriculum. If I re-write the curriculum so it runs smooth as butter, and then I go through and see what my learning goals are…if I didn’t have that in mind, I’d be rewriting it again. So I figured out the assessment [plan], and I still need to tweak it a bit.

Carl’s focus on defining student learning outcomes first, then structuring lessons and specific learning events such as labs, demonstrations, and student activities, indicate he internalized and consistently enacts the curriculum planning approach emphasized in the STEP science teaching methods courses.

Kari’s Case

Kari worked with her students’ cooperation and shared expectations to enact interactive formative assessment practices. In a post-study member checking interview, Kari told me several students in the class I observed took AP Chemistry or Organic Chemistry as Juniors and Seniors. According to St. Sebastian’s online
promotional material, in the year following this study, St. Sebastian’s Juniors (Kari’s Sophomores during the study) recorded a 29 average ACT score, and in the next year, 32% of the graduating class of 59 were awarded full tuition scholarships at four-year colleges or universities. Five students were selected for National Merit recognition, including one National Merit Scholar and one Finalist. Kari’s students, as Schlechty wrote, had “embraced and internalized the norms of the academy” (200X, p. 18). Kari leveraged her students’ cooperation to sustain whole-class discussions, and during her tenure at St. Sebastian, found her students reacted well to her preferred teaching style.

**Shared goals.** My prior work with St. Sebastian afforded me a view of Kari’s teaching from the perspective of the school administrators and support staff, as well as the St. Sebastian parents. I worked at St. Sebastian for eleven years as a science and math teacher, and had been connected to the school, in some capacity, for about fifteen years prior to the year of this study. It was not unusual for me to interact with St. Sebastian teachers or administrators, or parents of my former St. Sebastian students. Parents of Kari’s students, her colleagues and administrators rarely hesitated to express to me their enthusiasm for Kari’s work in chemistry and with their children. From these informal interactions, I concluded Kari’s approach to teaching and learning science aligned with the school climate, and her students’ and their parents’ expectations of what a chemistry course should be.

Kari’s approach to teaching seemed to match the expectations of her administrators and the St. Sebastian parents. Kari established high expectations for her students’ academic achievement, and she was available to assist outside of class time; these ideas were a common theme when parents would talk to me about Kari’s teaching.
In our initial teaching beliefs interview, Kari described a story of tutoring an undergraduate organic chemistry student:

“who was just doing terribly in organic [chemistry], and two weeks before the test, she had a ‘click’ moment. I felt validated. It was good.”

Kari noted a similar interaction as a teacher at St. Sebastian; Kari told me about a moment when a student understood bond polarity and expressed his excitement loudly enough to disrupt class.

Kari’s position as an expert in her field, with master’s degrees in chemistry and science teaching, also aligned with the college-preparatory mission of the school. As an academic, Kari had achieved a goal her students and their parents either shared or respected.

During our teaching beliefs interview, and while watching video of her teaching, Kari noted she “wanted to push students to see how far they could go,” and the academic rigor of her courses “had [students] questioning life enough already.” Kari told me parents reported their students loved the challenging organic chemistry class, despite all the homework. Kari perceived the alignment between student and parent expectations of what a college preparatory chemistry course should be, and the way she taught chemistry. Kari also perceived the value students and parents placed on the rigor of the course; Kari told me “even though [the class is] hard, I think the students realize what they’re getting here is invaluable for what they think they are going to do.”

**Kari’s beliefs about how students learn science.** Kari used the laboratory component of her chemistry classes to provide opportunities to talk with her students as they worked. In our teacher beliefs interview, Kari told me the lab activities provided a concept or phenomenon to discuss, or a skill to practice with coaching. During our initial
teaching beliefs interview, Kari told me the conversations she had with students, as well as the conversations students have with each other, provided “time to practice…to put their knowledge into writing…to talk chemistry.”

In a post-study member-checking interview, Kari re-affirmed her belief that science should be learned “by doing it,” and her support of an experiential approach to learning to solve calculations. Kari explained doing science is “doing problems, engaging in a lab that demonstrates some of those ideas [chemical concepts].” Kari placed special emphasis on experiential learning by working problems and the calculations she assigned as homework.

During our post-study member checking interview, Kari told me it is easier for students to learn science when they ask and pursue their own questions. Later in the interview, she told me she talks with her advanced students about possible designs of investigations, but does not enact the investigations; student inquiry starts with asking a question, and ends by imagining a way to answer it. <potassium in coffee example>

For Kari, asking “why” is the essence of academic chemistry; it is making connections between observed patterns and more conceptually deep explanatory ideas. Laboratory experiences allow students to observe a phenomenon and the macroscopic changes which evidence a chemical reaction. Answering “why” means developing a scientifically accurate conceptual explanation in a teacher-mediated conversation. In class, Kari uses a cognitive ladder of questions, starting with concepts understood by her students, and extending to the more abstract explanations Kari intends her students to apprehend.
In Kari’s class, conceptual or theoretical understanding is constructed socially through interactive discourse, and often based on the confirmatory lab activities, as shown in the lesson excerpt below. The lab activities I observed (as noted in the analysis of “the fifteen lessons”) were all scripted, step-by-step confirmation labs. Kari adapted to St. Sebastian’s short class periods by using the scripted labs, and using the following class period to discuss results and develop theoretical understandings:

I want to be sure that they don’t just memorize “this has to be higher than this in order for it to replace.” That’s not understanding chemistry; that’s understanding how to use a graph or how to use a table. And in the grand scheme of things, you could make it through that way, but…let’s use everything to understand the “why.” OK, so sodium is more reactive. Why is sodium more reactive?

The lesson cameo below was extracted from a lesson that followed a laboratory investigation of the types of reactions. The laboratory investigation included using a reactivity series to predict if a particular metal would react with a solution containing ions of a different metal.

<table>
<thead>
<tr>
<th>Turn</th>
<th>Speaker</th>
<th>Utterance</th>
<th>Teacher intent</th>
</tr>
</thead>
<tbody>
<tr>
<td>[1]</td>
<td>Kari:</td>
<td>So, questions you guys have about types of reactions...</td>
<td>X</td>
</tr>
<tr>
<td>[2]</td>
<td>Student A:</td>
<td>I don't remember the numbers on the sheet that tell you if a reaction...</td>
<td></td>
</tr>
<tr>
<td>[4]</td>
<td>Kari:</td>
<td>Yes. How do we know if a reaction will take place?</td>
<td>Kari reviewed homework assignments and identified student misunderstanding.</td>
</tr>
<tr>
<td>[5]</td>
<td>Kari:</td>
<td>Specifically, we're looking at one type of reaction.</td>
<td>Kari recalled students were inappropriately trying to use the reactivity series for precipitation</td>
</tr>
</tbody>
</table>
Kari asked a question “How do we know if a reaction takes place” (Turn 4) based on her evaluation of homework problems. As we watched the video clip, Kari told me “I noticed in the homework there were a ton of no reactions [for double replacement] and everything was
reacting in the single replacement reactions.” She noted “either they [ignore] the activity series, or
they use it for everything.” Kari told me she uses homework to “see where people are getting
confused” and to what extent; if only a few students are misunderstanding a concept, she will
work with the few individually. If the misunderstanding seems more prevalent, she will address
the misunderstanding in class.

Prior to this lesson, Kari used planned formative assessment (homework questions
aligned with learning objective) to elicit and evaluate student understanding, and interpreted the
misunderstanding (students were either ignoring the activity series or using it for every reaction).
During the lesson, she responded to the misunderstanding using a whole-class discussion. Kari’s
transition to interactive formative assessment started in Turn 8, where she asks the class for what
type of reaction the reactivity series should be used. From her quick review of homework, Kari
knew her students were using the reactivity series incorrectly, and she used an open-ended
question (“What does the reactivity series tell us?”) in Turn 8 to elicit student responses in order
to notice and respond to specific student misunderstandings. Kari attempted to sustain student talk
in Turn 12 (“What do you mean by that? I liked were you were going…”) by pressing for more
information and acknowledging the student’s initial effort.

By Turn 13, Kari recognized the discussion was not moving in the direction she intended;
students had not understood how to use the reactivity series. In response (Turn 14), Kari
improvises an example using two elements near the top of the reactivity series.

<table>
<thead>
<tr>
<th>Turn</th>
<th>Speaker</th>
<th>Utterance</th>
<th>Teacher intent</th>
</tr>
</thead>
<tbody>
<tr>
<td>[15]</td>
<td>Kari:</td>
<td>Alright, what does the activity series</td>
<td>Kari intended students to use the reactivity series to predict the hypothetical</td>
</tr>
<tr>
<td></td>
<td></td>
<td>tell you?</td>
<td>reaction she wrote on the board.</td>
</tr>
<tr>
<td>[16]</td>
<td>Student D:</td>
<td>so, first there's lithium</td>
<td></td>
</tr>
</tbody>
</table>
[17] Student E: Lithium is the highest...

[18] Kari: Lithium is the highest.

[19] Student E: I'm going to say it can't [react], too far away. <missed opportunity?>

[20] Kari: So, just looking at the activity series, sodium and magnesium, what can you tell me? Kari refocuses students on her intended question.

[21] Students: [Inaud. student-to-student discussion.]

[22] Kari: I have sodium on top, I have magnesium a little lower. Which means.... x

[23] Several students: [Off subject student talk disrupts Kari’s intended discussion.] Kari’s intended discussion.]

[24] Kari: shhhhh..... x

LZ: You guys were so quiet at lunch, what happened?

In Turn 23, students began to show their frustration with their understanding, and perhaps with not understanding where Kari was going with her line of questions. As I observed the discussion, I was unsure of Kari’s intent to connect observable reactions to periodic trends in ionization energy and electronegativity. This one question (“What does reactivity mean?”) had been pursued for some time with little progress, and students were becoming frustrated. Kari redirected the class to the question (in Turn 25 below).

<table>
<thead>
<tr>
<th>Turn</th>
<th>Speaker</th>
<th>Utterance</th>
<th>Teacher intent</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>Kari:</td>
<td>So sodium is higher on the activity series than magnesium. Just looking at the activity series, what does that mean? X</td>
<td></td>
</tr>
</tbody>
</table>
Students: They can't switch...

Kari: What can't switch?

Student E: Magnesium and sodium.

Kari: I'm just looking at sodium here, magnesium here. What can you tell me if I'm just looking at sodium here, magnesium here, what can you tell me about these two metals, in relation to one another? Ian?

Ian: Sodium can replace magnesium, but magnesium can't replace sodium.

Kari: Why?

Ian: Because sodium is higher on the reactivity ... on the list.

Kari: OK. Which means what? You guys are so close here. Andrew?

Andrew: Sodium doesn’t...sodium wants to move around more...

Kari: Wow. Are we going all the way back to ionization energy?

Student X: Oh, I remember that!

Once the class had quieted and refocused on the problem (Turn 25), Kari realized her students were not making the connection between the metal-metal ion reactions they observed the day before in lab, and the periodic trends they had studied earlier in the semester. Several students appeared to understand how to use the reactivity series to predict if a reaction will happen; however, they were unaware of the connection to periodic trends. As we watched the video of this interchange, Kari told me:

sometimes the way you ask the question puts kids totally [in] the wrong [direction]. So I try to give a leading question that isn’t giving away the answer,
but is at least giving them a carrot [gestures to show a leading motion]. “OK, go this way now.” And all of a sudden, you see a few who are “Well, I knew that. You just didn’t ask it that way.”

Kari’s intent to connect patterns of reactivity to ionization energy appeared to develop as Kari re-taught how to use the reactivity series. During the lesson, Kari did not explicitly state the lesson objective, and her stated intent was to review what students were consistently missing on their homework. The metal-metal ion pairs seemed to be an improvised example; strong electropositive elements like sodium and magnesium would react with water in aqueous solutions. As noted in (section on thing & misconception), Kari used demonstrations to build skills more than she used them to develop concepts. In this lesson, Kari relied on students to recall the reactions they observed the day before in lab, when a demonstration would have helped students develop the intended concept. Had Kari paired a demonstration with this discussion, students would have a physical event to describe, and Kari would have chosen a more sensible combination of metal and metal ion solution.

A more electronegative metal, such as copper, paired with a more strongly electronegative metal ion such as silver, would provide a more practical example than the metal-metal ion pair Kari used. Alternatively, magnesium metal in a zinc solution would have provided a visible reaction students could observe and explain, with less concern about disposal (silver solutions must not be flushed into sewers). In this lesson, Kari might have asked students to predict whether a reaction would take place, explain their reasoning, and then showed the class if the reaction happened.

Using a demonstration of a reaction was something Kari did in other lessons. For example, Kari showed color changes of indicators when demonstrating titration
techniques, and used an actual burning candle to provide mass data for stoichiometric calculations during lessons I observed. In this lesson, Kari relied on students to recall their observations from the day before.

During Kari’s whole class discussions, she often relied on student volunteers to initiate and sustain a teacher-student discussion, as the rest of the class listened. Most students appeared attentive during these discussions. In this lesson event, four to five students actively asked and answered questions, and one student appeared to understand Kari’s intended conceptual understanding; the relationship between observed reactivity, the tendency for atoms of one element to attract electrons more than ions of another element, and how these tendencies can be predicted using the periodic table.

This is my lecture style. I mean, we have powerpoints we go through, but I will always stop and ask the “why.” I think that tying it all together and making them think about it [what that means?] is what my goal is…So [asking why] is a way to really see if kids get to that deeper level. I try to be sure I can ask questions to try and get them there, instead of just expecting them to figure that out on their own. Especially [with] sophomores [who are] trying to think abstractly.

**Factors influencing Kari’s decisions.** I identified a chain of factors that provide a plausible explanation of Kari’s enacted decisions about teaching redox reactions. Kari’s students are generally cooperative, and Kari rarely needs to remind her students about behavioral expectations. During this lesson, Kari needed to remind her students to focus on her question (“What does reactivity mean?”) and the series of questions she used to guide students to make connections between periodic trends (ionization energy) and the reactivity of metals. Kari’s intent was to connect observable events (1), seen the day before in lab, to periodic trends (2), explored in detail earlier in the semester. Kari used homework questions as planned formative assessment (3), and adapted her lesson to attend to student misunderstandings. Kari relied on her students’ cooperation, and had
developed a positive and trusting relationship that helped her sustain student interest and in-class discussion (4). In addition to showing students how to use the reactivity series to predict reactions, Kari intended to use the series of questions to connect reactivity to ionization energy (5). Kari explicitly stated understanding why a reaction happens is more important than using a table to predict if a reaction will happen. Kari and her students interacted in an assessment conversation; Kari developed a sense of what her students understood, and her students constructed an incomplete understanding of the lesson objective.

Table 4L2x:

SMK and PK interactions with Carl’s enacted assessment and discourse decisions

<table>
<thead>
<tr>
<th>Internal factors</th>
<th>Teacher decisions</th>
<th>Observed practices</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SMK</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Content area expertise: reactivity of metals is related to electronegativity</td>
<td>5</td>
<td>PFA to evaluate student ability to perform task</td>
</tr>
<tr>
<td><strong>PK</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Formative assessment practices: monitored homework and adjusted lesson to meet students’ learning needs</td>
<td>3</td>
<td>IFA as assessment conversation in developing conceptual understanding</td>
</tr>
<tr>
<td>Established trusting relationship with students</td>
<td>4</td>
<td>Reflective practice: aware students may not understand questions as intended</td>
</tr>
</tbody>
</table>

| Discourse             |                                                                                  |                           |
|                       |                                                                                  |                           |
| Limited time to plan: Assessed student work shortly before class, used discussion to develop concept | 9                          | Adapted lesson in progress by changing direction of discussion |
| Used hypothetical examples, not physical examples, to support conceptual development | 10                         |                           |
Analysis of lesson cameo. This interaction would have been much more effective in connecting observable events (metal reactivity) to theoretical explanations (electronegativity predicts tendency to attract electrons), and perhaps NGSS structure and function, and patterns standards with an accompanying demonstration, a more rehearsed series of questions, and a clearly identified learning objective. A demonstration would have required more planning than a responsive question and answer session; however, Kari decided to change the focus of the lesson to address student misunderstanding earlier in the day <support earlier—no out of blue statements>. In this lesson cameo, Kari’s planning time was very limited; however, including a demonstration would have pushed Kari to be more intentional in choosing a reaction and using the reaction to point students to her intended learning objective. Having a demonstration for students to study may have helped focus their attention and keep the discussion moving in the intended direction, and may have helped students retain their focus (Turns 22-24). Using a physical example to support conceptual development would have tied the concept to the event and focused Kari’s questions more effectively than the hypothetical example she used (sodium and magnesium).

Perception of external pressures. During our teacher beliefs interview at the start of this study, and in our post-study member-checking interview, Kari told me she felt pressure to keep her sophomore chemistry students on pace with other schools, and felt considerably more pressure to address the AP content in two semesters. St. Sebastian
competes with other suburban high schools, both public and private, for students and tuition, and Kari’s focus on keeping pace with these competing schools may have driven some of her curricular decisions.

Kari and I selected this class section for me to observe specifically because of a wider range of student abilities than in her other chemistry classes, and Kari noted several students were struggling to maintain performance. However, during my observations of Kari’s lessons, I perceived her students’ generally high self-efficacy in their ability to learn. Based on my own work at St. Sebastian, I understood how the school’s culture supports student confidence in their learning. St. Sebastian schedules required study halls for all students during the school day and in the evening for its boarding students. Additionally, St. Sebastian requires struggling students to attend additional study halls immediately after school. In order to matriculate to St. Sebastian, students must meet academic requirements and pass entrance exams, and upon graduation, nearly all graduates continue their post-secondary education in college or university. St. Sebastian students often view their struggles in difficult courses as badges of honor, and, as Kari indicated, see their work in these classes as work toward a goal they value.

Kari’s approach worked for her students. Overall, Kari’s students successfully learned chemistry, and Kari reported a general good feeling about her students’ effort and their shared positive and trusting relationship. However, Kari’s declining teaching self-efficacy in employing instructional strategies (see Table 4. and specific page number) were not congruent with her statements of strong student effort and positive affect toward her students, and may be in part due to not measuring student progress efficiently and connecting her strategies to their learning—or using student data to refine specific
lessons. Kari identified asking more conceptual questions as a professional goal during the year of the study, and I observed her consistently ask conceptual questions. However, Kari relied on few student interlocutors to sustain classroom discourse and often relied on student self-reporting to assess their understanding, and student self-monitoring to address needs.

Kari used student self-monitoring and self-reporting during her student teaching (Carl and Kari completed student teaching at the same WPS high school), and Kari investigated possible connections between student self-evaluation and student motivation for her Master’s thesis. In a video analysis report she wrote during her student teaching, Kari reported using self-assessment to determine student understanding of electron configurations:

In my wrap up, I wanted students to communicate to me how they felt now after further clarification, which I gauged by students holding up their hands showing me a scale of 1-5. I felt like students did a good job communicating with me about how they were feeling about the material.

Kari described using a similar student self-reporting approach at St. Sebastian:

During the more confusing [lesson topics], at the end of the day I’ll do the thumbs up, thumbs down…and look at the general understanding of the class.

For her action-research thesis investigating student self-monitoring and motivation, Kari included student homework and daily short quiz results in addition to students’ assessment of their own understanding. For the complex ideas I observed her teach at St. Sebastian, such as the particulate nature of matter and periodic law, Kari’s emphasis on evaluation through student self-assessment (“thumbs up”) was insufficient to assess student conceptual understanding. In this lesson cameo, Kari supplemented her students’ self-reporting (asking questions in class when confused) with an un-announced
homework check, which led her to reconsider her original lesson plan in favor of a question-and-answer review session.

**Conclusion.** A standards-based approach to assessment, with consistent teacher monitoring of student progress, may have sustained and perhaps built Kari’s teaching self-efficacy, helped her refine and more carefully plan to meet learning objectives, and reduced the considerable stress she consistently reported as she strained to keep her curriculum apace with the calendar.
Appendix E: EQUIP instrument

EQUIP
(Electronic Quality of Inquiry Protocol)

Complete Sections I before and during observation, Sections II and III during the observation, and Sections IV-VII immediately after the observation. If a construct in Sections IV-VI absolutely cannot be coded based on the observation, then it is to be left blank.

Observation date: _______ Time start:_______ Time end: _______ Observer: ______________________________
School: __________________ District: ___________ Teacher: __________________
Course: __________________

I. Descriptive Information

A. Teacher Descriptive Information:
1. Teacher gender ____ Male (M), Female (F)
2. Teacher ethnicity ____ Caucasian (C), African-American (A), Latino (L), Other (O)
3. Grade level(s) observed _______ 4. Subject/Course observed ____________________________
5. Highest degree ___________________ 6. Number of years experience: _______ 7. Number of years teaching this content _______

B. Student/Class Descriptive Information
1. Number of students in class: ____________
2. Gender distribution: ____ Males ____ Females
3. Ethnicity distribution ____ Caucasian (C) ____ African-American (A) ____ Latino (L) ____ Other

C. Lesson Descriptive Information
1. Is the lesson an exemplar that follows the 4E x 2 Instructional Model? (PDI exemplar, non-PDI exemplar, non-exemplar)
2. Working title for lesson:
3. Objectives/Purpose of lesson: Inferred (I), Explicit (E) ____
4. Standards addressed: State (S), District (D), None Explicit (N) ____

IV. Instructional Factors

<table>
<thead>
<tr>
<th>Construct Measured</th>
<th>Pre-Inquiry (Level 1)</th>
<th>Developing Inquiry (2)</th>
<th>Proficient Inquiry (3)</th>
<th>Exemplary Inquiry (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11. Instructional Strategies</td>
<td>Teacher predominantly lectured to cover content.</td>
<td>Teacher frequently lectured and/or used demonstrations to explain content. Activities were verification only.</td>
<td>Teacher occasionally lectured, but students were engaged in activities that helped develop conceptual understanding.</td>
<td>Teacher occasionally lectured, but students were engaged in investigations that promoted strong conceptual understanding.</td>
</tr>
<tr>
<td>12. Order of Instruction</td>
<td>Teacher explained concepts. Students either did not explore concepts or did so only after explanation.</td>
<td>Teacher asked students to explore concept before receiving explanation. Teacher explained.</td>
<td>Teacher asked students to explore before explanation. Teacher and students explained.</td>
<td>Teacher asked students to explore concept before explanation occurred. Though perhaps prompted by the teacher, students provided the explanation.</td>
</tr>
<tr>
<td>13. Teacher Role</td>
<td>Teacher was center of lesson; rarely acted as facilitator.</td>
<td>Teacher was center of lesson; occasionally acted as facilitator.</td>
<td>Teacher frequently acted as facilitator.</td>
<td>Teacher consistently and effectively acted as a facilitator.</td>
</tr>
<tr>
<td>14. Student Role</td>
<td>Students were consistently passive as learners (taking notes, practicing on their own).</td>
<td>Students were active to a small extent as learners (highly engaged for very brief moments or to a small extent throughout lesson).</td>
<td>Students were active as learners (involved in discussions, investigations, or activities, but not consistently and clearly focused).</td>
<td>Students were consistently and effectively active as learners (highly engaged at multiple points during lesson and clearly focused on the task).</td>
</tr>
<tr>
<td>15. Knowledge Acquisition</td>
<td>Student learning focused solely on mastery of facts, information, and/or note processes.</td>
<td>Student learning focused on mastery of facts and process skills without much focus on understanding of content.</td>
<td>Student learning required application of concepts and process skills in new situations.</td>
<td>Student learning required depth of understanding to be demonstrated relating to content and process skills.</td>
</tr>
</tbody>
</table>
## V. Discourse Factors

<table>
<thead>
<tr>
<th>Construct Measured</th>
<th>Pre-Inquiry (Level 1)</th>
<th>Developing Inquiry (2)</th>
<th>Proficient Inquiry (3)</th>
<th>Exemplary Inquiry (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1. Questioning Level</td>
<td>Questioning rarely challenged students above the remembering level.</td>
<td>Questioning rarely challenged students above the understanding level.</td>
<td>Questioning challenged students up to application or analysis levels.</td>
<td>Questioning challenged students at various levels, including at the analysis level or higher; level was varied to scaffold learning.</td>
</tr>
<tr>
<td>D2. Complexity of Questions</td>
<td>Questions focused on one correct answer; typically short answer responses.</td>
<td>Questions focused mostly on one correct answer; some open response opportunities.</td>
<td>Questions challenged students to explain, reason, and/or justify.</td>
<td>Questions required students to explain, reason, and/or justify. Students were expected to critique others’ responses.</td>
</tr>
<tr>
<td>D3. Questioning Ecology</td>
<td>Teacher lectured or engaged students in oral questioning that did not lead to discussion.</td>
<td>Teacher occasionally attempted to engage students in discussions or investigations but was not successful.</td>
<td>Teacher successfully engaged students in open-ended questions, discussions, and/or investigations.</td>
<td>Teacher consistently and effectively engaged students in open-ended questions, discussions, investigations, and/or reflections.</td>
</tr>
<tr>
<td>D4. Communication Pattern</td>
<td>Communication was controlled and directed by teacher and followed a didactic pattern.</td>
<td>Communication was typically controlled and directed by teacher with occasional input from other students; mostly didactic pattern.</td>
<td>Communication was often conversational with some student questions guiding the discussion.</td>
<td>Communication was consistently conversational with student questions often guiding the discussion.</td>
</tr>
<tr>
<td>D5. Classroom Interactions</td>
<td>Teacher accepted answers, correcting when necessary, but rarely followed-up with further probing.</td>
<td>Teacher or another student occasionally followed-up student response with further low-level probe.</td>
<td>Teacher or another student often followed-up response with engaging probe that required student to justify reasoning or evidence.</td>
<td>Teacher consistently and effectively facilitated rich classroom dialogue where evidence, assumptions, and reasoning were challenged by teacher or other students.</td>
</tr>
</tbody>
</table>

## VI. Assessment Factors

<table>
<thead>
<tr>
<th>Construct Measured</th>
<th>Pre-Inquiry (Level 1)</th>
<th>Developing Inquiry (2)</th>
<th>Proficient Inquiry (3)</th>
<th>Exemplary Inquiry (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1. Prior Knowledge</td>
<td>Teacher did not assess student prior knowledge.</td>
<td>Teacher assessed student prior knowledge but did not modify instruction based on this knowledge.</td>
<td>Teacher assessed student prior knowledge and then modified instruction based on this knowledge.</td>
<td>Teacher assessed student prior knowledge and then modified instruction based on this knowledge.</td>
</tr>
<tr>
<td>A2. Conceptual Development</td>
<td>Teacher encouraged learning by memorization and repetition.</td>
<td>Teacher encouraged product–or answer-focused learning activities that lacked critical thinking.</td>
<td>Teacher encouraged process–focused learning activities that required critical thinking.</td>
<td>Teacher encouraged process–focused learning activities that involved critical thinking that connected learning with other concepts.</td>
</tr>
<tr>
<td>A3. Student Reflection</td>
<td>Teacher did not explicitly encourage students to reflect on their own learning.</td>
<td>Teacher explicitly encouraged students to reflect on their learning but only at a minimal knowledge level.</td>
<td>Teacher explicitly encouraged students to reflect on their learning at an understanding level.</td>
<td>Teacher consistently encouraged students to reflect on their learning at multiple times throughout the lesson; encouraged students to think at higher levels.</td>
</tr>
<tr>
<td>A4. Assessment Type</td>
<td>Formal and informal assessments measured only factual, discrete knowledge.</td>
<td>Formal and informal assessments measured mostly factual, discrete knowledge.</td>
<td>Formal and informal assessments used both factual, discrete knowledge and authentic measures.</td>
<td>Formal and informal assessment methods consistently and effectively used authentic measures.</td>
</tr>
<tr>
<td>A5. Role of Assessing</td>
<td>Teacher solicited predetermined answers from students requiring little explanation or justification.</td>
<td>Teacher solicited information from students to assess understanding.</td>
<td>Teacher solicited explanations from students to assess understanding and then adjusted instruction accordingly.</td>
<td>Teacher frequently and effectively assessed student understanding and adjusted instruction accordingly; challenged evidence and claims made; encouraged curiosity and openness.</td>
</tr>
</tbody>
</table>
Appendix F: Teacher Beliefs Interview Protocol

Interview #1: Teacher Belief Interview (adapted form Luft and Roehrig, 2007)

Time of interview:

Date:

Place:

Interviewee:

Hi (participant). Thank you for agreeing to talk with me today. If it’s ok with you, can we start with last year? How did your second year of teaching go?

Introductory questions based on previous personal conversations and classroom observations:

Carrie—You took your students to UNL for the chemistry open house last year—is that right? Are you planning to do that again this year?

Carrie—So the Field Day turned out well for your teams?

Carl—Did you find the lego molecule kit you were looking for last year? How do the activities look?

Both / either: Do any particular lessons or units from last year stand out for you? Any that you plan to use again this year?

Tell me how you maximize—or promote—student learning in your classroom? (allow some time to think, rephrase as needed) Can you describe some examples to help me understand your process?

How would you describe your role as a teacher? Can you share a story about your teaching that really captures *you* as a teacher?

When do you know—or how do you know—when your students understand a topic or an idea?

In your setting—in this school with your students—how do you decide what to teach and what not to teach?

How do you decide when to move on—how do you decide when to move on to a new topic?
How do your students learn science best? Could you share an example?

How do you know when learning is happening in your classroom? (what do you look for, what does it sound like—what’s it feel like?)

End: I’m working with preservice teachers in the methods classes pretty regularly now—is there anything that I should share with them about being a science teacher that might help out in understanding how the first years will go?

Thanks so much—I really enjoyed the conversation!
Follow-up interviews:

Follow-up based on analysis of first interview. Exploration of interesting instances of teacher questions observed in the first group of classroom observations. Cognitive interview with transcript, audio recording, and memos from post-observation discussions.
# Appendix G: Teaching Self-Efficacy Survey Questions

## TEACHER BELIEFS

**Purpose:** To determine the level of self-efficacy among staff members.

**Time:** 30 minutes.

**Materials:** Survey.

**Directions:** Provide the survey to staff members. Allow results to remain anonymous since the purpose is to gather information about teachers’ sense of efficacy as a group. Gather the surveys and compute the mean. To understand more about teachers’ sense of specific areas, group questions as follows:
- Efficacy in Student Engagement: Items 1, 2, 4, 6, 9, 12, 14, 22
- Efficacy in Instructional Strategies: Items 7, 10, 11, 17, 18, 20, 23, 24
- Efficacy in Classroom Management: Items 3, 5, 8, 13, 15, 16, 19, 21

### Teachers’ Sense of Efficacy Scale

<table>
<thead>
<tr>
<th>Question</th>
<th>Nothing</th>
<th>Very little</th>
<th>Some</th>
<th>Quite a bit</th>
<th>A great deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. How much can you do to get through to the most difficult students?</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2. How much can you do to help your students think critically?</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. How much can you do to control disruptive behavior in the classroom?</td>
<td></td>
<td></td>
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<tr>
<td>4. How much can you do to motivate students who show low interest in school work?</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>5. To what extent can you make your expectations clear about student behavior?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. How much can you do to get students to believe they can do well in school work?</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>7. How well can you respond to difficult questions from your students?</td>
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<td></td>
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<tr>
<td>8. How well can you establish routines to keep activities running smoothly?</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>9. How much can you do to help your students value learning?</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>10. How much can you gauge student comprehension of what you have taught?</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>11. To what extent can you craft good questions for your students?</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**Source:** Megan Tschannen-Moran, College of William and Mary, and Anita Woolfolk Hoy, The Ohio State University.
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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>12.</td>
<td>How much can you do to foster student creativity?</td>
<td>Nothing</td>
<td>Very little</td>
<td>Some</td>
</tr>
<tr>
<td>13.</td>
<td>How much can you do to get children to follow classroom rules?</td>
<td>Nothing</td>
<td>Very little</td>
<td>Some</td>
</tr>
<tr>
<td>14.</td>
<td>How much can you do to improve the understanding of a student who is failing?</td>
<td>Nothing</td>
<td>Very little</td>
<td>Some</td>
</tr>
<tr>
<td>15.</td>
<td>How much can you do to calm a student who is disruptive or noisy?</td>
<td>Nothing</td>
<td>Very little</td>
<td>Some</td>
</tr>
<tr>
<td>16.</td>
<td>How well can you establish a classroom management system with each group of students?</td>
<td>Nothing</td>
<td>Very little</td>
<td>Some</td>
</tr>
<tr>
<td>17.</td>
<td>How much can you do to adjust your lessons to the proper level for individual students?</td>
<td>Nothing</td>
<td>Very little</td>
<td>Some</td>
</tr>
<tr>
<td>18.</td>
<td>How much can you use a variety of assessment strategies?</td>
<td>Nothing</td>
<td>Very little</td>
<td>Some</td>
</tr>
<tr>
<td>19.</td>
<td>How well can you keep a few problem students from ruining an entire lesson?</td>
<td>Nothing</td>
<td>Very little</td>
<td>Some</td>
</tr>
<tr>
<td>20.</td>
<td>To what extent can you provide an alternative explanation or example when students are confused?</td>
<td>Nothing</td>
<td>Very little</td>
<td>Some</td>
</tr>
<tr>
<td>21.</td>
<td>How well can you respond to defiant students?</td>
<td>Nothing</td>
<td>Very little</td>
<td>Some</td>
</tr>
<tr>
<td>22.</td>
<td>How much can you assist families in helping their children do well in school?</td>
<td>Nothing</td>
<td>Very little</td>
<td>Some</td>
</tr>
<tr>
<td>23.</td>
<td>How well can you implement alternative strategies in your classroom?</td>
<td>Nothing</td>
<td>Very little</td>
<td>Some</td>
</tr>
<tr>
<td>24.</td>
<td>How well can you provide appropriate challenges for very capable students?</td>
<td>Nothing</td>
<td>Very little</td>
<td>Some</td>
</tr>
</tbody>
</table>