PRACTICE-BASED PEDAGOGIES IN SCIENCE TEACHER PREPARATION: SUPPORTING PRESERVICE TEACHERS' CAPACITY TO ATTEND TO THE SUBSTANCE OF STUDENTS' IDEAS AND REASONING TO ADAPT INSTRUCTION

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ABSTRACT

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A vision of science education guiding reform efforts in the United States is intended to guide substantial change in K-12 teaching practices and, in parallel, university pedagogies that prepare the next generation of science teachers to make high standards of disciplinary learning both accessible and achievable to diverse student populations (NRC, 2012). Distinct from past standards of learning that separated entities of content and process skills (e.g., AAAS, 1993; NRC, 1996), a contemporary vision of science education positions students as legitimate participants in the conceptual, epistemic, and social processes of science to build and refine increasingly sophisticated explanatory ideas and models of the world around them (NRC, 2012). In teacher preparation, this means that prospective science teachers learn to orchestrate learning around the "big ideas" of science that afford students great capacity to access, build, and explain a coherent storyline of the world around them. They learn to elicit, attend to, and make visible students' evolving ideas and reasoning about scientific phenomena as the terrain for co-constructing, negotiating, and refining explanatory ideas and models over time. And they learn to continually monitor and adjust instruction *in response to what students do*.

With a deliberate orientation to achieving ambitious learning goals for all students, a growing number of policymakers, scholars, and educators have advocated for practice-centered approaches to preservice teacher education, focusing directly on the

interactive and relational work of responsive teaching as the content and context for novice teacher learning (Ball & Cohen, 1999; Levine, 2006; Grossman, Compton, et al., 2009; National Council for Accreditation of Educator Preparation [NCATE], 2010). Accordingly, this qualitative embedded single-case study explored preservice science teacher participation in practice-centered pedagogies, grounded in tool-supported analyses of student work, to enact one of four high-leverage practices identified as central to supporting student learning in science: *attending to the substance of students' emerging ideas and reasoning to adapt instruction* (NRC, 2007; 2012, Windschitl et al., 2012; Thompson et al., 2013). More specifically, informed by a situative perspective, this study traced three preservice science teachers' (a) repertoires of practice as related to attending to, interpreting, and responding to student work; and (b) stances toward science, toward student learning, and toward teaching over time and in interactions with peers, with pedagogical tools, and with classroom artifacts of practice (e.g., researcher-generated student work, student work generated in prospective teachers' secondary science classrooms during student teaching, case studies).

Positively, situating preservice teacher learning in the interactive and relational work of teaching (i.e., recurrent cycles of analyzing and responding to student work), coupled with representations of "what is possible" (i.e., case studies), helped all prospective science teachers attend to dimensionality in students' ideas *and* their ways of thinking and reasoning about these ideas. Two influential features of these practice-oriented learning experiences that supported preservice teacher learning included: (1) cultivating preservice teacher learning within a discourse community; and (2)

disciplinary-specific protocols, consistent with a vision of science-as-practice (NRC, 2012), that mediated student work analyses and collegial conversation.

However, while promising, preservice teachers' developing readiness to interpret and respond to student work in increasingly sophisticated ways was closely related to their stances toward science, toward student learning, and toward teaching. Notably, one teacher started to access a more problematized representation of science, student learning, and science teaching (i.e., science as a theory-building endeavor anchored in student pursuit of explanatory accounts of the world around them). Likewise, this teacher made sense-of and positioned the disciplinary substance of students' ideas in a shared space between the teacher and students – a resource for adapting instruction in ways that built on and fostered continued student participation in disciplinary activity. Further, "problems of practice" were framed in terms of hypothesizing differing pedagogical possibilities that afforded students opportunities to revisit and refine their tentative explanations over time. In contrast, preservice teachers that maintained unproblematized representations of science, student learning, and teaching science (i.e., didactic approaches to teaching science centered on the accumulation of knowledge and skills) positioned student thinking a space between a student and teacher only – an evaluative check on student learning outcomes. Moreover, "problems of practice" were framed as "problems with students." Insights from this study inform the design of science teacher learning trajectories within systems of teacher preparation.

DEDICATION

To my parents,

Rob & Connie Germundson.

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CHAPTER 1: INTRODUCTION

The Problem Space

> *Because universities are currently thought to be unsuccessful in preparing novices for practice, [teacher educators] are faced with two challenges: preparing beginning teachers to actually be able to do teaching when they get into classrooms, and preparing them to do teaching that is more socially and intellectually ambitious than the current norm.*
>
> *Lampert et al., 2013, p. 226*

Preparing the next generation of science teachers[1] to successfully make high standards of disciplinary learning both accessible and achievable to diverse student populations is a pressing challenge in American science education. In public school classrooms today, these teachers will work with student populations that continue to grow more ethnically, racially, socioeconomically, and linguistically diverse (Kena et al., 2015). Academic disparities in science achievement and patterns of learning between subgroups of students persist (National Research Council [NRC], 2012) and among all learners, "too many American students conclude early in their education that STEM subjects are boring, too difficult, or unwelcoming, leaving them ill-prepared to meet the challenges that will face their generation, their country, and their world (President's Council of Advisors on Science and Technology [PCAST], 2010, p. viii).

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[1] In this dissertation, I use refer to teachers in preparation pathways interchangeably as *preservice teachers*, *prospective teachers*, *teacher candidates*, *novice teachers*, or *the next generation of science teachers*.

While myriad reasons for these lackluster national trends exist, one evidence-based principle remains salient: all youth, regardless of age, sex, cultural or ethnic background, disabilities, aspirations, and interests, have an abundance of nascent, albeit diverse, intellectual, epistemological, and social resources for making sense of the world around them (NRC, 2007, 2012). For decades, the day-to-day pedagogies of educators, largely centered on the role of teachers as primary arbiters of normative science content and practice, have grossly underestimated the potential of all students to engage in sophisticated thinking and reasoning (NRC, 2012). A growing body of evidence in science education reflects the promise of engaging a wide range of learners in science through instructional practices that surface, support, and leverage students' diverse ideas, ways of reasoning, and curiosities as assets in building complex explanatory ideas and models (e.g., Buxton, 2010; Duschl, 2008; NRC, 2007, 2012; Rodriguez & Berryman, 2002; Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001).

Premised on this principle, calls more rigorous forms of learning that provide every student equity of access to, engagement with, and continuous growth in intellectual work of science couple with calls for equally rigorous forms of teaching. More fully articulated in the *Framework for K-12 Science Education* (NRC, 2012) and carried forward in the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013), an evolved vision of teaching intentionally works to achieve three primary goals for every student: (a) building a coherent understanding of core disciplinary concepts and explanatory ideas that ascend in depth and complexity over the course of schooling, (b) participating in a set of eight authentic discourses and domain-specific practices of science (e.g., developing models, constructing scientific explanations, and engaging in argument from evidence) to generate and iteratively refine explanatory models and ideas, and (c) actively pursuing real-world issues of interest to students' everyday lives (Duncan & Rivet, 2013; Newmann & Associates, 1996). Said differently, this vision engages students in the conceptual, epistemic, and social processes of science to build "big ideas," or "substantive relationships between concepts in the form of scientific models that help learners understand, explain, and predict a variety of important phenomena in the natural world" (Windschitl, Thompson, Braaten, & Stroupe, 2012, p. 888). Stemming from decades of research underpinning how students learn science, a new vision of science education is intended to guide substantial change in kindergarten through high school (K-12) teaching practices and, in parallel, pedagogies of teacher education that support the next generation of science teachers working toward more ambitious forms of student learning.

Distinct from past systems of standards that separated entities of content and inquiry skills (e.g., American Association for the Advancement of Science [AAAS], 1993; NRC, 1996), a contemporary vision of science education details a rigorous corpus of student performances that seamlessly integrate core disciplinary concepts, ideas, and practices into a comprehensive portrait of substantial student learning. For a wide range of learners, an explicit focus on active student participation in authentic forms of disciplinary talk and activity foregrounds attention to the critical role that student diversity plays in teaching and learning processes. Consistent with Tomlinson's philosophy of responsive teaching (Tomlinson, 1999, 2014), approaches to pedagogy that balance disciplinary integrity with youth as scientific thinkers necessarily acknowledge and attend to student differences in ways of knowing, ways of participating in, and ways of doing science as "assets on which to build- both for the benefit of the student and ultimately of science itself" (NRC, 2012, p.28). In science classrooms, this means that teachers orchestrate learning around the "big ideas" or the explanatory mechanisms of science that offer students great capacity to access, construct, and explain a coherent storyline of the world around them. They elicit, attend to, and make visible the substance of students' everyday ideas, experiences and discourses; ways of characterizing, organizing, and reasoning about scientific phenomena; and areas of interest and curiosity as the terrain for co-constructing, negotiating, and refining explanatory models over time. And they continually develop, monitor, and adjust instruction to ensure that high standards of disciplinary learning are both accessible and achievable for all students on an individual and social plane.

Grounded in a deep understanding of subject-matter and responsive to students' evolving thinking and needs, these types of day-to-day instructional patterns have been particularly influential in broadening student access points to, participation in, and understanding of science content and practice (e.g., Barton & Tan, 2009; Ballenger, 1997; Duschl, 2008; Lee & Buxton, 2011; NRC, 2007; Rodriguez & Berryman, 2002; Warren et al., 2001). Appropriately labeled as ambitious, however, images of responsive teaching are rare across American science classrooms where commonplace pedagogies remain rooted in "teacher-dominated discourse, textbook-based lessons, [and] coverage as the main curricular principle" (Sykes, Bird, Kennedy, 2010, p. 465). Moreover, university-based teacher education, as a primary path for those seeking teacher certification, is routinely criticized for failing to ensure that all candidates develop a beginning repertoire of knowledge, skills, and dispositions to carry out the interactive work of responsive teaching, or the "core tasks that teachers must execute to help pupils learn" (Ball & Forzani, 2009, p. 497). More recently, Secretary of Education Arne Duncan (2009) stated, "By almost any standard, many if not most of the nation's 1,450 schools, colleges, and departments of education are doing a mediocre job of preparing teachers for the realities of the 21st century classroom." Broadly, two recurring and interrelated dilemmas of teacher education underpin an emerging agenda of change: (a) the curriculum of teacher preparation, or *what* beginning teachers learn, and (b) the pedagogies of teacher preparation that support the development of professional practice, or *how* beginning teachers learn.

Challenges to realizing ambitious teaching in teacher preparation programs.

From a curricular perspective, the design of high-quality curriculum originates from a clear set of goals and objectives that reflect the essence of the discipline (Tomlinson & McTighe, 2006). Clarity in such goals for teacher education has the potential to facilitate a cohesive vision and progression of what novice teachers learn, how they learn, and how they demonstrate what they have learned across preparatory experiences. Yet, for decades, studies of teacher education have illuminated the lack of consensus in a core set of professional knowledge, skills, language, and shared resources that orient novice teacher learning across and between systems of teacher preparation (Ball & Forzani, 2009; Cochran-Smith & Zeichner, 2005; Darling-Hammond, 2006; Levine, 2006; NRC, 2010). To date, what prospective teachers learn appears to be more reflective of an instructor's background experiences, level of expertise, orientations to learning, and personal preferences (Berry & VanDriel, 2012; Levine, 2006; Wilson, Rozelle, & Mikeska, 2011). In his influential report, Levine (2006) characterized teacher education programs as “unruly and chaotic,” lacking a coherent and cohesive progression of novice teacher learning. Consequently, beginning teachers often struggle to reconcile tensions between differing conceptions about “what counts” as effective and equitable science teaching across learning-to-teach contexts (e.g., personal experiences, university coursework, field-based placements), experiencing an eclectic mix of activities rather than an evolution of ideas, skills, and dispositions that can be built, shaped, and refined over time (Levine, 2006; Roth & Garnier, 2006).

Further, while the field of teacher education has progressed in specifying and supporting myriad types of knowledge domains for teaching (e.g., content knowledge, theories of student learning, instructional frameworks and strategies), surprisingly little scholarship has focused on the pedagogies of teacher preparation that build teachers’ capacity to skillfully carry out, reflect on, and refine course-developed ideas and skills in real-time teaching contexts. In the traditional model of university-based teacher preparation, the bulk of learning how to navigate the dynamic interactions of students around subject matter occurs in school settings during "the rush of minute-to-minute practice" (Ball & Cohen, 1999, p. 14). University faculty are largely absent in these settings (Levine, 2006) and in too many instances, the prevailing “cultural script” or the commonplace norms and features of teaching (Sykes et al., 2010) have worked against the development of innovative pedagogies (Kennedy, 1999; Thompson, Windschitl, & Braaten, 2013). Therefore, while beginning teachers can often articulate and demonstrate student-centered learning approaches in written lessons and units, teacher preparation programs typically fall short of helping novices transition from what they know and believe into action (Clift & Brady, 2005). Also referred to as the “problem of enactment," or the distance between teachers' knowledge for teaching and their readiness to enact this knowledge (Kennedy, 1999), this disjuncture has been described as one of the most daunting challenges novices face in attempting to appropriate responsive pedagogy with diverse student populations (Clift & Brady, 2005; Davis, Petish, & Smithey, 2006; Hammerness et al., 2005; Kennedy, 1999; Rochkind, Ott, Immerwahr, Doble, & Johnson, 2008).

A *potentially* promising pathway: Practice-based pedagogies in teacher education.

With a deliberate orientation to achieving ambitious learning goals for all students, a growing number of policymakers, scholars, and educators have advocated for a practice-centered approach to teacher education and learning, focusing directly on the interactive and relational work of responsive teaching as the content and context for novice teacher learning (Ball & Cohen, 1999; Levine, 2006; Grossman, Compton, et al., 2009; National Council for Accreditation of Educator Preparation [NCATE], 2010). Within this broad conceptualization, the curriculum of teacher education shifts away from a dominant emphasis on knowledge for teaching and toward specifying a core set of interrelated "learning-to-teach" practices or a "candidate core" (Windschitl et al., 2012) that: (a) orient the development of a shared vision, pedagogy, and testable theory of novice teacher learning across and between systems of teacher preparation; (b) are limited in number, evidence-based, and reflect the priorities of equitable and responsive pedagogy or those at the heart of the work of teaching that are most likely to affect student learning (Ball & Forzani, 2011); (c) function as frameworks of meaning (Sousa & Tomlinson, 2011), entangling the coevolution of teachers' knowledge, dispositions, and skills; and (d) ascend in depth and complexity, allowing ample time for novices to build and demonstrate increasingly sophisticated and systematic instantiations of these practices as they move through preparatory experiences and into the initial years of teaching (Grossman, Hammerness, & McDonald, 2009; McDonald, Kazemi & Kavanagh, 2013; Windschitl et al., 2012). Also referred to across the literature as high-leverage teaching practices (HLTPs), Windschitl et al. (2012) pointed out that the identification of these practices is not intended to "replace novices' experiences with assessment, curriculum development, use of material resources, etc., but rather they would act as an organizational framework into which these other components would be integrated during preparation" (p. 879). Examples of HLTPs that have emerged specifically in science education include: selecting the big ideas of the discipline and treating them as evolving explanatory ideas and models; attending to the substance and diversity of students' ideas and reasoning to adapt instruction; and pressing for evidence-based explanations (Thompson et al., 2013; Windschitl et al., 2012).

Closely related is the development of practice-centered pedagogies in higher education that draw on novices' current pedagogical visions and developing repertoires of practice to support the development and enactment of core practices. For teacher educators, this means "unpacking and specifying practice in detail and designing professional education that will offer novices multiple opportunities to practice the work and fine-tune their skills" (Ball & Forzani, 2009, p.498). In their cross-professional investigation of how novices are prepared for professional practice in seminaries, in schools of clinical psychology, and in teacher education, Grossman, Compton, et al. (2009) identified three key and interrelated components of practice-based pedagogies in professional education: decompositions, representations, and approximations of practices. *Decomposing practices* offer novices opportunities to deconstruct and reconstruct complex practices, examining the salient parts of teaching and subsequent connections to student learning (Grossman, Compton, et al. 2009). For example, the core practice of *attending to the substance of students' ideas and reasoning to adapt instruction* can be systematically unpacked as three differing, yet interrelated practices: attending to or "seeing" the substance of students' ideas and reasoning, interpreting the substance of students' ideas and reasoning, and linking patterns in individual and collective students' ideas and reasoning, inclusive of strengths, struggles and motivations, to "next steps" in instruction. *Representations of practice*, such as video analysis, case analysis, and modeling, make visible and represent images of the HLTPs under study (Grossman, Compton et al., 2009; McDonald et al., 2013). Also referred to as *pedagogies of investigation* (Grossman, Hammerness, et al., 2009), decompositions and representations of practice focus on "seeing" and learning about key aspects of teaching. Notably different, *approximations of practice* or *pedagogies of enactment* (Grossman, Hammerness, et al., 2009) engage novices in "opportunities to rehearse and enact discrete components of complex practice in settings of reduced complexity" (Grossman, Hammerness, et al., 2009, p. 283). For example, activities such analyzing student thinking to inform pedagogical decisions afford novices opportunities to rehearse, revise, and retry interactive "slices" of larger HLTPs with targeted feedback and reflection (e.g., Lampert et al., 2013; Windschitl, Thompson, & Braaten, 2011).

Taken together, Grossman and colleagues (Grossman, Compton, et al., 2009; Grossman, Hammerness, et al., 2009) pointed out that teacher educators tend to emphasize pedagogies of investigation at the expense of pedagogies of enactment. Scholars theorize that better integrating pedagogies of investigation and enactment in university settings can potentially support teachers in weaving together knowledge of responsive teaching with their evolving readiness to enact this knowledge across learning-to-teach settings (McDonald et al., 2013). However, empirical studies are just beginning to document what and how preservice teachers learn in cyclic interactions of pedagogies of investigation and enactment, or *practice-centered pedagogies,* in pathways of teacher preparation (Lampert, Beasley, Ghousseini, Kazemi, & Franke, 2010).

Statement of the Problem

Today, science classrooms are being viewed as working communities in which a teacher's primary role is to mediate increasingly sophisticated forms of disciplinary discourse and activity in ways that maximize the potential of students with varying backgrounds and experiences; ways of talking, thinking and reasoning; and areas of interest and curiosity to grow and succeed (Tomlinson, 1999, 2014; NRC, 2012). Lampert and her colleagues (2013) argued that realizing equity and excellence in disciplinary learning for all students, hinges, in part, on bolstering the curriculum and pedagogies of higher education that prepare the next generation of teachers to interact with students around subject matter in ways that are not common in schools today. This argument resonates with nationwide recognition that "the interactions between teachers and students in individual classrooms are the determining factor in whether students learning science successfully" (NRC, 2012, p. 255).

In turn, a rethinking of the field of teacher education around a curriculum of core practices has inspired a growing research agenda in science education that examines: (a) a developing theory of how and why beginning teachers learn to *appropriate* ambitious or responsive teaching; (b) the pedagogies of practice that optimize prospective teachers' understanding and enactment of ambitious teaching across learning-to-teach contexts; and (c) the development of a shared and evidence-based system of socio-professional routines, tools, and resources tailored to the needs of novices and supportive of these endeavors (e.g., McDonald et al., 2013; Thompson et al., 2013). However, while there are early and promising indications that ambitious teaching is within the grasp of beginning teachers (Windschitl et al., 2012), empirical studies are just beginning to unravel whether, why, and how novices develop early-career expertise of HLTPs with principled conditions of support.

In this study, I explore the use of practice-centered pedagogies as a vehicle for building novice teacher capacity to *attend to the substance of students' ideas and reasoning in adapting instruction.* This core practice has been identified as central to engaging a wide range of learners in the conceptual, epistemic, and social processes of science to generate evidence-based explanations of the world around them (Coffey, Hammer, Levin, & Grant, 2011; Hammer, Goldberg, & Fargason, 2012; NRC, 2007; Windschitl et al., 2012). Hammer and van Zee (2006) posited that "the most effective teaching is responsive to students' ideas and reasoning. What we see and hear in children's thinking affects our judgments about methods and strategies, both on the fly during class and in planning" (p. 37). That is, if students' ideas and experiences, ways of thinking and reasoning, and interests are to influence the content and inquiry norms as practiced in science classrooms, then teachers must work to surface and attend to students' ideas - "seeing", interpreting, and following up on their thinking in ways that value students' ideas and reasoning as objects of inquiry (Levin, Hammer, & Coffey, 2009; Tomlinson, 1999).

Research has revealed, however, that attending to the substance and diversity of students' ideas and reasoning to inform instruction is difficult for prospective teachers (Levin et al., 2009; Levin & Richards, 2011; Meyer, 2004; Otero & Nathan, 2008). While studies have shown that preservice teachers acknowledge the importance of students' ideas in shaping teaching and learning, they often lack an understanding of the substance and complexity of students' thinking, embracing student ideas as evidence of content coverage (Crespo, 2000; Larkin, 2012; Morrison & Lederman, 2003; Otero & Nathan, 2008). Further, researchers have also documented the struggle to incorporate student thinking into instruction in ways that advance individual and collective student learning (Davis et al., 2006; Meyer, 2004). Levin and Richards (2011) posited that these challenges may originate, in part, from a lack of opportunities in university settings for preservice teachers to engage with the intellectual work of interrogating and making sense of students' thinking to inform instruction. In their review of formative assessment practices in teacher education, Coffey et al. (2011) noted that science content and practice is frequently, while perhaps unintentionally, treated as a correct body of information, and the assessment of student thinking and reasoning as a check on its correctness against this information (i.e., a gap to be fixed). To date, teacher educators tend to distill myriad strategies for probing and assessing student understanding, often neglecting opportunities for teacher candidates to unravel and engage with multiple facets of students' thinking and reasoning "in ways that are consistent with how students should learn to assess ideas as participants in science" (Coffey et al., 2011, p. 1122). A small but growing number of studies, however, have shown that novices can learn to be more responsive to the substance of students' thinking in instruction when challenged to systematically inquire into the day-to-day work of teaching (e.g., analyzing and interpreting student work to inform pedagogical decisions) as a primary mechanism of teacher learning (Grossman & McDonald, 2008). For example, Windschitl et al. (2011) engaged prospective science teachers in multiple cycles of analyzing student work, supported by a protocol designed to mediate teachers' talk in ways that balanced accountability to the discipline with accountability to student thinking. These educators found that collegial inquiry into student work helped teachers "see" and build on students' nuanced understandings in designing next steps in instruction that were responsive to students' evolving thinking and needs across learning-to-teach contexts. This study, as an introductory example, reflects the potential of attending to the substance of students' ideas and reasoning less in terms of what teachers *do* in terms of strategies, and more of what teachers *see* in informing responsive instruction (Coffey et al., 2011).

In an effort to make the interactive and relational work of *attending to the substance of students' ideas and reasoning to adapting instruction* more accessible to early career teachers, I build on this existing work, engaging prospective teachers in a practice-centered module that uses analyses and interpretation of student work as the content and context of novice teacher learning. More specifically, this dissertation situates teacher learning in collaborative analyses of student work, guided by pedagogical tools that align socio-professional work, to support interrelated connections between: (a) preservice teachers' understanding of the substance and function of students' intellectual, epistemological, and social resources in developing explanatory ideas and models, and (b) their developing readiness to attend to or "see," interpret, and use students' ideas and reasoning to inform "next steps" in instruction. Through this study, I am interested in learning whether, how, and why novice teachers learn in contexts where teaching practices such as analyzing and responding to students' nuanced thinking are represented, are rehearsed by candidates, and are supported by interactions with peers, classroom artifacts, and pedagogical tools. To date, few finely-grained and contextualized descriptions of how beginning teachers learn to appropriate responsive instructional practices in relationship to learning in, from, and for practice exist. The following research questions guide this study:

1. How do preservice teachers participate in pedagogies of practice, grounded in tool-supported analyses of student work, to attend to, interpret, and use student thinking to adapt secondary science instruction?
2. What features and conditions of a practice-oriented pedagogical approach seem to shape how preservice teachers attend to, interpret, and use student thinking to adapt secondary science instruction?

Research Significance

With a deliberate orientation to realizing ambitious learning for all students, this dissertation seeks to understand how and why novice teachers learn to teach in ways that engage a wide range of learners deeply with science. While systems of teacher preparation remain a *potentially* powerful leg of a teacher's journey, emerging research has shown that traditional approaches to teaching and learning in these systems fall short of preparing teachers to skillfully interact with diverse students over high standards of disciplinary thinking and learning (Levine, 2006). In this study, I join a growing collaboration of teacher educators who are working to re-imagine and improve the pedagogies of higher education that support the development and enactment of responsive teaching. While early studies have reflected the promise of situating novice teacher learning in the interactive and relational work of teaching as a primary learning mechanism, research is needed to conceptualize and unpack what this type of teaching and learning "looks" like in a university setting, and what, how, and why beginning teachers learn to use knowledge in action (Cook & Brown, 1999). In a conceptual sense, this dissertation builds on and extends current work in the field.

I also seek to contribute to the educational research community. Wilson (2013) identified the lack of theory describing teacher learning processes as a "grand challenge" of improving science teacher learning and education in the United States. Central to this challenge is a lack of sound measures needed to systematically assess, inform, and improve teacher learning and development over time (Wilson, 2013). Consistent with her points, a search of the literature revealed that studies tracing preservice teacher learning in science commonly (a) measured teacher learning outcomes at few and varied time scales (e.g., beginning of the semester, after a teaching episode, end of the semester), and (b) utilized gross and summative measures of teachers' knowledge, conceptions, or dispositions as a proxy for the uptake of reform-based practice. Collectively, these studies paint a limited picture of *how* teachers learn in, from, and for practice (Lampert, 2010). As such, I use a methodological approach that affords a fine-grained and contextualized analysis of teacher thinking and doing in examining the "dialectical relationship between learning opportunities and (at least intended) learning outcomes as they evolve over time and the theories about how novices learn that underlie them" (Moss, 2011, p. 2886). Methodologically, this study seeks to inform (a) a growing theory of how and under what conditions novices, both individually and collectively, learn to teach responsively over time, and (b) the design of university curriculum, instruction, and assessment that catalyze early-career expertise in responsive teaching.

Finally, and most practically, Windschitl and his colleagues (Windschitl et. al, 2012; Thompson et al., 2013) have repeatedly emphasized the need for a shared vision, language, and pedagogy of ambitious teaching in the field of science education. Practically, teacher educators would benefit from the on-going development of a shared repertoire of socio-professional routines and pedagogical tools that orient and support novice teacher learning in ways that balance integrity to the scientific discipline with the thinking and needs of both K-12 students and beginning science teachers. In this study, I draw from, extend, and add to an emerging and shared repertoire of pedagogical tools in science education that have been designed to support the development of responsive teaching in science.

Theoretical Perspective

This study is informed by a situative perspective (Borko, 2004; Cobb & Bowers, 1999; Greeno, 2006; Lave & Wenger, 1991; Putnam & Borko, 2000). Within this lens, an individual teacher's knowledge, thinking, and learning is constructed and refined through participation in the discourses and practices of a community, and are shaped by local interactions with the cultural scripts, people, artifacts, and tools in these settings (Greeno, 2006; Lave & Wenger, 1991; Sykes et al., 2010). Traditionally, preservice education programs have fostered and studied the development of knowledge and skills for responsive teaching independently of the dynamic contexts in which they are applied, leaving this aspect of development to the idiosyncrasies of fieldwork (Levine, 2006). From a situative perspective, however, Peressini, Borko, Romagnano, Knuth, and Willis (2004) have suggested that:

> Rather than asking whether or how knowledge transfers across situations, researchers within a situative tradition ask questions about the consistency of patterns of participation across situations, conditions under which successful participation in activity in one type of situation facilitates successful participation in other types of situations, and the process of recontextualizing resources and discourses in new situations. p. 70

With respect to teacher education, situative theorists emphasize the value of creating opportunities for teachers to work together on developing and improving repertoires of practice, and locating these opportunities in the day-to-day challenges and practices of ambitious teaching – regardless of the venue (Ball & Cohen, 1999; Putnam & Borko, 2000).

In this dissertation, I draw on the situative perspective as compelling framework for designing and studying the broad influence of practice-centered pedagogies on novice teachers' developing readiness to understand and enact ambitious forms of teaching with diverse student populations. Derived from this perspective, the design of the practice-centered module used in this study is built on three guiding principles:

1. Novice teachers have been participants and will continue to participate as "learners of teaching" across multiple contexts in their lifetime (Lortie, 1975). Practice-centered approaches to teaching and learning must capitalize on and build from teachers' current pedagogical visions, ways of making sense of teaching, and evolving instructional repertoires.

2. Novice teacher learning is situated in the interactive, relational, and day-to-day practices of teachers, such as analyses and interpretation of classroom records of practice, enabling them to continue learning over time.

3. Novice teacher learning entails ongoing development of a shared vision of rigorous and responsive science teaching in a community of teacher-learners.

Consistent with these principles, I view teacher learning in this dissertation as changing participation how teachers *attend to substance students' ideas and reasoning in adapting instruction* across planning and reflection activities, and in interactions with peers, with records of classrooms practice, and with pedagogical tools.

To adequately capture and study novice teacher learning, a situative perspective enables a researcher to focus attention on individual teachers as learners and on their participation in communities of learners (Putnam & Borko, 2000). Employing a multifocal lens, I will use multiple units of analysis in this study, including the individual teachers, the learning context, and the social interactions of teachers (Borko, 2004) to analyze whether, how, and why prospective learn to appropriate HLTPs with principled conditions of support.

Overview of Study

This qualitative embedded single-case study traces preservice teachers' developing repertoires of practice as related to attending to, interpreting, and using students' ideas to adapt instruction over time, and in interactions with with peers, with pedagogical tools, and with classroom artifacts. Notably, this type of inquiry necessitates a fine-grained and contextualized description and analysis of action, capturing teacher voice and interactions with peers and pedagogical tools. The interpretive tradition or qualitative methods, which purposes are to "document in detail the conduct of everyday events and to identify the meanings that those events have for those who participate in them and for those who witness them" (Erickson, 2012, p. 1451), are well-matched to this study.

Accordingly, multiple sources of qualitative data will be collected before, during, and after the module implementation to: (a) ascertain teachers' initial and unfolding repertoire of ideas and enacted practices as related to attending to, interpreting, and using students' ideas and reasoning to inform "next steps" in instruction across planning and reflection activities; (b) build a "thick description" and understanding of how and why preservice teachers' developing ideas and practices shift over time; and (c) identify features and conditions of practice-oriented pedagogies that may facilitate or hinder novice teacher learning. These sources of data include: university class observations, semi-structured interviews, and sets of tasks and prompts within an online learning tool. Using a cross-unit analysis of teachers' developing instructional repertoires and evolving stances towards subject matter, stances towards how students learn science, and stances towards science teaching, I am interested in learning whether, how, and why novice teachers learn in contexts where teaching practices aimed at analyzing and responding to student thinking are represented, are rehearsed, and are supported by a range of interactions with peers and pedagogical tools.

CHAPTER TWO: LITERATURE REVIEW

Preparing the next generation of science teachers to enact rigorous and responsive instruction is at the core of reform in science education (NRC, 2012). For a wide range of learners, a vision of science-as-practice scaffolds students' legitimate participation in disciplinary work and activity to develop and refine increasingly sophisticated, evidence-based explanations of the world around them. This requires, in part, that teacher educators learn how to build novice teacher capacity to systematically attend to or "see", interpret, and respond to diversity of students' ideas and reasoning as they evolve over time (Ball & Cohen, 1999). In this chapter, four topics function cohesively to inform this study: (1) the role of students' conceptual, epistemological, and social resources, or students' ideas and reasoning, in teaching and learning science; (2) preservice teachers' understanding and use of students' ideas and reasoning in teaching and learning science; (3) the role practice-based pedagogies in teacher preparation in supporting novice teacher learning; and (4) the specific role of tool-supported, collegial analyses of classroom records of practice in building novice teacher capacity to analyze and respond to student thinking.

The Role of Students' Ideas and Reasoning in Teaching and Learning Science

> *How we, as researchers and teachers, view the sense-making resources that children bring from their backgrounds of life experience will have very real consequences for how children are about to participate in science.*
>
> *Warren, Ogonowski, & Pothier, 2005, p. 144*

A large body of research in science education has indicated that students arrive in classrooms with diverse resources for interacting with and making sense of the world around them (Maskiewicz & Winters, 2012; NRC, 2012). These resources can be loosely examined as three interrelated types of student contributions: conceptual, epistemological, and social.

Conceptual resources. Conceptually, a prolific line of research in science education has shown that learners have and draw on a diversity of intuitions and ideas about the behavior the natural world in learning science (Driver & Easley, 1978; Duit, 2009; NRC, 2007). These naïve intuitions and ideas, while often inconsistent with currently accepted scientific ideas (i.e. non-normative), are largely derived from and have explanatory power in students' engagement with the environment around them – both in and out of formal schooling contexts (NRC, 2007, 2012). And while there is clear consensus that students' initial ideas about the subject matter influence learning (Bransford, Brown, & Cocking, 1999; Vygotsky, 1978), the literature depicts varying perspectives on the role of students' ideas in classrooms, or *how* and *why* teachers use students' ideas in teaching and learning science.

On one hand, eliciting and interpreting students' diverse ideas has been and continues to be widely couched in terms of revealing "misconceptions," or ideas at differing levels of "correctness" against canonical ideas that need to be overcome or replaced with targeted instruction. For example, in their work with 8th grade students, Yenilmez and Tekkaya (2006) elicited students' pre-instructional ideas about photosynthesis and respiration of plants. Common student ideas included: "photosynthesis provides energy for plant growth," and "plants respire only at night because they undergo photosynthesis in the sunlight" (Yenilmez & Tekkaya, 2006). Following up on students' ideas, Yenilmex and Tekkaya engaged students with text and discussion aimed at "identifying common misconceptions, activating students' misconceptions by presenting examples and questions, presenting descriptive evidence in the text that the typical misconceptions were incorrect, and providing a scientifically correct explanation of the situation" (p. 83). Likewise, in a study of tiered instruction on academic achievement in secondary science, Richards and Omdal (2007) grouped high school freshman based on "correctness" of pre-instructional ideas in relationship to an astronomy unit (e.g., low background knowledge learners, middle background knowledge learners, high background knowledge learners). Described by the researchers, instructional tasks were tailored to each group of students as they moved toward content mastery, ranging from engagement with basic information and at-grade level work for low background learners to engagement with a greater depth of information and above grade level work for high background learners (Richards & Omdal, 2007). In both of these representative examples, researchers and teachers maintained what Stroupe (2014) described as cognitive or instructional authority - eliciting a range of students' pre-instructional ideas, assigning levels of "truth" or value to these ideas, and to adapting instruction in ways that remediate, remedy, and extend students' ideas with more sophisticated scientific understandings. Notably, both examples are also compatible with much of school science, emphasizing what Schwab (1966) calls a "rhetoric of conclusions," or teacher-centered instruction aimed at mastering unmitigated entities of scientific knowledge. Problematically, this weak role of students' ideas in teaching and learning science (a) leaves students little agency in their own work (Stroupe, 2014), and

(b) grossly overlooks or underestimates the rich repertoire of resources students have for developing sophisticated explanatory ideas and models of the world around them (Lee and Buxton, 2011; NRC, 2012).

In contrast, a growing number of scholars have cast the diversity of students' ideas and intuitions as rich intellectual resources, or the raw materials of learning science (Hammer, 2000; Larkin, 2012; Maskiewicz & Winters, 2012; Stroupe, 2014). This perspective is grounded in the premise that all learners have valuable ideas, intuitions, and experiences that can be leveraged as objects of continual inquiry as leaners work to build, negotiate, and refine increasingly coherent explanatory ideas of world around them - on an individual and social plane (NRC, 2012). For example, in his work with secondary science teachers, Stroupe (2014) described a student who hypothesized that the earth is closer to the sun in the summer than in the winter. Rather than identifying and treating this intuition or idea as "correct" or "incorrect," the teacher made the hypothesis visible on a class poster and over time, students worked on peer-reviewing this claim, coordinating ideas and evidence from class investigations (Stroupe, 2014). As reflected in this case, teachers working within this perspective share cognitive authority with students - eliciting, making visible, and using a wide range of students' ideas in combination with other resources (e.g. peer ideas, primary and secondary data sources) to orchestrate rich disciplinary activity in working communities of learners. Positioning students' diverse ideas, intuitions, and lived experiences as integral resources to learning science, pedagogy in these classrooms stems from, is responsive to, and cultivates students' emerging ideas, their questions, and their curiosities as the terrain of on-going investigation (Lee & Buxton, 2011) – ultimately privileging students' epistemological and social contributions to learning science.

Epistemological and social resources. In contrast to a view of science as a "rhetoric of conclusions" (Schwab, 1966), current reform efforts in science education are driven by a view of science-as-practice (Lehrer & Schauble, 2006; NRC, 2012). This perspective acknowledges that "science is not just a body of knowledge that reflects current understanding of the world; it is also a set of practices used to establish, extend, and refine that knowledge" (NRC, 2012, p. 2-3). Said differently, science is portrayed as a dynamic and social theory-building enterprise that problematizes knowledge in dialogic interactions (Mortimer & Scott, 2003). In classrooms, this means that teachers work to scaffold students' on-going participation and growth in valued forms of disciplinary talk and activity (e.g. modeling, representation, and argumentation discourse) to develop knowledge and to understand how scientific knowledge is generated and assessed over time (Lehrer & Schauble, 2006; NRC, 2007). Disciplinary rigor for all students, then, is conceptualized around explanatory rigor (Thompson et al., 2016), or communities of students working to continually build, test, and refine evidence-based and generalizable explanations of phenomena around them.

Importantly, a science-as-practice view "embraces greater, rather than less, heterogeneity" in the classroom (Tomlinson, Brimijoin, & Narvaez, 2008, p. 30). That is, pedagogy that balances disciplinary integrity with youth as scientific thinkers intentionally acknowledges and leverages the inevitable diversity of students' personal and culturally-based ways of knowing, ways of talking, and ways of thinking and reasoning about scientific phenomena, or students' epistemological and social resources, as (a) profoundly continuous with the way science is practiced in scientific communities (Gutiérrez & Rogoff, 2003, Lee & Buxton, 2011; Warren et al., 2001), and (b) integral to learning science. For example, Emdin's (2010) research has explored the use of analogy in hip-hop culture as a powerful means of connecting students and their everyday worlds to teaching and learning science, thereby reducing urban students' alienation in schools. Likewise, the Chèche Konnen Project has provided myriad examples of how students, many of whom are traditionally marginalized in today's science classrooms, make sense of scientific phenomenon using differing ways of talking and thinking about the world in ways that generatively intersect with scientific practices (Hudicourt-Barnes, 2003; Warren et al., 2001). Researchers from this project have suggested that:

> [learners'] inventive use of narrative, animated modes of argumentation, dynamic ways of imagining themselves into physical phenomena, among other sense-making resources, have repeatedly challenged teachers and researchers to examine their own, often limited and limiting, assumptions about what constitutes productive reasoning and deep understanding in the sciences. (Warren, Ogonowski, & Pothier, 2005, p. 122)

As such, it is important for teachers to recognize and support productive seeds of disciplinary thinking and reasoning, or students' sense-making practices, within evolving ideas and intuitions - regardless of how "scientific" these initial ideas may seem (Russ, Coffey, Hammer & Hutchinson, 2009). For example, Russ et al. (2009) analyzed a classroom episode in which a second-grade teacher elicited possible explanations for why an empty juice box, begins to collapse when a person drinks with a straw. One student, Erin, suggested that air inside the box is what holds the shape, so that when the air is sucked out, there is not as much air pushing the box out – making it collapse. When the teacher asked Erin to explain why the box would collapse without anything pushing it in, Erin stated that "Maybe it's pressure, I don't know" (Russ et al., 2009, p. 12). Showing interest in the term "pressure," the teacher asked Erin what the term means, to which she replied "It's something that's hard to explain" (Russ et al., 2009, p.12). The teacher then directed the class towards explaining what pressure is.

Working to explain this example, Russ et al. (2009) argued that the teacher's focus on reaching a canonical understanding overlooked strengths in this student's mechanistic reasoning, or the causal story Erin was actively constructing to make sense of this phenomenon. Likewise, in a mixed-methods study that explored differences in sense-making classroom discourse within and across 222 secondary science lessons stemming from 37 teachers involved in a two-year preparation and induction program, Thompson et al. (2016) also found that 32 out of 37 teachers (i.e., 74.3 percent) elicited a range of students' ideas, but subsequently narrowed the set of possible ideas to normative ideas, doing little to recognize and support students' sense-making capabilities. These studies may help to illuminate, in part, why the sense-making resources of children from diverse communities are so rarely seen and valued in the science classroom (Warren et al., 2001).

Perhaps, to more effectively leverage Erin's productive ways of reasoning in furthering the development this partial understanding on an individual and social plane, this teacher may have opted (a) to ask students compare and contrast this phenomena with similar instances from their everyday lives, (b) to encourage students to compare and contrast their explanations, and (c) to offer students an opportunity to negotiate and revise their developing "storylines" based on emerging observations and evidence (Russ et al., 2009). In this differing turn of events, students are positioned as epistemic agents in their learning - building and assessing the merits of their own ideas and reasoning in ways that reflect how ideas are assessed in science: "they make sense; they are supported by the available evidence; [and] they have explanatory and predictive power" (Coffey et al., 2011, p. 1122). Such an approach privileges questions such as: How are students participating? What types of evidence and logic are they using, and what meanings are they trying to convey? What are key strengths and struggles in how students are making sense of phenomena – individual and collectively? And what types of resources, routines, or tools can scaffold students' continual access to, participation in, and growth in rigorous disciplinary work?

In summary, students bring diverse repertoires of conceptual, epistemic, and social resources to learning science (i.e., ideas, ways of knowing, ways of participating in, and ways of doing science) – largely grounded in and extending from their everyday experiences, interactions, and discourses across multiple communities (Lee and Buxton, 2011; NRC, 2012; Warren et al., 2001). As such, recognizing and attending not only the "conceptual aspects" of student thinking, but to the ways that students take up the pursuit of scientific understanding is central to (a) broadening student access points to, participation in, and understanding of science content and practice (e.g. Barton & Tan, 2009; Ballenger, 1997; Duschl, 2008; Lee & Buxton, 2011; NRC, 2007, 2012; Rodriguez & Berryman, 2002; Warren et al., 2001); (b) helping teachers and their students better "see" what learners are capable of, and (c) informing "next steps" in instruction in ways that best leverage and support the diverse repertoire of resources students individually and collectively bring to learning.

Preservice Teachers' Understanding and Use of Students' Ideas and Reasoning in Teaching and Learning Science

In realizing rigorous learning goals for all students, Thompson et al. (2016) argued that teacher educators and teachers will need to focus not only on furthering a vision for what is possible in classroom activity, but on the pedagogies that afford educators the capacity to work in interactions of diverse learners and subject matter on a day-to-day basis. In working in the gap between idealized and realized pedagogy (Michaels, O'Connor, & Resnick, 2008), this study seeks to build novice teacher ability to *attend to the substance of students' ideas and reasoning in adapting instruction*. When students' diverse repertoires of conceptual, epistemic, and social resources, or ideas and reasoning, are positioned as central assets in learning, Forzani (2014) noted that the classroom becomes, in part, an unpredictable place. Thus, the capacity of teachers to attend to or "see," to interpret, and to respond to the substance of student thinking within the complexities of disciplinary activity – across planning, instructing, and reflection activities – is central to engaging a wide range of learners in science (Ball & Cohen, 1999; Barnhart & van Es, 2015; Coffey et al., 2011; Jacobs, Lamb, & Philipp, 2010; Windschitl et al., 2012).

Specifically in pathways of teacher preparation, *attending to the substance of students' ideas and reasoning to adapt instruction* has been identified as a high-leverage teaching practice, or one that (a) reflects the priorities of equitable and responsive teaching, or the day-to-day pedagogies at the heart of teaching that are most likely to affect student learning (Ball & Forzani, 2011; Windschitl et al., 2012); (b) functions as a "framework of meaning " (Sousa & Tomlinson, 2011), or a sense-making structure that can be revisited in increasingly sophisticated instantiations as novices make sense of how students learn and "what counts" in understanding and realizing ambitious learning for all students; and (c) scaffolds teachers' developing capacity to problematize teaching, affording them early mechanisms to systematically analyze and learn from their own practice (Hatch & Grossman, 2009). To date, researchers have used records of classroom practice as one means of investigating or scaffolding teachers' attention and responsiveness to student thinking. For instance, Sherin and her colleagues (e.g., Barnhart & van Es; 2015; Sherin & van Es, 2005, 2009), among other scholars (e.g., Star & Strickland, 2008), have done extensive work using video of classroom interactions to help both preservice and inservice teachers "learn to notice" and interpret differing dimensions of learners' scientific or mathematical thinking. Others have used artifacts of student work to examine how prospective science teachers approach the analysis of written student responses (e.g., Talanquer, Bolger, & Tomanek, 2015), or collegial analysis of student work to facilitate critique and change in practice (e.g., Kazemi & Franke, 2004; Windschitl et al., 2011). Across these studies, several themes have emerged in relationship to: (1) how prospective teachers attend to or determine "what counts" in students' ideas and reasoning; (2) how they interpret the meanings in what they see and hear; and (3) how they link patterns in students' ideas and reasoning, both individually and collectively, to "next steps" in instruction. Together, and working in tandem, these practices have been defined under the umbrella of "teacher noticing," or learning how individuals process and make sense of complex situations (Jacobs et al., 2010). Developed most extensively in mathematics education, I draw from this body of literature to illuminate strengths and struggles in novices' developing readiness to understand, support, and use students' diverse resources to cultivate genuine engagement in disciplinary activity.

Attending to students' ideas and reasoning. As previously articulated, all students bring to learning a diverse repertoire of resources for engaging in rigorous disciplinary talk and activity (NRC, 2007, 2012). Supporting continual growth for learners largely depends on a teacher's capacity to pay close attention to the substance of and nuances in these resources. Hammer and van Zee (2006) argued that "the most effective teaching is responsive to students' ideas and reasoning. What we see and hear in children's thinking affects our judgments about methods and strategies, both on the fly during class and in planning" (p. 37).

Positively, studies have shown that preservice teachers generally acknowledge the importance of eliciting and attending to student thinking in teaching and learning science (Davis et al., 2006; Hammer & van Zee, 2006; Larkin, 2012). Research has indicated, however, that novices often notice and attend to generalities in or superficial aspects of students' ideas (Levin & Richards, 2011; Windschitl et al., 2011; Talanquer et al., 2015), or on how the whole class is reasoning (Erickson, 2011). For example, Talanquer, Bolger, and Tomanek (2015) asked 32 prospective teachers to analyze and assess four samples of chemistry students' responses to two formative assessment probes. Each probe prompted students to select one among three multiple-choice answers to a question, followed with an explanation of their thinking and reasoning. Talanquer et al. (2015) noted that preservice teachers had a tendency to describe students' ideas (i.e., restate what a student said) or make judgments about the quality of student work, in lieu of seeking nuances in individual student's ideas and understandings. Windschitl, Thompson, and

Braaten (2009) likewise found that when working with secondary preservice science teaching to examine student work, they often attended to broad generalizations, unlinked to details in students' ranging ideas. Thus, what teachers attend to and use as evidence of students' evolving ideas may not afford them enough information to construct meaningful inferences about and connections between student learning and pedagogical decisions.

Additionally, Talanquer et al. (2015) noted that a student's selection of a correct multiple-choice answer seemed to divert teacher attention away from examining the substance of students' reasoning, while a student's selection of an incorrect multiple-choice answer seemed to divert teacher attention away from productive elements in students' reasoning (Talanquer et al., 2015). Likewise, Hammer (1997), among a handful of other scholars (e.g. Coffey et al., 2011; Levin & Richards, 2011), have also documented teachers' struggle to "see" students' sense-making practices within their developing ideas. For example, Levin and Richards (2011) indicated that at the beginning of a science pedagogy course, teacher candidates tended to make general claims about student reasoning, such as "They're doing good stuff, they're reasoning, they're connecting with prior knowledge" (p. 7). And while studies that examine teachers' attention to facets of disciplinary practices within the substance of students' evolving ideas and intuitions are scarce, it appears that novices exhibit differing levels of readiness to "see" a holistic portrait of students' strengths, struggles, and motivations not only in students' ideas and intuitions, but in their ways of thinking, reasoning, and communicating portrayed within these ideas.

These representative cases, among other studies (e.g. Jacobs et al., 2010; Levin et al., 2009; Otero & Nathan, 2008; Sun & van Es, 2015), have suggested that while novices certainly have nascent resources for attending to student thinking (Levin & Richards, 2011), they often struggle to "see" or privilege attention to multiple facets of and meaning in students' ideas *and* their ways of reasoning – individually and collectively. In a mixed-methods analysis of the relationships between preservice science teachers' capacities to attend, to analyze, and to respond to student thinking, Barnhart and van Es (2015) found that without sophisticated attention to student thinking, teachers demonstrated low occurrences of sophisticated analysis (i.e., interpretation of student thinking) and response (i.e., taking up and using evidence of student thinking to inform "next steps" in instruction). As such, building novice teacher capacity to attend to multiple dimensions of students' ideas and reasoning as they build and refine explanatory ideas may function as a cornerstone practice in cultivating rigorous and responsive teaching in teacher preparation pathways.

Interpreting students' ideas and reasoning. What teachers "see" or notice in interactions of students and subject matter can enable or constrain inferences about how students are understanding, how students are reasoning, and how students are participating in disciplinary work. Stemming primary from work in mathematics education, scholars have used the construct of "analytic stance" to discern the extent to which teachers evaluate or interpret what they observe. Researchers characterize shifts towards more responsive teaching as moving from an evaluative stance, or diagnosing "correctness" in student thinking to an interpretive stance, or working to access, draw out, and make sense of the meanings students are trying to convey, or the rationality of their reasoning (e.g. Barnhart & van Es, 2015; Larkin, 2012; Levin et al., 2009; Levin & Richards, 2011; Talanquer et al., 2015; Windschitl et al., 2011). For example, working to interpret how a chemistry student explained what happens over time to the total mass of jar filled with wet iron nails, one preservice teacher stated:

> Not only did this student get both wrong, she applied bizarre reasoning to both. The student fails to understand that in her system mass has not magically disappeared. She again fails to reason through the second answer very well. She claims that first there's water and nails in the jar. Then a few weeks later she claims that since there's water, nails, and now rust, that it has to weigh more. She fails to account how the mass making up the rust occurred. (Talanquer et al., 2015, p. 597)

In this example, the teacher primarily restated what the student wrote, and centered interpretations on failed or "incorrect" aspects of this students reasoning. Moreover, there is little emphasis on trying to understand the meanings this student was trying to convey, or on the strengths and struggles in how this chemistry student was working to piece together and communicate a causal storyline of the phenomenon (Russ et al., 2009). In a similar vein, Windschitl et al. (2011) engaged 11 secondary science teachers in collegial analyses of student work as a basis of systematic critique and growth in practice over two years - in teacher preparation and into the first year of teaching. They found that participants who interpreted student learning as a "get it" or "don't get it" occurrence often framed dilemmas of practice as "problems with students," attributing a "failure to learn" on individual student abilities or effort (Windschitl et al., 2011). Operating from this stance, teachers focused on adapting instruction to "fill in the gaps" for students who didn't learn from instruction-as-planned (Windschitl et al., 2011).

Contrasting this stance, Talanquer et al. (2015) offered another example of a preservice teacher who interpreted the same student's response to the probe. The teacher candidate explained:

> In the first example, the student is using previous knowledge of how smoke behaves in a room on fire to account for what they are seeing within the burning jar. He or she is also assuming that rust is heavier than water (because it doesn't float?) based on some idea of the molecules of rust and water that isn't quite explained in his or her answer. This student has a pretty solid belief about density and states of matter and seems to be able to use his or her logic in both situations, which means whether or not the student's understanding is correct, it's robust enough to not just be applied to one instance like the first two students did. (Talanquer et al., 2015, p. 597)

Reflecting an interpretive stance, this teacher attended to students' ideas *and* productive aspects of reasoning with the aim of accessing a student's understanding, independently of whether the student was "correct" or "incorrect." Moreover, this teacher linked specific evidence from student work student to emerging interpretations. Likewise, Windschitl, et al. (2011) noted that participants who interpreted student work with the aim of inquiring into differing facets of learner understanding – individually and collectively – made references to specific details in students' work, looked for evidence of partial understandings, and developed evidence-based hypotheses that connected student learning with pedagogical decisions. Framing dilemmas of practice as "puzzles of practice," Windschitl et al. (2011) indicated that teachers' collegial discussions were often accompanied by talk of high expectations of all students, using the language of "support and scaffolding" to ensure that all students had access to and support in evolving disciplinary learning.

Drawing attention to the critical role of interpretation in a teacher's developing repertoire of practice, van Es & Sherin (2008) argued that how educators make sense of what they "see" is as important as what they attend to in classroom records of practice. As such, supporting teachers' developing readiness to synthesize and make sense-of students' ideas and reasoning is central not only to cultivating an interpretive stance toward classroom data, but to enacting teaching practices that continually build on, support, and extend students' thinking.

Responding to students' ideas and reasoning. Consistent with Tomlinson's philosophy of responsive teaching (Tomlinson, 1999, 2014), pedagogy that balances disciplinary integrity with youth as scientific thinkers necessarily attends to, leverages, and supports student differences in everyday ideas, experiences, and discourses; ways of thinking, reasoning, and communicating about scientific phenomena; and interests and curiosities (i.e., students' resources) to scaffold on-going participation and continual growth in disciplinary activity. Yet, teaching that is simultaneously accountable to disciplinary rigor (i.e., the pursuit of increasingly coherent and evidence-based explanations of the natural world) and responsive to students' evolving strengths, struggles, and motivations is inherently complex. Beginning with an intellectually-rich learning framework that is grounded in the "big ideas" or the "substantive relationships between concepts in the form of scientific models that help learners understand, explain, and predict a variety of important phenomena in the natural world" (Windschitl et al., 2012, p. 888), Hammer et al. (2012) pointed out that at any given time, there may be substantial variability in students' evolving ideas and reasoning. Managing this uncertainty stems, in part, from teachers developing capacity to "see", to interpret, and to link patterns in students' individual and collective ideas *and* reasoning, inclusive of their strengths, struggles, and motivations, to pedagogical decisions that maximize the potential of all students to participate, learn, and succeed (Tomlinson, 2014). At times, this means that teachers leverage and make visible students' differing ideas and intuitions as key resources for building and refining evidence-based explanations (Lee & Buxton, 2011; Stroupe, 2014). For example, in a high school physics unit on force and motion, Windschitl et al. (2012) described how one teacher, Camille, anchored this unit in a phenomenon familiar to students in an urban landscape – gymnastics. After showing a video clip of a young person running up to a building, launching upward with one foot on the wall, and then flipping backward to land, Camille's students "spontaneously" began developing myriad hypotheses, or tentative explanations of this phenomenon- all of which were recorded as claims for student investigation (Windschitl et al., 2012). Students constructed initial models of this phenomenon and over time, these models functioned as objects of on-going talk and revision as students continually linked observation and evidence from a range of sources (Windschitl et al., 2012). As reflected in this example, Camille leveraged the diversity of students' everyday ideas, experiences, and language as legitimate resources in building explanatory ideas, furthering discussion, catalyzing substantial student participation and learning.

At other times, however, teachers recognize the need to provide students with resources or tools that scaffold, mediate, or extend participation in rich disciplinary discourse and reasoning. For example, Wang, Thompson, and Windschitl (2014) found that the strategic use of scaffolds, such as sentence frames and explanation checklists, provided learners with differing strengths and struggles access to and growth in disciplinary activity and talk. And at other times, this means that teachers use students' differing lived experiences or curiosities as rich and familiar contexts for (a) building explanatory ideas or models, or (b) exploring how explanatory ideas and models play out in differing and sometimes complex conditions (Wang et al., 2014). Importantly, these pedagogical approaches reflect a "menu of possibilities" (Hammer et al., 2012) that scaffold students' access to as well as legitimate participation and growth in intellectually demanding tasks that integrate the conceptual, epistemic, and social processes of science.

While compelling, portraits of teaching and learning that balance disciplinary rigor and responsiveness to students in science are rare across the literature. In their analysis 222 secondary science lessons and 1,174 teaching episodes stemming from 37 teachers involved in a two-year preparation and induction program, Thompson et al. (2016) found that only six percent of the observed lessons were high in both rigor and responsiveness. Research has indicated prospective teachers struggle to know what to do with students' ideas and experiences (Davis et al., 2006; Jacobs et al., 2010; Levin, 2012; Meyer, 2004). Further, their capacity to adapt instruction appears to be, in part, intertwined with their developing readiness to "see," and to interpret differing facets of students' evolving ideas and thinking, and then use what they have learned to make evidence-based instructional decisions (e.g., Barnhart & van Es, 2015; Jacobs et al., 2010; Windschitl et al., 2011). For example, Windschitl et al. (2011) found that novices who framed dilemmas of practice as "puzzles of practice" (a) engaged in an in-depth analysis and interpretation of student work over time, and (b) reshaped classroom discourse, tasks, and lines of student thinking based on patterns of evidence in students' evolving ideas and reasoning – individually and collectively. In contrast novices who framed dilemmas of practice as "problems with students" minimally engaged in analyses and interpretation of student work, focusing primarily on implementing instructional strategies to "fix" deficits in lackluster student performance (Windschitl et al., 2011). Likewise, using video cases and structured protocols to help secondary science teacher candidates learn to systematically attend and respond to students thinking as evidenced in lesson plans, student work, and a video of teaching, Barnhart and Van Es (2015) also found that highly sophisticated follow-up moves (i.e., taking up student ideas to inform and propose evidence-based "next steps" in instruction), whether proposed or enacted, were dependent on highly sophisticated attention to and analyses and interpretation of student ideas. These researchers noted, however, that learning to attend or see the details in student thinking did not guarantee that prospective teachers would take up those ideas and use them as evidence to inform instruction (Barnhart & van Es, 2015). As such, these, in addition to a handful of other studies (e.g., Sun & van Es, 2015; Jacobs et al., 2010), have suggested that beginning teachers may benefit from learning experiences that help them more effectively link patterns of individual and collective student thinking to "next steps" in instruction in ways that are (a) accountable to the integrity of a specific discipline, and (b) accountable to a range of learners.

In summary, recent research in science education advocates for an increased focus on preparing beginning teachers enact teaching practices that are at the core of rigorous and responsive teaching and learning. In this study, the core practice of *attending to the substance of students' ideas and reasoning to adapt instruction* entails: (1) learning to "see" multiple facets of students' ideas and their ways of thinking, reasoning, and communication about scientific phenomena, (2) learning to interpret the meanings students, individually and collectively are working to convey; and (c) learning to use this evidence to proactively increase student access to, success with, and growth in high-level intellectual and disciplinary activity, or adapting "next steps" in instruction (Tomlinson, 2014). As indicated, a growing body of work suggests that collegial inquiry into records of classroom practice, such as student work, is a *potentially* promising avenue of scaffolding teachers' developing attention and responsiveness to student thinking. Stemming from the cited literature, engaging novice science teachers in this type of professional work may support the following indicators of growth:

- Shifts from making broad generalizations about student ideas to bringing forth and "seeing" multiple facets of students' conceptual, epistemic, and social resources in developing explanatory ideas and models. Novices can make individual and collective student claims about students' strengths, struggles and motivations, and support these claims with evidence.

- Shifts from an evaluative stance toward student thinking or diagnosing "correctness" to an interpretive stance toward student thinking. Novices can look for and interpret the meanings or reasoning students are working to convey.

- Shifts from reasoning about "next steps" in instruction in the abstract, to linking patterns of individual and collective student ideas and reasoning – inclusive of strengths, struggles, and motivations – to evidenced-based and defensible "next steps" in rigorous and responsive science instruction. Novices can propose or develop a range of conceptual, epistemic, and social scaffolds and extensions to ensure that learning is relevant, accessible, and continually challenging for students – individually and collectively.

A host of scholars posited that purposefully designed teacher learning communities, supported by shared system of tools and routines that prioritize student thinking, can help catalyze such shifts (e.g., Barnhart & van Es, 2015; Levin & Richards, 2011; Sun & van Es, 2015; Thompson et al., 2013; Windschitl et al., 2011). In the next section, I draw from this literature, exploring pedagogies in higher education that support rigorous teacher learning "in, from, and for practice" (Lampert, 2010).

Supporting Novice Teacher Learning: Pedagogies of Practice in Teacher Preparation

A vision of science education guiding national reform efforts is intended to guide substantial change in K-12 teaching practices and, in parallel, university pedagogies that support the next generation of science teachers working toward more ambitious forms of student learning. Distinct from past standards of learning that separated entities of content and process skills (e.g., AAAS, 1993; NRC, 1996), a contemporary vision of science education positions students as legitimate participants in the conceptual, epistemic, and social processes of science to build and refine increasingly sophisticated explanatory ideas and models of the world around them (NRC, 2012). Premised on this vision, calls for more rigorous forms of student learning couple with calls for equally ambitious forms of teaching. Appropriately labeled as *ambitious* (Smylie & Wenzel, 2006), this type of teaching deliberately works beyond the status quo of teacher-dominated discourse and content coverage (Sykes et al., 2010) to ensure that every student has equity of access to, engagement with, and continuous growth in the intellectual work of science. In teacher preparation, this means that novices learn to orchestrate learning around the "big ideas" of science that afford students great capacity to access, build, and explain a coherent storyline of the world around them. They learn to elicit, attend to, and make visible students' evolving ideas and reasoning about scientific phenomena as the terrain for co-constructing, negotiating, and refining explanatory ideas and models over time. And they learn to continually monitor and adjust instruction *in response to what students do*, ensuring that high standards of disciplinary learning are both accessible and achievable for all students on an individual and social plane.

Historically, pathways of teacher preparation have been successful in helping novices articulate new visions of science teaching and learning, and take up a range teaching strategies to support these visions (Clift & Brady, 2005). Yet, while beginning teachers can often demonstrate student-centered learning approaches in written lesson plans and units, teacher preparation programs typically fall short of helping novices *enact* rigorous and responsive teaching practices that realize such visions (Clift & Brady, 2005; Davis et al., 2006; Kennedy, 1999). To date, teaching and learning in higher education remains largely grounded in a knowledge- and skills-acquisition perspective of learning-to-teach, privileging teacher educators as the primary arbiters of normative ideas and practice. As Levine (2006) explained in his influential review of teacher education: "University-based teacher education has focused on teaching rather than learning. The mark of program success has been whether graduates have been taught the skills and knowledge necessary to teach, rather than whether they are effective in promoting student learning" (p. 28). As Coffey et al. (2011) argued, a dominant focus in teacher preparation on developing knowledge and strategies for teaching, however, often neglects novice teacher attention to and meaningful engagement with the types of student thinking and reasoning that these very strategies are intended to support. Presently, the literature indicates that there are few opportunities for prospective teachers to participate in the rigorous and sense-making practices of the profession (e.g., attending to, interpreting, and linking evolving instantiations of student thinking to evidence-based pedagogical decisions) to build, test, and continually refine a beginning instructional repertoire consistent with responsive science teaching over time (Clift & Brady, 2005, Levin & Richards, 2011; Zeichner, 2010).

With a deliberate orientation to achieving ambitious learning goals for all students, a growing number of policymakers, scholars, and educators have advocated for the development of practice-centered pedagogies in higher education, anchoring teacher learning in interactive and relational work of the profession (Ball and Cohen, 1999; Levine, 2006; NCATE, 2010). In response, a growing number of teacher educators have worked on organizing preparation of preservice teachers around a "learning-to-teach" core of teaching practices, such as *attending to substance of students' ideas and reasoning to adapt instruction,* that underpin a robust system of rigorous, responsive, and student-centered pedagogy (e.g., Boerst, Sleep, Ball, & Bass, 2011; Kazemi, Lampert & Franke, 2009; McDonald et al., 2013; Windschitl et al., 2012). Notably, Windschitl et al. (2012) posited that the identification of these practices is not intended to "replace novices' experiences with assessment, curriculum development, use of material resources, etc., but rather they would act as an organizational framework into which these other components would be integrated during preparation" (p. 879). For example, opportunities to *attend to the disciplinary substance of students' ideas and reasoning* through analysis of classroom data (e.g., student work and thinking) can be worked on repeatedly, and in increasingly sophisticated ways through preparatory experiences and into the initial years of teaching to (a) gain insights into a wide range of students as evolving learners of science, (b) make sense-of and grapple with the efficacy of formative assessment strategies and data in teaching and learning, and (c) link individual and collective student thinking to proposing, assessing, and innovating differing instructional adaptions that further individual and collective student growth. Notably, functioning as frameworks of meaning (Sousa & Tomlinson, 2011), the development of these core practices entangles teacher development of knowledge, dispositions, and skills into coherent vision of "what counts" in realizing and enacting ambitious learning goals for all students.

Closely related is the development pedagogies in higher education that support the progression and enactment of core practices over time. Working beyond an acquisition model of teacher learning (McDonald et al., 2013), practice-centered pedagogies structure novice teacher learning within the tasks and challenges that permeate teachers' day-to-day work. Situating learning in approximations of professional practice, such as analyses and interpretation of student work to adapt instruction, seeks to provide teachers with opportunities to grapple with both the science itself and how students are learning in complex interactions of subject matter and diverse learners (Reiser, 2013). As such, practice-centered pedagogies are intended to help novices develop, negotiate, and refine a beginning repertoire of knowledge, skills, and dispositions to enact core practices *in the contexts* of their use (Ball and Cohen 1999).

Further elaborating on practice-centered pedagogies, Grossman and colleagues (2009) described three key components these pedagogies: decompositions, representations, and approximations of practice. *Decomposing practices* affords novices opportunities to deconstruct, examine, rehearse, and reconstruct core practices, examining the salient parts of teaching and subsequent connections to learning (Grossman, Compton, et al. 2009). For example, the larger core practice of *attending to the substance of students' ideas and reasoning to adapt instruction* can be temporarily "sliced," unpacked, and examined as three interrelated sub-practices: (a) "seeing" the substance of students' ideas and their ways of thinking, reasoning, and communication about scientific phenomena, or attending to students' ideas and reasoning; (b) finding nuances and meaning in individual and collective student thinking, or interpreting the substance of students' ideas and reasoning; and (c) using the substance of students' ideas and reasoning to proactively increase student access to and growth in high-level intellectual and disciplinary activity, or linking patterns in individual and collective student thinking to "next steps" in instruction (see Figure 1). Consistent with the body of literature on "teaching noticing," these three sub-practices appear to work systematically to support teachers' attention and responsiveness to student thinking (e.g., Barnhart & van Es, 2015; Kang & Anderson, 2015; Jacobs et al, 2010).

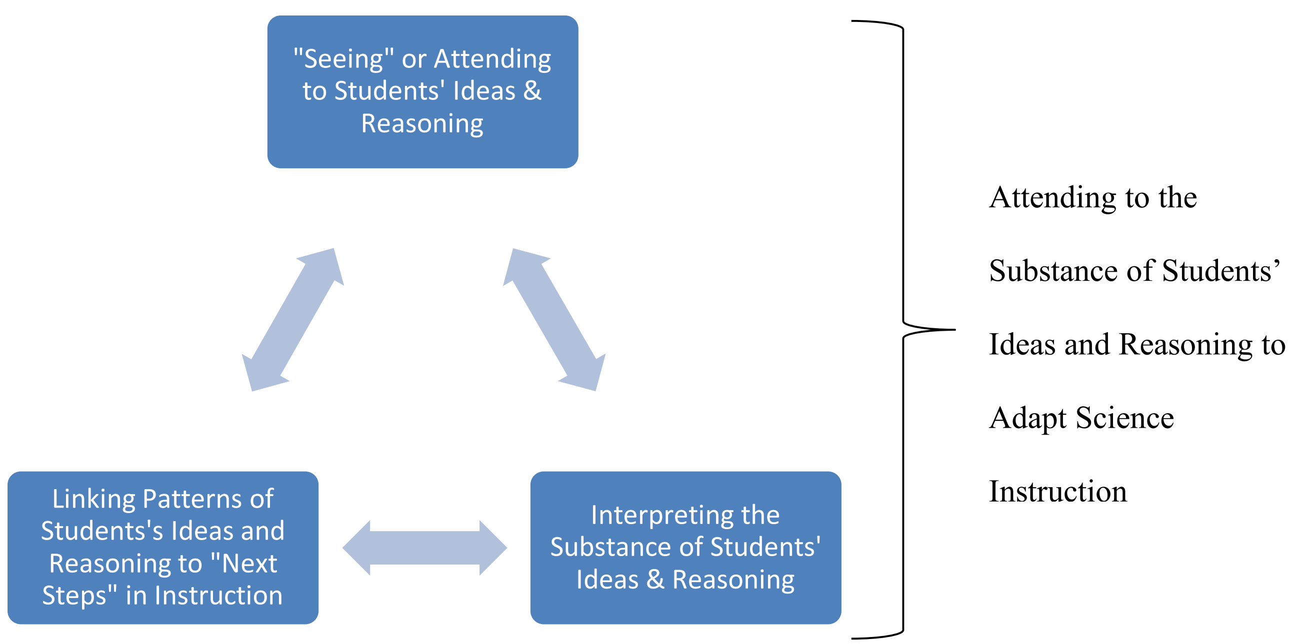


Figure 1. Beginning repertoire of teaching practices under study.

Next, *representations of practice* help preservice teachers access, interrogate, and develop an image of the embedded practices under study (McDonald et al., 2013). Used frequently in teacher education, examples of these pedagogies include video examination of classroom teaching and learning, analysis of vignettes or case studies, and modeling, or simulated segments of lessons. Collectively, these types of pedagogies work to structure teacher sense-making around rich images of teaching and learning that reflect the complexities of teacher-learning interactions in specific contexts (Reiser, 2013). For example, in this study, novices will analyze two case studies of teachers who use student work to plan an upcoming lesson, interrogating salient features of a teacher's pedagogical reasoning and practice underpinning differing instantiations of attending and to responding to student thinking in science (e.g., stances toward interpreting student thinking, differing ways of linking patterns of student thinking to pedagogical decisions, and types of resources used to support broad participation of students). Also referred to as *pedagogies of investigation* (Grossman, Hammerness, et al., 2009), decompositions and representations of practice *represent* images or core practices, in contrast to being practice itself.

Markedly different and significantly less visible in university coursework, *approximations of practice,* or *pedagogies of enactment* (Grossman, Hammerness, et al., 2009) engage novices in "opportunities to rehearse and enact discrete components of complex practice in settings of reduced complexity" (Grossman, Hammerness, et al., 2009, p. 283). That is, novices are given opportunities to participate in day-to-day practices of teaching, catalyzing teacher learning in ways that approximate the development of knowledge and learning in the profession. Britzman (1991) postulated that this type of learning space provides "encouragement to raise questions that attend to the possible and acknowledge the uncertainty of our educational lives. For in doing so, we can begin to envision the discourses, voices, and discursive practices that can access the possible" (p. 243). For example, in work novice secondary science teachers, Windschitl et al. (2011) found that collegial analysis of classroom records of practice opened spaces for teachers to talk about, to interrogate, and to problematize features of and connections between subject matter, the complexity of students' thinking, and differing teaching approaches. And as evidenced in their research, these types of learning experience have the potential to catalyze shifts in thinking and practice as teachers construct and negotiate identities as members of a community focused on students' thinking (Windschitl et al., 2011). In this same vein, this study situates novice science teacher learning in the interactive practices of attending to and interpreting student work to adapt "next steps" in instruction.

Taken together, scholars theorize that better integrating pedagogies of investigation and pedagogies of enactment in university settings *can potentially* help beginning teachers weave together knowledge of responsive teaching with their evolving readiness to enact this knowledge across learning-to-teach contexts (Ghousseini & Herbst, 2014; McDonald et al., 2013). However, empirical studies in science education are only just beginning to reveal what and how novices learn in university contexts where responsive teaching practices are made visible in myriad ways and worked on repeatedly in the context of classroom practice. In this study, I draw from this scholarship, exploring the use of practice-centered pedagogies that decompose, make visible, and engage novices in the interactive and relational work of *attending to the substance of students' ideas and reasoning to adapt instruction.*

A Situative Perspective: The Design and Support of Novice Teacher Learning Experiences

Preparing teachers to enact rigorous and responsive instruction, consistent with science-as-practice, is at the core of reform in science education (NRC, 2012). This requires, in part, that teacher candidates learn to systematically attend to, interpret, and respond to the nuances of students' ideas and reasoning as they evolve over time (Ball & Cohen, 1999). In an effort to make the interactive and relational work of *attending to the substance of students' ideas and reasoning to adapt instruction* more accessible to early career teachers, this study situates teacher learning in a practice-centered module (i.e., sequence of learning experiences) that is grounded primarily in collegial analyses of records of classroom practice, and guided by pedagogical tools that frame professional work to support interrelated connections between: (a) preservice teachers' understanding of the substance and function of students' conceptual, epistemic, and social resources in developing explanatory ideas and models and (b) their developing readiness to attend to, to interpret, and to use students' ideas and reasoning to adapt "next steps" in instruction – across planning and reflection activities.

Notably, the design of module (i.e., teacher learning experiences) is informed by a situative perspective (Borko, 2004; Cobb & Bowers, 1999; Greeno, 2006; Lave & Wenger, 1991; Putnam & Borko, 2000). Within this lens, an individual teacher's knowledge, thinking, and learning is constructed and refined through participation in the discourses and practices of a community, and shaped by local interactions with the cultural scripts, people, artifacts, and tools in these settings (Greeno, 2006; Lave & Wenger, 1991; Sykes et al., 2010). As such, I conceptualize prospective teacher learning around the representative and changing ways that novices individually and collectively participate (a) in teaching practices related to attending to student thinking, interpreting student thinking, and linking patterns of individual and collective student thinking to "next steps" in instruction; and (b) in interactions with peers, with records of classroom practice, and with pedagogical tools. In viewing learning as meaningful participation in a community of practice (Lave & Wenger, 1991), the social and material context of practice emerge as two central concepts in supporting teacher learning and growth.

Social context of teacher learning. Prospective science teachers have been and continue to be members of multiple discourse communities as "learners of teaching" (e.g., as learners in K-12 settings, as learners in college or university settings, and as teacher-learners across learning-to-teach contexts). In these differing communities, Gutierrez and Rogoff (2003) posited that individuals often develop ways of engaging in activity that are related to their past form forms of participation. Undoubtedly, teachers' interactions with actors, artifacts, tools, and institutional messages within and across these communities have influenced and continue to influence "what counts" in developing pedagogical visions, instructional repertoires, and ideas about learners and learning in science (Lortie, 1975; Kennedy, 2010; Skyles, et al., 2010).

Accordingly, approaches to teaching and learning within this practice-centered module draw on, make visible, and leverage teachers' current pedagogical visions, ways of reasoning and making sense of teaching, and evolving instructional repertoires as key intellectual and social resources in working communities of teacher-learners. Ball and Cohen (1999) argued that it is "not sufficient simply to see what one already assumes about students, learning, and content; one would also need to see others' assumptions, differences in their content and effects, or unexpected effects of one's own ideas and practices" (p. 14). As such, this module privileges peer collaboration, affording novices a space to problematize elements of and connections between subject matter, student learning, and approaches to teaching as they work to co-construct, refine, and negotiate an instructional repertoire related to analyzing and responding to student work.

Further, within these collegial conversations and work, Thompson, Windschitl, and Braaten (2013) emphasized the importance of teachers' "critical pedagogical discourses" or evolving personal stances on "what counts" in productive teaching and learning. Drawing from Cochran-Smith and Lytle's work on inquiry-as-stance (1999), the notion of a stance is conceptualized around:

> the positions teachers and others who work together in inquiry communities take toward knowledge and its relationships to practice. We use the metaphor of stance to suggest both orientational and positional ideas, to carry allusions to the physical placing of the body as well as to the intellectual activities and perspectives over time. In this sense, the metaphor is intended to capture the ways we stand, the ways we see, and the lenses we see through." (pp. 288-289)

That is, when teachers interact and work together, studies have indicated that they often take stances, or positions toward subject matter, toward how students learn, and toward images of teaching. For example, Thompson et al. (2013) found that teachers who appropriated ambitious practices over time developed critical pedagogical discourses that focused intensely on understanding how students make sense of science, and how to advance differing learner ideas. In contrast, they also found that critical pedagogical discourses, or stances developed "around the execution of instructional strategies (even strategies aimed at supporting student reasoning) result[ed] in trajectories that do not readily incorporate ambitious practice" (Thompson et al., 2013, p. 607). In studies of mathematics teacher groups, Kazemi and Franke (2004) likewise described shifts in teachers' stances as they interacted around examination of student work over an academic school year. Specifically, Kazemi and Franke noted that as teachers worked on practices such as eliciting student thinking and analyzing student work, their stances towards how students learn shifted from students as "unsuccessful learners of math," in which learning follows linearly from teaching, to "learners as powerful mathematics thinkers," in which learning is inherently complex, and necessitates multiple opportunities and ways to reason with and make sense-of mathematics. Additionally, Warren et al. (2001) posited that "researchers' and teachers' evaluations of children's talk as scientific or not derive in significant part from their view of what constitutes scientific practice and ways of knowing" (p. 546). In totality, these representative studies have shown that teachers' evolving stances towards science as a discipline, towards how students learn science and toward images of teaching science, or the commonly referenced "instructional triangle" in the literature (Cohen, Raudenbush, & Ball, 2013; Tomlinson, 2014), can potentially shape or be shaped by interactions with colleagues, with artifacts of classroom practice, and with pedagogical tools. However, this literature remains substantially underdeveloped in teacher preparation. In this study, as beginning teachers work to develop instructional repertoires aimed at attending and responding thinking, I will trace novices' stances toward science as a discipline, toward how students learn science, and toward images of science teaching within collegial discourse and work in an effort to gain insights into (a) a nuanced portrait of novices' pedagogical reasoning as it co-evolves with the development of practice, and (b) potential conditions of support or "stepping-stones," tailored to novices' thinking and needs, that support individual and collective teacher learning trajectories.

Material context of teacher learning. A focus on the situated nature of teacher learning suggests that teachers' classrooms function as powerful learning contexts (Putnam & Borko, 2000). However, while it is not always feasible to situate preservice teacher learning in "live classrooms," it is possible to bring elements of classroom practice, such student work, into university settings. Yet, simply gathering teachers together to look at artifacts of classroom practice does not ensure that meaningful learning will occur (Little, Gearhart, Curry, & Kafka, 2003; Slavit, Nelson, & Deuel, 2013). Guidance and support, in the form of pedagogical tools, appears to be a key element of cultivating collegial construction and critique of ideas and reasoning (e.g., Levin et al., 2009, Star & Strickland, 2008; Windschitl et al., 2011, Thompson et al., 2013).

Accordingly, prospective teachers will interact with two forms of pedagogical tools within the practice-centered module. The first type includes protocols or guides that scaffold teacher inquiry into student work, classroom case studies, and simulated lessons. Of central importance, protocols can help (a) structure a safe context for opening up and representing one's practice to others (Little & Curry, 2008), (b) scaffold focused and in-depth conversation (Horn & Little, 2010), and (c) novices "see" a vision of what is possible in realizing ambitious teaching and learning (Putnam & Borko, 2000; Thompson et al., 2013). In work with secondary science novice teachers, Windschitl and colleagues (e.g., Windschitl et al., 2011; Thompson et al., 2013) illuminated the potential of these tools to embody the ideas, reasoning, and language congruent with a community of teachers working to deliberately taking up ambitious teaching. More specifically, in facilitating analyses of student work and thinking, Windschitl et al., 2011 found that a protocol and rubric were central to facilitating teacher learning in two primary ways: (1) providing a structure and language that helped participants attend to, "see," and talk about facets of students' evolving ideas, and (2) pressing teachers to dually grapple with and be accountable to an understanding of science subject matter and student thinking represented in work. However, few, if any published protocols across the literature scaffold teacher inquiry into artifacts of classrooms practice in ways that are aligned a vision of science-as-practice, privileging attention to students' evolving ideas *and* reasoning, inclusive of strengths, struggles, and motivations. Expanding on the work of Windschitl et al. (2011), the protocols and guides in this study are designed to help novices (a) "see" and interpret multiple dimensions of students' ideas as their ways of reasoning, communicating, and making sense of natural phenomena on both an individual and collective level; and (b) link patterns of individual and collective student thinking, inclusive of strengths, struggles, and motivations, to "next steps" in instruction in ways that balance integrity to science with youth as scientific thinkers. As Thompson et al. (2013) emphasized, these types of discipline-specific tools can potentially diminish vision-to-practice gaps, and fuel experimentation and innovation as novices grapple with appropriating disciplinary rigorous and responsive teaching.

Secondly, as previously articulated, novices bring diverse repertoires of ideas, practices, and dispositions to learning – largely formed from negotiated participation in multiple discourse communities as "learners of teaching" over a lifetime (Lortie, 1975). Effective teaching in higher education, in parallel to K-12 education, occurs when novices are given opportunities to build on this repertoire; adding, testing, integrating, and refining ideas and practices over time (Darling-Hammond, 2006; Linn & Eylon, 2011). However, although teacher education programs can and should offer differing types and amounts of support for ambitious teaching, ultimately, Alsup (2006) postulated that it is preservice teachers themselves who must make grapple with and assess the value of differing aspects of pedagogies in light of ongoing work in developing classroom practice. To this end, scholars have noted that novices need substantial support in making sense of and reflecting on participation in reform-based work (Davis, 2004), narrating their own stories of struggles and growth across a learning trajectory (Sfard and Prusak, 2005).

As such, novices will engage with technology-enhanced tools within the module to help "narrate a storyline" of their learning progression through practice-centered learning experiences. More specifically, I will use the Web-Based Inquiry Science Environment (WISE) interface, an open-source digital learning platform maintained at the University of California, Berkley, to support novice teacher inquiry into classroom records of practice as the basis of advancing practice. Notably, the WISE platform is grounded in the knowledge integration (KI) framework (Linn, 1995; Linn & Eylon, 2011). Built on a robust body of literature underpinning how individuals learn, the KI framework catalyzes learning through patterns of making learners' initial ideas visible, introducing new insights or resources, and helping individuals continually distinguish, integrate, revisit and refine myriad ideas (e.g., students' ideas, primary and secondary data sources) over time. Primarily used with K-12 students, WISE hosts a variety of middle and high school inquiry-based curriculum modules with embedded tools, such as dynamic visualizations, explanation builders, online discussion boards, and reflection prompts to facilitate and capture on-going student thinking. As students engage with WISE, teachers have the capability of monitoring student thinking and progress, illuminating student ideas on a social plane, and offering feedback. In K-12 settings, WISE has been instrumental in helping educators "see" and link evidence of on-going student thinking to customizations of WISE curriculum projects (e.g., Gerard, Spitulnik, & Linn, 2010; Slotta, 2004; Matuk, Linn, & Eylon, 2015).

Applying KI to higher education, Gerald, Varma, Corliss, & Linn (2011) postulated that teacher educators can support novices in building repertoires of practice by making visible the focal practices under study, introducing new insights into teaching and learning, and privileging evidence of student learning (e.g., student thinking and work) to help teachers distinguish, integrate, and continually reflect on and refine ideas and practice over time. To facilitate this endeavor, I will use the WISE platform, and embedded tools for making individual teacher thinking visible, for engaging teachers in a continuous cycle of revisiting and refining their own ideas, and for monitoring teacher thinking and providing feedback – over time and in interactions with classroom records of practice, peers, and tools – to engage teachers in "narrating" their own learning trajectories.

In summary, as a vision of science-as-practice vision works to shift not only what is taught in science, but how science is experienced by a wide range of learners in K-12 settings, university pedagogies will undoubtedly need to shift as well (Reiser, 2013). In this dissertation, I examine the influence of practice-centered pedagogies on teacher candidates developing readiness to attend *to substance of students' ideas and reasoning to adapt instruction* across planning and reflection activities, and in interactions with peers, with records of classrooms practice, and with pedagogical tools. Consistent with a situative perspective, I will trace the co-evolution of teacher candidates' (a) participation in practices related to attending to, interpreting, and linking patterns of student thinking within student work to "next steps" in science instruction, and (b) their evolving stances towards students as science learners, stances towards science content and practice, and stances towards science teaching (see Figure 2). By situating novice teacher learning "in, from, and for practice" (Lampert, 2010), I examine the possibility that with principled conditions of support, novices can develop an early-career instructional repertoire that enables them to *enact* practices central to making high standards of student learning – across disciplinary knowledge and practice - both accessible and achievable to diverse student populations.

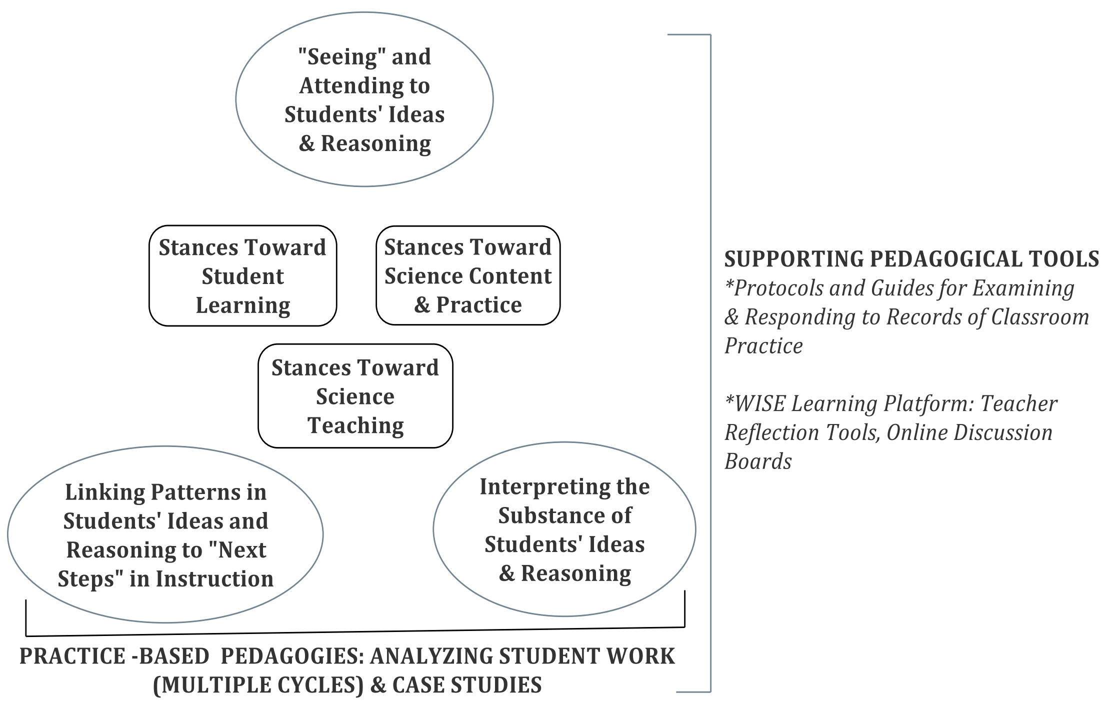


Figure 2. Conceptual framework: The influence of practice-centered learning on novice teacher capacity to *attend to the substance of students' ideas and reasoning to adapt instruction.*

CHAPTER 3: METHODS

This qualitative embedded single-case study explores how preservice science teachers participated in practice-centered pedagogies, grounded in tool-supported analyses of student work, to enact one of four high-leverage practices identified as central to supporting student learning in science: *attending to the substance of students' emerging ideas and reasoning to adapt instruction* (NRC, 2007; Reiser, 2013; Windschitl et al., 2012). More specifically, this study situates novice teacher learning in the interactive and relational work of teaching (e.g., analyzing and responding to student thinking) to ascertain: (a) preservice teachers' unfolding ideas and repertoires of practice as related to attending to, interpreting, and responding to student work across planning and reflection activities; and (b) features and conditions of practice-oriented pedagogical approaches that potentially supported novice science teacher learning and growth.

Methodologically, adequately examining relationships between pedagogical approaches and shifts in novice teacher learning over time necessitates a fine-grained description of actions that capture teacher voice and discourse, and privilege attention to context or as Erickson (1985) described, local meaning. Stemming from a relativist oncology and a constructivist epistemology, the interpretive tradition, which purposes are to "document in detail the conduct of everyday events and to identify the meanings that those events have for those who participate in them and for those who witness them" (Erickson, 2012, p. 1451), were well-matched to this study. Two overarching research questions framed this study:

1. How do preservice teachers participate in pedagogies of practice, grounded in tool-supported analyses of student work, to attend to, interpret, use student thinking to adapt secondary science instruction?
2. What features and conditions of a practice-oriented pedagogical approach seem to shape how preservice teachers attend to, interpret, and use student thinking to adapt secondary science instruction?

The remainder of this chapter outlines the research design and rationale, introduces the participants, and details the methods used to collect and analyze the data in the aforementioned overview.

Case Study Design and Rationale

As described by Stake (1995) and corroborated by others (Creswell, 2013; Merriam, 1998), case study design relies on multiple sources of data to develop an in-depth understanding of a contemporary phenomenon within its natural context. Privileging attention to nuanced and contextualized data, this particular research design preserves the "image of teaching as a complex intellectual endeavor that unfolds in an equally complex socio-cultural context" (Borko, Whitcomb, & Byrnes, 2008, p. 1025). Said differently, case study research retains the "noise" of lived reality by focusing on the processes of learning to teach, not just outcomes. These deeper insights and illustrations open doors to understanding the *how* and *why* underpinning beginning teachers' journey to better understand, plan for, and use student thinking in shaping instruction over time and through participation in practice-centered interactions and learning.

Specifically, this study was designed as an embedded single-case study (Yin, 2014). Miles and Huberman (1994) have defined a case as, "a phenomenon of some sort occurring in a bounded context" (p. 25). In this research, a contextual boundary guided the selection of the case. As I am interested in exploring relationships between practice-based pedagogies and novice science teacher learning in preparation programs (i.e., the phenomenon), I defined a case as a single group of secondary science preservice teachers who (a) are enrolled in the same university science teaching course, and (b) will participate in a common curriculum or sequence of learning experiences (i.e., cycles of tool-supported analyses of student work). In order to provide an empirically-rich, context-specific, and nuanced portrait of how novice teachers learn to appropriate ambitious teaching practices, this study intensely focused on one case.

Yin (2014) further identified two types of single-case study designs: holistic single-case and embedded single-case. The primary intent of embedded single-case design is to use units of analysis at more than one level, or subunits, to better illustrate the central phenomenon (Yin, 2014). In this study, a single teacher's learning-to-teach trajectory, as related to the HLTP of *attending to the substance of students' emerging ideas and reasoning to adapt instruction* across planning and reflection activities, was defined as a subunit. Analyzing similarities and variations within, between, and across teacher learning trajectories are intended to illuminate (a) patterns and trends with individual variations in the ways that beginning teachers learn to attend to, interpret, and respond to student work in adapting instruction, and (b) pedagogical approaches in teacher education that can help shape this development.

Selection of the Case and Participants

Purposeful selection of a case is central to understanding the research phenomena (Creswell, 2013). Three primary parameters guided the selection of a case that maximized the opportunity to examine relationships between practice-based pedagogical approaches and novice science teacher learning in preparation programs (i.e., the phenomenon). Inclusionary criteria included a cohort of secondary science preservice teachers who: (1) resided in university teacher preparation program; (2) were enrolled in culminating internship or student teaching experience; and as such; (3) had multiple opportunities to analyze, interpret, and respond to student work across learning-to-teach contexts (e.g., university coursework, secondary science classrooms). Selecting a case that was locally accessible limited the number of potential research sites. Of two potential sites, Middle State University[2] met the parameters.

Research context. Located in the mid-Atlantic region of the United States, the Secondary Teaching Program at Middle State University is fully accredited by the Teacher Education Accreditation Council (TEAC) and consistently ranks within the top 20 schools of education nationwide. Preservice teachers working toward a Master of Teaching degree in secondary science specialize in Chemistry, Physics, Earth Science, or Biology Education. All prospective science teachers must have or earn a bachelor's degree in their specified content area. Following a trajectory of preparation that includes the integration of coursework and field work (e.g., Instruction and Assessment, Exceptional Learner, and Teaching Science in Secondary Schools), secondary science teaching candidates graduate with a Master in Teaching degree, a grades 6-12 teaching license, and a content area endorsement.

[2] All names of institutions and people used throughout the remaining chapters are pseudonyms.

In this study, the case consisted of secondary science preservice teachers enrolled in: (a) the Fall 2015 Teaching Internship at Middle University (i.e., student teaching experience in local area schools) and (b) the accompanying Fall 2015 Teaching Internship Seminar. The Teaching Internship Seminar, held once a week at Middle State University for the duration of the fall semester, afforded teachers a space to reflect on and discuss topics central to their student teaching experiences. Examples of these topics included classroom management, school-community relationships, student motivation, and scaffolding higher-order thinking. As part of this course, and with support from the faculty instructor, I facilitated multiple cycles of analyzing and responding to student work as a means of (a) building teacher capacity to "see," plan for, and use multiple dimensions of students' ideas and reasoning to adapt instruction in their day-to-day work, and (b) reflecting on and grappling with "problems of practice" stemming from their student teaching experiences. For the time span for seven weeks, I assumed dual roles as a team leader and a researcher.

Participants. Following approval from Middle State University's Institutional Review Board to proceed with the study, I invited all three secondary science preservice teachers enrolled in the Fall 2015 Science Teaching Internship Seminar to participate in the study. Notably, I had no relationship with these preservice teachers prior to this semester, and was not the course instructor. That is, I had no influence over grades or course standings. At the beginning of fall semester, the the nature of the study and the goals were briefly explained. It was made clear that participation was voluntary, with no adverse consequences for not participating. The study information and consent form were sent home with teachers, giving them time to make an informed decision. All three prospective science teachers returned written consent forms to me directly. Every effort was made to conceal the identities of the participants (e.g., keeping data stored in a safe way and place, using pseudonyms). Table 1 provides an overview of three participants in this study. In-depth preservice teacher profiles are described in Chapter 4.

Table 1

Participant Overview

Secondary Science Preservice Teacher	**Bachelor Degree**	**Masters in Teaching: Subject Specialization**	**Student Teaching School and Course(s)**
Allie Evans	Chemistry	Secondary Chemistry	Mountain Ridge High School: *Academic Chemistry* and *Honors Chemistry*
Owen Clark	Civil Engineering	Secondary Physics	Eagle High School: *AP Physics*
Kate England	Biology Minor: Religious Studies	Secondary Biology	Hilltop Middle School: *Life Science*

Overview of Teacher Learning Experiences

In an effort to make the interactive and relational work of *attending to the substance of students' ideas and reasoning to adapt instruction* more accessible to early career teachers, this practice-centered curriculum, or sequence of learning experiences (hereafter referred to as the "curriculum module") situated teacher learning in analyses of student work, guided by pedagogical tools that framed professional work, to support interrelated connections between (a) preservice teachers' understanding of the substance and function of students' ideas and reasoning in developing explanatory ideas and models, and (b) their developing readiness to attend to, interpret, and use students' ideas and reasoning to inform "next steps" in planning instruction. The guiding learning goals are depicted in Table 2.

Table 2

Module Learning Goals

<table>
<tr><td colspan="2">Essential Questions:
• What resources do students have for making sense of the world around them? What is the relationship between these resources and how differing students access and learn science?
• How can we elicit and "see" multiple dimensions of students' ideas and ways of reasoning on a daily basis? Why is this a central component of your professional work and learning?
• What does responsive teaching in science "look" and "sound" like – to teachers and to students? How can we leverage and support students' evolving ideas and reasoning as objects of inquiry in a process and building and refining explanatory ideas over time?</td></tr>
<tr><td>Primary Ideas</td><td>Practices</td></tr>
<tr><td>• Students bring diverse repertoires of conceptual, epistemic, and social resources to learning (i.e., ideas, ways of knowing, ways of participating in, and ways of doing science) – largely grounded in and extending from their everyday experiences, interactions, and discourses. Rich and rigorous learning spaces make visible and leverage this diversity as an asset to an unfolding learning process.
• The ability to "see" multiple dimensions of students' ideas and reasoning in science provides teachers with insights into students' evolving strengths, struggles, and motivations – on an individual and collective level. This is a key stepping stone to making defensible pedagogical decisions that open access to, engagement with, and growth in science for a wide range of learners.
• Responsive teaching elicits, probes, builds on, and supports students' conceptual, epistemic, and social resources as objects of inquiry – in a process of building, making sense-of, and refining explanatory ideas and models over time.</td><td>• "Seeing" and attending to the substance of students' ideas, ways of reasoning, and curiosities.
• Analyzing and interpreting student work; "seeing" multiple dimensions of and meaning in student ideas and reasoning – on both an individual and collective level.
• Linking patterns of individual and collective student thinking, including strengths, struggles, and motivations, to pedagogical decisions in ways that are (a) accountable to individual and collective student growth, and (b) accountable to science itself.</td></tr>
</table>

The module was broken into three primary learning sequences: describing a vision of intellectually rich science learning; attending to and interpreting student thinking; and bridging patterns in individual and collective student thinking to planning "next steps" in instruction. This cycle of learning experiences was implemented twice, using student work across two learning-to-teach settings. During the first cycle, prospective teachers interacted with a common set of researcher-generated student work, engaging in a guided rehearsal of analyzing and responding to student thinking. In the second cycle, novices individually and collaboratively analyzed and responded student work generated in their unique student teaching placements (i.e., secondary science classrooms).

Describing a vision of intellectually rich science learning. To introduce the target science content and practice of the module, preservice teachers unpacked the "big" or explanatory ideas framing a middle school unit centered on the topics of thermal energy, heat, and temperature. In science, the big ideas can be understood as "substantive relationships between concepts in the form of scientific models that help learners understand, explain, and predict a variety of important phenomena in the natural world" (Windschitl, Thompson, Braaten, & Stroupe, 2012, p. 888). In this scenario, seventh grade students were working to construct an explanatory model of a solar cooking system, portraying how and why the sun can be used make water drinkable in some parts of the world. Notably, the model depicts relationships between energy conservation, transformation, and interactions with matter into, throughout, and out of this system. As an anchoring unit phenomenon, adequately developing an evidence-based explanation or "storyline" underpinning *how* and *why* this system works, and related applications to environmental and social issues, involves investigating, making sense of, and integrating a web of disciplinary ideas that include: relationships between thermal energy, heat, and temperature; mechanisms of heat transfer (e.g., conduction, convection, radiation); and light behavior. A central focus on developing, evaluating, and refining a model that (a) changes over time and in light of new investigation, evidence, and argument; and (b) can be used to explain other phenomena extending from students' everyday experiences and interests drives a vision of rigorous student work and thinking in this unit.

The target subject matter of this module was chosen for two primary reasons. First, as depicted in the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013), the energy concept and interrelated aspects of conservation, transformation, transfer, and degradation through systems functions as a powerful interdisciplinary and conceptual framework for understanding myriad processes and phenomena in the natural and designed world (Duit, 2014). All teachers will likely have the opportunity to engage students with this framework, albeit at differing levels of depth and complexity, to investigate core disciplinary ideas, processes, and phenomena across fields of science. Likewise, the interrelationships of thermal energy, heat, and temperature are also foundational ideas to myriad fields of science. For these reasons, this particular content facilitated interdisciplinary conversation and exploration among participants. Secondly, research has suggested that students enter classrooms with a myriad energy conceptions stemming from their everyday experiences and language (e.g., Driver & Warrington, 1985; Neumann, Viering, Boone, & Fischer, 2013). As such, this subject matter affords a rich context for examining the origins, the substance, and the diversity of students' conceptual, epistemological, and social resources – used to develop evidence-based explanations models of the world around them.

Notably, while learning *how to* construct a big-idea framed unit is not a central focus of this module or research, it is nonetheless important to begin with a vision of intellectually rich science learning. A host of studies have shown that prospective science teachers struggle to refocus goals of student learning from a collection of topics and procedures to the development of explanatory ideas that are iteratively built and refined across time and fields of science (Davis et al., 2006; Larkin, 2012; NRC, 2012; Reiser, 2013; Thompson et al., 2009). Unpacking the big ideas, which embody the core ideas, theories, and practices of science, was intended to help preservice teachers (a) develop an understanding of "what counts" as defensible disciplinary rigor, work, and in-depth understanding as related to this subject matter and (b) expand the range of what they can recognize or "see" as student assets, resources, and contributions to an unfolding learning process.

Attending to and interpreting student thinking. The overarching design of this curriculum module is grounded in the perspective that powerful teacher learning is situated in the interactive and day-to-day practices of responsive teaching, such as analysis and interpretation of student thinking to inform pedagogical decisions (Ball & Cohen, 1999). For novices in particular, research has indicated that the practices of analyzing and interpreting student work function as critical stepping stones in helping them learn how to connect with their learners, how to reason about and make defensible and evidence-based instructional decisions, and how to adapt instruction in ways that are responsive to a range of student strengths, struggles, and motivations (e.g., Barnhart & van Es, 2015; Crespo, 2002; Windschitl et al., 2011).

Accordingly, prospective teachers analyzed and interpreted student work in this sequence of learning experiences, collaboratively inquiring into student ideas *and* their ways of making sense of, representing, and communicating these ideas. Specifically, I explored the possibility that with principled conditions of support (e.g., collegial work, protocol that guides student work analyses and discussion, a shared language), novices can grow in their readiness to "see" and engage with multiple dimensions of students' everyday ideas, experiences and discourses; ways of characterizing, organizing, and reasoning about scientific phenomena; and areas of interest and curiosity (a) in ways that help them learn to teach *in response* to what students think and do, and (b) in ways that approximate work and learning in the profession.

To gain insights into how preservice teachers initially *attended to the substance of students' ideas and reasoning to adapt instruction*, each teacher was given the context of a student task, the accompanying learning goals, and three samples of researcher-generated student work. The selected task was designed to elicit seventh grade students' ideas and reasoning about minimizing thermal energy transfer as heat within and across everyday structures and systems. At this point in the unit scenario, students were working to solidify relationships between temperature, molecular motion, thermal energy transfer as heat, and conduction - through the on-going development of explanatory ideas.

The first prompt, entitled "*The Mitten Problem*," originated from the assessment collection "Uncovering Student Ideas in Science" published by the National Science Teacher Association in the United States (Keeley, Eberle, & Farrin, 2005). In particular, students were asked to predict if the temperature reading on a thermometer, located inside a mitten, is *higher than, lower than,* or *equal to* the temperature reading on a second thermometer sitting on a classroom table – after three hours and given a constant room temperature. Students are also prompted provide a justification for their selected answer. Informed by “real” student work, the generated samples included diverse types of student responses. For example, while one student selected the technically “correct” multiple choice answer, her response reveals partial understanding but minimal use of evidence and reasoning to support her ideas. In another example, while a student selected a technically “incorrect” multiple choice answer, his response reveals productive mechanistic reasoning (e.g., working to explain the underlying mechanism of the phenomenon).

The second set of prompts framing this student work depicted a visual of the solar cooking system (i.e., unit anchoring phenomenon), inviting students to: (a) describe the best way to minimize heat loss from the bottom floor of the system to the surrounding air, and (b) represent and explain why the particular idea would work, in a way that their peers would understand. This series of prompts was intended to elicit students’ initial ideas about potential variables that influence the rate of thermal energy transfer as heat, via conduction. Again, the student reponses reflected a range of student ideas, as well as ways that they attempted to make-sense, reasoning about, and communicate their thinking. A sample of these prompts can be found in Appendix A.

Participants were asked to analyze and interpret the student work samples, suggest “next steps” in planning instruction, and offer a justification for their thinking. Notably, this introductory task provided insights into: (1) what preservice teachers noticed when examining student work, (2) how they interpreted and made-sense of what they identified as important, and (3) how and to what extent they took up student ideas and thinking to inform next steps in planning instruction. All responses were logged in the Web-Based Inquiry Science Environment (WISE) interface maintained at the University of California, Berkley[3]. An open source learning platform, WISE offers a variety of pedagogical tools for making teacher thinking visible, for engaging teachers in a continuous cycle of refining their own understandings over time and for providing on-going feedback to participants. For example, in this part of the module, participants logged their initial thinking in a WISE questionnaire as they analyzed student work and offered instructional recommendations. Throughout the module, their initial and on-going thinking reappeared, offering participants the opportunity to reflect on and add, integrate, and modify earlier thinking related to analyzing, interpreting, and suggesting "next steps" in instruction (see Figure 3).

[3] I have no affiliation with the Web-Based Inquiry Science Environment (WISE) project.

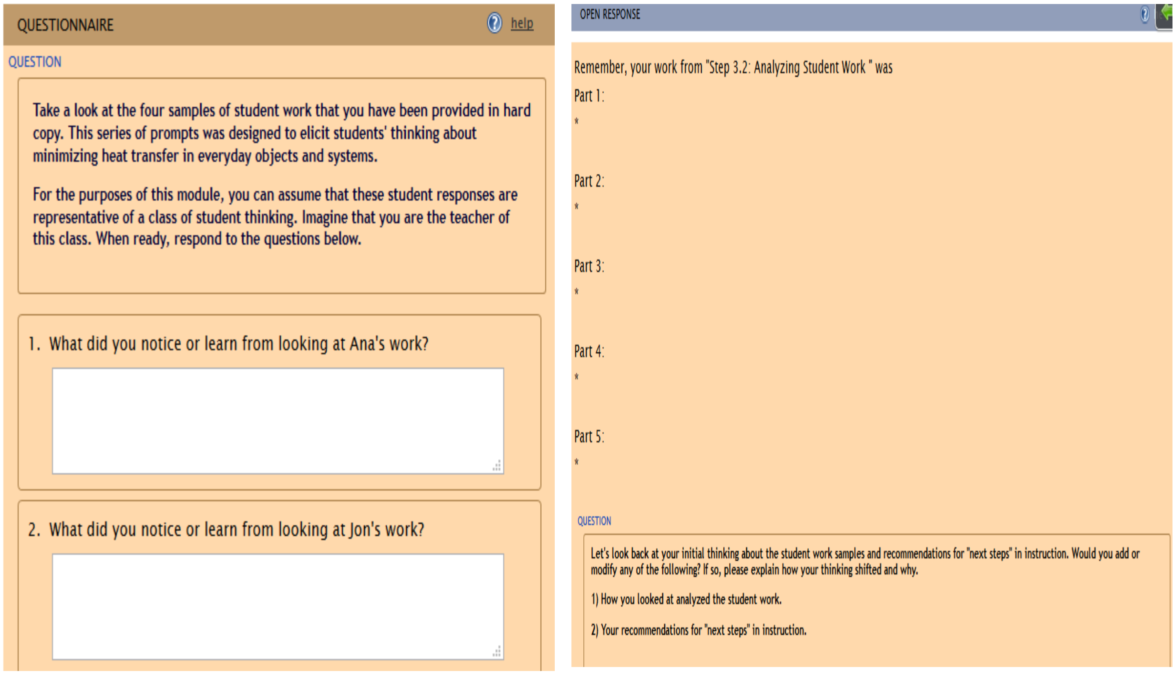


Figure 3. The left figure depicts a portion of a WISE questionnaire that elicits how preservice teachers initially attend to, interpret, and respond to a sample of student ideas and reasoning. As represented in the right figure, participants' initial thinking will reappear later in the module along with reflection prompts that elicit potential shifts in teacher thinking over time.

Next, preservice teachers revisited and interpreted the same student work samples in small teams, using a protocol to guide thinking and discussion. Examining student work within a collegial space was intended to provide novices an opportunity to surface their own assumptions, and develop ideas about subject matter, about learners, and about how students learn by considering, responding to, and challenging each other's ideas (Kazemi & Franke, 2004). However, just gathering teachers together to simply look at student work does not ensure that meaningful learning will occur (Ball & Cohen, 1999). A number of scholars have suggested that prospective teachers benefit from using frameworks or tools to guide analysis of students' work and support collegial critique (e.g., Levin et al., 2009, Windschitl et al., 2011). Consistent with this literature, participants used a protocol designed to scaffold inquiry into "seeing" and understanding multiple dimensions of students' ideas as well as their ways of reasoning, communicating, and making sense of natural phenomena on both an individual and collective level (see Appendix B for a condensed form of this protocol). Following this activity, teachers analyzed one additional sample of student work, and returned to their initial analysis of student work on WISE to add, integrate, and modify earlier thinking.

Bridging patterns of individual and collective student thinking to responsive pedagogy. In the third component of this module, preservice teachers linked patterns in individual and collective student thinking to adapting instruction (a) in ways that are accountable to students, and (b) in ways that are accountable to science itself. To begin, preservice teachers collectively examined how two teachers interpreted and used the *same set* of student work to plan and implement a lesson on minimizing heat transfer in everyday structures and systems (i.e., the same lesson participants have engaged with thus far in the module). Both lessons were depicted in the form of case studies.

Notably, teaching and learning in the first case study was more reflective of conventional approaches to science teaching, emphasizing the role of a teacher as the primary arbiter of content and practice. Consistent with an evaluative orientation, student ideas were positioned according to levels of "correctness" against canonical science ideas. As such, adaptations to instruction in this case study were primarily in service of remediating and extending student thinking, "filling the gaps" of students' ideas to reach a canonical understanding.

Contrasting this scenario, the teacher in a second case study attends to multiple dimensions of as well as strengths and struggles in students' ideas *and* reasoning, working to make sense of the meanings that students were trying to convey. Importantly, this teacher identifies multiple patterns of claims in student work (i.e., lines of student thinking and hypothesizing about the how the phenomenon works), and makes these visible to the class as public objects of continual inquiry. Importantly, the teacher considers the type of resources and experiences that students will interact with in “next steps,” encouraging her learners to seek out their evidence for supporting, refuting, or modifying and making sense of these claims. Drawing from strengths and struggles in student work, she works to ensure that all students have access to, are challenged by, and have the resources that they need, individually and collectively, to develop an increasingly sophisticated explanation for this phenomenon for themselves (e.g., ranging complexity of resources, establishing a public forum for students’ evolving ideas and thinking, language scaffolds for translating between everyday and scientific language, tools for supporting the development of evidence-based explanations). In this case, the teacher *and* her students assess the “quality” of evolving ideas by the evidence and arguments that support them, leveraging student ideas and their ways of thinking, reasoning, and communicating as a resource for engaging all learners in authentic disciplinary work.

Following these two lesson episodes, preservice teachers analyzed both lessons with a focus on the role of the teacher; on student access to high-level intellectual activity; on how ideas are being developed, refined, and critiqued on an individual and social plane; on how students are participating and contributing; and on how the teacher attends to both individual and collective patterns in student strengths, struggles, and motivations. In turn, novices looked at “what counts” in terms of specific conditions that supported or hindered these focus areas (e.g., curriculum structure, teacher interactions with students, scaffolds, extensions, and material resources). Teacher reflections were logged in WISE.

In application and preparation for cycle two, novices were asked to: (1) select a topic and segment of a lesson that they planed to teach in the near future; (2) identify the learning goals; and (3) construct a series of prompts that elicited and made visible a wide range of student ideas and reasoning. Over the next weeks, when possible, teachers revised these prompts in conjunction with peers, with the course instructor, with myself before implementation with secondary science students in cycle two.

Cycle two. In cycle two, participants implemented a set of prompts with their students, collecting 3-5 samples of de-identified student work that reflected a range of learner ideas and ways of thinking, reasoning, and communicating. Individually, each teacher analyzed the selected student work samples and suggested "next steps" in planning instruction. Once again, this task provided insights into: (1) what preservice teachers noticed when examining student work, (2) how they interpreted and made-sense of what they identified as important, and (3) how and to what extent they took student ideas and thinking to inform next steps in planning instruction. During the seminar course, teachers presented and revisited student work samples with peers. Collegial conversations were mediated by a team discussion protocol, entitled "*Seeing and Making Sense of Multiple Dimensions of Student Ideas & Reasoning in Science"* (see Appendix C). Within this space, issues related to subject matter, to how students learn, and to pedagogical approaches were leveraged as "problems of practice" that novices collectively grappled with.

Following cycle two, participants reflected on their own progression of understanding and practices related to attending to, interpreting, and adapting "next steps" in instruction using a questionnaire in WISE. They were encouraged to share specific features of these learning experiences that supported or hindered this progression. An overall summary of module steps and timeline in conjunction with the corresponding essential questions, primary teacher learning experiences, and pedagogical tools are depicted in Table 3.

Table 3

Timeline and Overview of Teacher Learning Experiences: Fall Semester, 2015

CYCLE ONE: Describing a Vision of Intellectually Rich Science Learning September 10th
Primary Teacher Learning Experiences: • Overview of simulated middle school unit on heat, temperature, and thermal energy: Unpacking the "big" ideas through the development evidence-based explanations and models; anchored in a unit phenomenon.

CYCLE ONE: Attending to & Interpreting Student Work		**September 17th – 24th**
Essential Questions:	**Primary Teacher Learning Experiences:**	**Pedagogical Tools**
What resources do students have for making sense of the world around them? *What is the relationship between these resources and how differing students access and learn science?* *How can we elicit and "see" multiple dimensions of students' ideas and ways of thinking, reasoning, and communicating?*	• Individual Analyses of Student Work: In WISE, PTs analyzed three samples of student work and suggested "next steps" in instruction. • Collaborative Analyses of Student Work: TAs revisited and interpreted the same student work samples a small team, using a science-specific protocol designed to scaffold inquiry into "seeing" and understanding multiple dimensions of students' ideas and their ways of reasoning, communicating, and making sense of natural phenomena (consistent with a vision of science-as-practice depicted in the NGSS).	*Protocol: "Seeing" Multiple Dimensions of Student Ideas & Reasoning in Science* *WISE: Teacher Elicitation & Reflection Prompts*

Table 3 – Continued

CYCLE ONE: Bridging Patterns in Individual & Collective Student Thinking to "Next Steps" in Instruction		October 1st
Essential Questions:	**Primary Teacher Learning Experiences:**	**Pedagogical Tools**
What does responsive teaching in science "look" and "sound" like – to teachers and to students? *How can we leverage and support students' evolving ideas and reasoning as objects of inquiry in a process and building and refining explanatory ideas over time?*	• Case Studies: Exploration and analysis of two differing teachers that each plan and implement a lesson guided by the student work samples: "What counts" in balancing youth as scientific thinkers with disciplinary integrity?" • Preparation for cycle two: (1) select a topic and segment of an upcoming lesson; (2) identify the learning goals, focusing on the development of "big" ideas and evidence-based explanations; and (3) construct a series of prompts that elicit and made visible a wide range of student ideas and reasoning. • Overview of Team Consultancy Protocol	*WISE: Teacher Elicitation & Reflection Prompts* *Lesson Analysis & Reflection Guide* *Team Consultancy Protocol: Collaborative Inquiry into Student Work and Planning "Next Steps" in Science Instruction*

CYCLE TWO: Attending to, Interpreting, & Responding to Student Work		October 7th –22nd
Essential Questions:	**Primary Teacher Learning Experiences:**	**Pedagogical Tools:**
What does responsive teaching in science "look" and "sound" like – to teachers and to students? *How can we leverage and support students' evolving ideas and reasoning as objects of inquiry in a process and building and refining explanatory ideas over time?*	• Implementation of elicitation prompts with secondary science students; PTs collected 4-5 samples of de-identified student work. • Collaborative inquiry into student work - THREE ROTATIONS. Discussions mediated by Team Consultancy Protocol.	*Team Consultancy Protocol Collaborative Inquiry into Student Work and Planning "Next Steps" in Science Instruction* *WISE: Teaching Elicitation and Reflection Prompts*

Module Design and Refinement

The researcher piloted an early version of this module, or sequence of teacher learning experiences, in the second semester of a secondary science methods course in a large university. Stemming from "lessons learned," the module in this study reflects the following adaptations:

- Guided analysis of a *common set* of student work, in lieu of engaging preservice teachers with content-specific student work *initially.* This modification was intended to anchor early conversations in a common "text." Further, creating a more heterogeneous group, in this sense, provoked multiple perspectives on interdisciplinary scientific content and practice.

- Modifying the protocol used to analyze student work to include explicit attention to "seeing" and making sense of ways that learners reason about, represent, and communicating their ideas. While novices in the pilot worked to identify dimensions of and patterns in students' ideas (e.g., understandings, partial understandings), they struggled to consistently "see" the underlying character of students' reasoning - used to support ideas at the macro- and micro-level. Adding this element to the protocol was intended to support beginning teachers' capacity to (a) "see" and make-sense of a more holistic portrait of students' thinking and understanding in science as it evolves over time, and (b) adapt instruction to leverage and support students' diverse ways of thinking, hypothesizing, and representing ideas as objects of inquiry over time.

- Addition of an annotated "team consultancy" protocol that scaffolds collaborative teacher inquiry into student work in ways that privilege intersections of subject matter, of diverse student thinking, and pedagogical decisions. This tool was designed to mediate teacher conversation, locating student thinking at the core of evidence-based pedagogical decisions.

Data Collection

Consistent with case study design, I collected multiple sources of data before, during, and after the curriculum module. These sources included (a) interviews and (b) data stemming from seminar class activities: audio-recordings of group discussions, teacher generated artifacts, field notes, and embedded tasks and reflection prompts in WISE.

Phase 1: Pre-module individual teacher interviews. Prospective teachers have been participating and will continue to participate as "learners of teaching" across multiple contexts in their lifetime (Lortie, 1975). As such, they bring a diverse and evolving array of ideas, ways of thinking, and instructional practices to new learning. To elicit and gain insights into novices' existing awareness of and attention to the substance of students' ideas and reasoning in adapting instruction, each teacher was asked to bring a lesson plan and corresponding samples of student work to one semi-structure interview. Consistent with the structure of a semi-structured interview, a thematically-organized protocol focused conversation with participants.

Establishing a contextual backdrop, the first portion of the interview included three general questions that ascertained each participant's educational background, reasons for entering the teaching profession, and broad beliefs about teaching and learning in science. The remaining portion of the interview questions elicited insights into the teacher's planning process, reflections on the lesson implementation and student work, and projection of "next steps" in instruction. The entire interview protocol can be found in Appendix D. Each interview was audio-recorded. All audio recordings were transcribed and combined with the lesson plan (if provided in hard copy form) into individual participant dossiers.

Phase 2: Module data collection. As described, participants engaged in two cycles of analyzing, interpreting, and responding to student work. To adequately capture teachers' evolving instructional repertoires and pedagogical thinking over time and through participation in practice-centered learning, I collected the following sources of data: audio-recordings of teacher discussions in the seminar course; field notes; teacher generated artifacts; and embedded tasks, prompts, and discussion boards in WISE.

Group discussions and field notes. At several points during this time, preservice teachers worked collaboratively to analyze, interpret, and respond to student work. To capture these dialogic interactions, all conversations specifically related to this work were audio-recorded – with consent from all participants. Additionally, field notes stemming from observations of activities occurring outside of these team discussions were recorded and most often, expanded upon after class completion each evening (e.g., individual questions that preservice teachers asked the course instructor, peers, or myself during a brainstorming session). All audio-recordings were transcribed and combined with the field notes and any teacher generated artifacts to produce a "portrait" of each class session.

Online tasks, reflective prompts, and discussion boards. This study leveraged the capacity of technology to support novice teacher learning processes. Specifically, I used a suite of tools within the Web-Based Inquiry Science Environment to capture individual teacher practice, pedagogical reasoning, and reflection on their own personal learning and growth. All participant responses were logged, saved, and exported in text form to Microsoft Excel.

Phase 3: Post-module individual teacher interview and questionnaire. Following the module, I again met with each preservice teacher, conducting one interview. The primary purpose of this interview was to elicit teachers' "walk away ideas" from this set of learning experiences – in their own words. Here, I used one framing question (i.e., What are your "walk away ideas" from our time together over these past weeks?), allowing participants to focus on what they thought was most relevant to the question. However, a set of accompanying probes (e.g., Can you explain more about that? Can you give me an example?) aided in gaining depth and detail in teachers' thinking.

Following the completion of interviews, all participants were asked to complete a Reflection Questionnaire within WISE. The questionnaire consisted of four questions that provided insight into (a) teachers' reflections on their own learning and growth; (b) factors that shaped their evolving practice and thinking; and (c) suggestions for improving this module. The post-module reflection questions, framing both the interview and the WISE questionnaire, can be found in Appendix E.

Data Coding and Analysis Process

There are many approaches to analyzing data within an interpretive paradigm (Charmaz, 2006; Miles & Huberman, 1994). For some qualitative research experts (e.g., Glaser and Strauss, 1967), the recommended approach to data analysis and developing codes is purely inductive. This approach minimizes the tendency of researchers to erroneously "force" predetermined findings. However, other qualitative researchers (e.g., Miles and Huberman, 1994) point to the benefits of a more deductive approach to data analysis, beginning with an organizational framework for coding. In particular, these preliminary code structures can help researchers draw on and integrate well established concepts in the extant literature. In this study, I adopted an integrated approach to analyzing the data, using both deductive and inductive approaches to allow for new inquiries while building from existing field insights regarding relationships between practice-based pedagogies and novice teacher learning.

To gain a broad sense of novice teacher participation in, or learning in pedagogies of practice, I initially leaned on a priori codes stemming from the study's conceptual framework. Summarized by Miles and Huberman (1994), "A conceptual framework explains, either graphically or in narrative for, the main things to be studied – the key factors, constructs, or variables – and the presumed relationships among them" (p. 440). This type of working framework affords a researcher an opportunity to (a) logically assemble general ideas into intellectual "containers," and (b) place parameters on what is to be studied (Miles & Huberman, 1994).

The conceptual framework in this study is consistent with a situative view of teacher learning (Greeno, 2006; Lave & Wenger, 1991), or changing participation in how teachers *understand and attend to substance students' ideas and reasoning to adapt instruction* across planning and reflection, and in interactions with peers, with records of classrooms practice, and with pedagogical tools. Described in chapter two, the primary conceptual constructs, and initial a priori codes included: (a) the HLTP of *attending to the substance of students' ideas and reasoning in adapting instruction*, decomposed into attending to, interpreting, and responding to students' ideas and reasoning; (b) practice-based pedagogies, anchoring teacher learning in cycles of analyzing classroom records of practice, and (c) preservice teachers' evolving pedagogical reasoning, including interrelated stances towards students as science learners, stances towards science content and practice, and stances towards science teaching; and (d) pedagogical routines and tools that potentially support evolving teacher learning (see Figure 4). Derived from the literature, an expanded analysis guide corresponding to indicators of more "expert-like" teacher practices and stances as related to this study can be found in Appendix F.

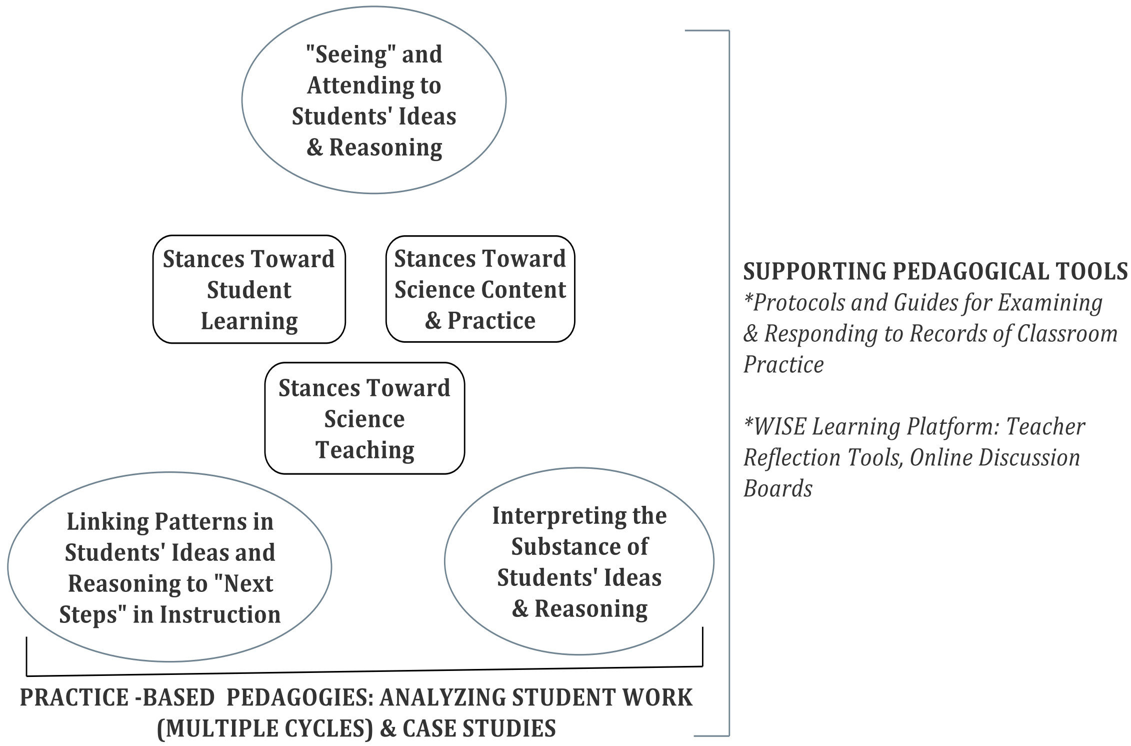


Figure 4. Conceptual framework: The influence of practice-centered learning on novice teacher capacity to attend to the substance of students' ideas and reasoning to adapt instruction.

More specifically, to gain a broad sense of novice teacher learning outcomes in relationship to the first research question, "How do preservice teachers participate in pedagogies of practice, grounded in tool-supported analyses of student work, to attend to, interpret, and use student thinking in adapting instruction?" I looked at, coded, and characterized their practices as related to attending to student work (i.e., *What do teachers notice in student work*?), interpreting student thinking (i.e., *How do teachers make sense of what they notice or identify as important*?), and responding (i.e., *How do teachers link what they noticed and interpreted in student work to next steps in instruction*?) – across participation in the module learning experiences. In gain further insights into their thinking and reasoning, I also looked at and coded their stances toward, or representations of science (i.e., *How are scientific ideas are developed and validated*?), of student learning (i.e., *Who are students as learners? How do students learn science*?), and of science teaching (i.e., *What images of science teaching do teachers portray*?) in conversations.

Next, I used a constant comparative method of qualitative analysis to further refine and parse the codes. Broadly, this process begins with immersion in the data, breaking down the data into "incidents" (Glasser & Strauss, 1967), and coding these incidents into further conceptual categories. Emerging categories largely derived from (a) participants' experiences and language, and (b) theoretical insights into the constructs under study. As this process proceeded, I worked to iteratively test relationships between conceptual categories; using analytic memos reflect on, modify and refine categories; and generate assertions about the phenomenon (Charmaz, 2006; Creswell, 2013).

A second "layer" of coding was employed to gain insights into second research question: "What features and conditions of a practice-oriented pedagogical approach seem to shape how preservice secondary science attend to, interpret, and use student thinking in adapting instruction?" That is, I looked for potential influences that shaped preservice teachers' participation in the module learning experiences. These initial codes included tools, peers, and how teachers negotiated membership across learning-to-teach contexts. Again, I further parsed the codes and built inferences.

Following the tradition of embedded single-case study, I analyzed the data by subunit (i.e., individual preservice teacher learning trajectory) followed by a cross-unit analysis -affording insights into how teachers' developing repertoires shape and are shaped by participation in practice-centered interactions and learning.

Validation Strategies

In qualitative studies, the goal of research is to produce findings that are worthy of attention, or trust. In single-case study design, this is an important consideration given a number of criticisms, the most common of which include methodological rigor, external validity, and researcher subjectivity. Creswell (2013) summarized eight primary strategies that are frequently used in qualitative approaches to ensure the rigorous nature of the research and trustworthiness of the findings. I employed three: using of multiple sources of evidence, peer debriefing, and clarifying researcher bias.

Triangulation is the "act of bringing more than one source of data to bear on a single point" (Marshall & Rossman, 2006, p. 202). In this study I used myriad sources of evidence, including interviews, seminar discussions, and embedded prompts within the WISE platform. Corroborating these differing types of data sources, I was able to consistently check emerging insights about each teacher's developing practice and thinking in person, through collegial conversation, and through their written reflections. Collectively, these sources worked to inform a rich understanding of how preservice teachers participated in practice-centered learning to analyze and respond to student work.

Next, peer debriefing provided an external check of the research process (Merriam, 1998). In particular, this validation strategy is useful for "exploring aspects of the inquiry that might otherwise remain only implicit within the inquirer's mind" (Lincoln & Guba, 1985, p. 308). In addition to keeping an audit trail, or a series of memos that documented the research process and corresponding decisions, I shared the data analyses process as well as emerging categories and themes with a colleague - a former teacher who also focused her doctoral work on the development of core practices in teacher education. As a "critical friend," my peer-debriefer was especially helpful in confirming, challenging, and proposing emerging insights and meanings.

Finally, working within the interpretivist paradigm, the researcher is the primary instrument for data collection and analysis. Erickson (1986) noted that the first major task of a researcher is the examination of her own research interests, biases, and experiences with the topic. Reflexivity, a hallmark of qualitative research and integral part of this study, was enacted through dialogue with my peer debriefer and consistently reviewing the data and interpretations against the biases, assumptions, and experiences I make explicit. I offer the following:

Prior to beginning my formal teaching career, I was fortunate to have participated in a National Science Foundation teacher preparation program, in lieu of the regular program at the university. This program centralized student thinking in the development of teaching practice, seeding an early interest in unraveling and building on the diverse ideas, experiences, and ways of thinking students bring to learning science and mathematics. Over the next five years, I taught a variety of Physics, Chemistry, Mathematics courses at both the high school and middle school level. My boundless interactions with students and their thinking and curiosities on a daily basis inspired me to learn how to better meet individual and collective student learning needs - while balancing the external pressures of accountability. To further my own professional learning, I returned to graduate school, while still teaching, to pursue a master's degree in science curriculum and instruction, and space science. During my time in graduate school, I wrote a thesis on differentiated instruction in secondary science classrooms.

Needless to say, I am biased towards student-centered instruction that fosters knowledge-building within disciplinary activity; privileges and supports multiple student learning trajectories; and elicits and leverages student strengths with working communities of learners.

In leaving the K-12 setting to pursue a Ph.D., I have endeavored to "keep one foot in the classroom," bridging doctoral learning with the realities of classrooms today. To this end, I have worked alongside myriad administrators and teachers in school systems and organizations, both national and internationally, on curriculum design and instructional approaches that inspire and meet the needs of diverse learners in classrooms today. Working within numerous professional development models, I have gained key insights into teacher learning processes and the systems in which teachers work. As a teacher educator, I feel strongly about improving our "own backyard" and collaboratively exploring ways to effectively support teachers in making high standards of disciplinary learning both accessible and achievable to diverse student populations.

CHAPTER 4: INDIVIDUAL PORTRAITS OF NOVICE TEACHER LEARNING

In this chapter, I narrate individual storylines of how three prospective secondary science teachers - Allie, Owen, and Kate - engaged in pedagogies of practice, grounded in tool-supported analysis of student work, to *attend to substance students' ideas and reasoning to adapt instruction* across planning and reflection activities. Consistent with a situative perspective (Cobb & Bowers, 1999; Greeno, 2006; Lave & Wenger, 1991; Putnam & Borko, 2000), I trace each teacher's repertoire of practice as related to attending to, interpreting, and responding to students' ideas and reasoning, over time and in interactions with peers, with pedagogical tools, and with artifacts of classroom practice.

Following the chronological sequence of the module learning experiences as an organizing framework, this chapter offers key insights into each teacher's practice and pedagogical reasoning within and across three time points: (1) at the beginning of the curriculum module, (2) during cycle one, or guided rehearsal of collaborative analysis and response to a common set of researcher-generated student work, and (3) during cycle two, or rehearsals of collaborative analysis and response to student work generated in each teacher's secondary science classroom. As much as possible, I draw from their work, their conversations, and their "voices" – individually and collectively at times – to illustrate their experiences and interactions with student work, with colleagues, and with pedagogical tools. In the final section of this chapter, I synthesize these insights over time, narrating a "storyline" of how each teacher learned in, from, and for practice (Lampert, 2010). Relevant themes stemming from analyses of similarities and variations across these teacher learning trajectories (i.e., cross-unit analysis) illuminate the larger case phenomenon, or relationships between and influences of practice-based pedagogies and novice science teacher learning in preparation programs, in Chapter 5. Citation abbreviations are described in Table 4.

Table 4

Citation Abbreviations

Source	**Abbreviation**
Team Discussion	TD
WISE Learning Platform	WS

Beginning Where They Are: Novices' Initial Repertoires of Instructional Practice

As educators, we have been "learners of teaching" across multiple contexts and communities, formal and informal, throughout our lives (Lortie, 1975). These experiences have undoubtedly shaped our current pedagogical visions, our ways of making sense of teaching and learning, and our evolving instructional repertoires. In this section I introduce Allie, Owen, and Kate; offering insights into their backgrounds and initial repertoires of instruction as related to the practices of attending to, interpreting, and using student work to adapt instruction. My sources are limited to (a) one pre-module interview, in which each teacher was asked to share an analysis, interpretation, and response to a student work sample generated in their individual student teaching placements; and (b) one seminar course task, in which each participant was asked to analyze and interpret a researcher-generated student work sample, suggest “next steps” in planning instruction, and offer a justification for their thinking.

Combined, these samples of student work afforded early insights into: (1) what preservice teachers attended to, or noticed when examining student work, (2) how they interpreted, or made-sense of what they identified as important, and (3) how and to what extent they took up student ideas and thinking to inform “next steps” in planning and adapting instruction, if at all. As a teacher educator, eliciting novices’ pre-module thinking and practice was invaluable to gaining insights into teachers’ ideas, experiences, and thinking; adapting “next steps” in the sequence of module learning experiences; and tracing teacher learning over time.

Allie Evans

Contextual Background. Allie Evans, a woman in her early 20s, had a bubbly personality. Always the first to arrive to seminar class each week, Allie was eager to talk about her chemistry students and what had happened over the past week of student teaching. Allie will dually earn a Bachelor of Science degree in Chemistry and Master of Teaching from Middle University. While she did not begin the Chemistry degree with the intention of pursing a high school teaching career, after a particularly challenging Organic Chemistry Laboratory, she began to ask herself, “Why am I putting myself through this? What’s the point of it?” (Evans Interview, September 10, 2015). After attending a local career fair, Allie reflected on her past work experiences and what she enjoyed doing in life. Allie realized that whether it was working with her siblings, teaching Hebrew school during her high school years, or tutoring, she had been involved in some type of teaching capacity throughout her life. Following in the footsteps of her mom, also a teacher, Allie enrolled in the Master of Teaching – Secondary Science program with a specialization in Chemistry. She frequently stated that she loves teaching and in particular, working with students in chemistry.

During the fall 2015 semester, Allie student taught Academic Chemistry and Honors Chemistry at Mountain Ridge High School, a large local school. Allie seemed to forge a productive relationship with her mentoring teacher, Ms. Jones, and appreciated the freedom that she had to design her own lessons and "try-out" different teaching approaches. Allie described her students as diverse:

> I currently have students who are ESL students. Instruction needs to be differentiated in order for them to understand words problems, and sometimes they need things read to them. Then I have students who it might be their first honors course, taking chemistry, and to do so they have different study habits. I have students who are interested in different things, and some who are passionate about chemistry, and some who are like, I don't really want to be here. I don't want to do this. (Evans Interview, September 10, 2015)

Teaching science, Allie stated that she had learned in class (i.e., Teacher Education Program) that science is taking evidence and drawing conclusions. However, she hoped that students would come to understanding that chemistry is part of everything: "Well, did you eat this morning? . . .How did you get to school? That's science" (Evans Interview, September 10, 2015).

Attending to and Interpreting Student Work. For Allie, attending to and interpreting student work focused on "seeing" answers or broad pieces of student ideas, ultimately determining if students had acquired the "correct" information. To the first interview, Allie enthusiastically brought student work from a recent "Do Now" that she had used with students at the beginning of class. She explained that the primary learning goal was to "review the history of the periodic table" (Evans Interview, September 10, 2015). In prior days leading up to this task, the learning goals for students included "understand[ing] why elements are placed in specific locations on the periodic table; practic[ing] assigning elements atomic numbers, atomic mass, protons, neutrons, electrons; drawing Bohr diagrams and Lewis Dot diagrams; and, discover[ing] certain trends on the periodic table" (Evans Interview, September 10, 2015). Within this "Do Now," students were asked a series of identification and matching questions such as: How many valence electrons does carbon have? How many valance electrons do the elements below Helium have? Alkaline metals have… (match the correct response). Allie scored each question out of five points. For every student, quantitative scores for each question were entered into an elaborate master spreadsheet stored on her laptop. In talking about her student work, Allie largely referenced "student answers" in the form of a quantitative score.

Consistent with an evaluative orientation, or interpreting student work in terms of "correct" or "incorrect" outcomes, Allie made sense of this quantitative data by making whole-class generalizations originating from low student scores (i.e., incorrect responses). For example, she explained: "The most missed question was this missed question, throughout all the classes. That tells me that they did not get the proper information, because they took the notes themselves" (Evans Interview, September 10, 2015). Elaborating further, she stated:

> Yeah. I would say with this I don't really much look at individual students. It's mainly about what big pictures the class missed. I like to look cross-classes, because then I think about, okay, what was going on in that class. Did I word something differently? Is it later in the day so I had already taught it and it dissipated? I like to see that. (Evans Interview, September 10, 2015)

At this point, however, I also note that the corpus of factual "Do Now" questions, framed by a collection of knowledge-level learning goals, certainly constrained space for "seeing" and interpreting dimensions of and nuances in student ideas *and* their ways of thinking, reasoning, and communicating. Thus, I looked to the seminar task for further insights into Allie's initial thinking and repertoire of practice.

In the seminar task, Allie largely attended to broad concepts or pieces of student ideas (e.g., concept of heat transfer, how heat flows, how insulators work) that learners either "understood" or "did not understand." For example, in analyzing the totality of responses from a student named Jon, she wrote: "Jon also seems to understand heat transfer. He still has a misconception about what insulators do. He knows that they trap heat, but he also believes that they can produce heat" (Evans, WS, Q:1.3). Shown here, at times, Allie provided a level of specificity in her analysis that offered some insight into and support of her broad inferences. In this example, she attempted to unpack Jon's "misconception," or tentative idea about the function of insulators. At one other point, she elaborated on an inference, stating: "He understands that heat is transferred by molecules bumping into each other and giving each other energy" (Evans, WS, Q:1.3). Thus, while most of what Allie attended to in student work was typified by inferences centered on broad concepts or pieces of student ideas stemming from parts the learning goals, she unpacked her inferences with specific insights from student work at times.

Allie interpreted what she noticed or inferred from student work in terms of generic claims such as: "Ana really seems to understand the concept of heat transfer," or "Riley doesn't fully understand how insulators work" (Evans, WS, Q1.3). Once again, she takes an evaluative stance towards student work, using broad portions of student ideas to categorize levels of student understanding (e.g., understand or do not understand).

Linking Student Work to "Next Steps" in Instruction. Drawing from her analysis and interpretation of the "Do Now," Allie first linked collective patterns in student "mistakes" to content that she didn't get across the first time: "I think about, okay, what was going on in that class. Did I word something differently? Is it later in the day so I had already taught it and it dissipated?" (Evans Interview, September 10, 2015). In terms of "next steps" in instruction, these patterns informed whole-class content that needed to be reviewed, re-emphasized, or retaught. For example, in reference to an answer that many students missed, she posited: "That [identifying the number of valence electrons an element has] was a common mistake that was made when people got this question wrong. That's something that should also be re-emphasized" (Evans Interview, September 10, 2015).

Likewise, in the seminar task, Allie suggested that the students "be given examples of different types of insulators and do some experiments with insulators because they seem to be unsure of the purpose of an insulator and how insulators function" (WS, Q1.3). Once again, she used broad and collective trends in students' "inaccurate" conceptions to inform whole-class "next steps" in instruction, bolstering students' areas of struggle.

Stances. As Allie talked about student work *in this instance*, she tended to portray science as body of knowledge to be acquired through and validated by an authoritative source – the teacher in this instance. Student learning was depicted as a "get it" or "don't get it" undertaking, grounded in the accumulation of information over time.

Consistently, teaching was represented by Allie as ensuring that students received the "proper information" (Evans Interview, September 10, 2015). The practices of attending to, interpreting, and responding to student work were largely represented as "seeing" and assessing levels of student "correctness" in pieces of student ideas, ensuring that points of student struggle were re-emphasized or addressed in upcoming class activities.

Owen Clark

Contextual Background. A male in his mid-20s, Owen Clark often arrived to seminar class late from cross-country practice - juggling dual roles as head coach and a student teacher at Eagle High School, a local area school. Owen earned a Bachelor of Science in Civil Engineering and started a graduate program in Structural Engineering at a university approximately three hours from Middle University. However, he left the graduate program and moved home, deciding not to pursue a career in the corporate world. Over the next two years, Owen coached cross-country at Eagle High school. "The first year I was completely volunteer, but I was there every day. Fell in love with the kids. Fell in love with doing that" (Clark Interview, September 10, 2015). Finding a niche working with high school students, Owen enrolled in the Master of Teaching – Secondary Science program at Middle University with a specialization in Physics.

During the fall 2015 semester, Owen student taught in an AP Physics class. He spoke highly of his mentoring teacher, Mr. Riggs, characterizing their working relationship as positive. Owen described his students as "diverse in a way where some kids are really into it, some kids aren't into this, some kids understand it, some kids don't, in that regard, in terms of how you approach teaching them" (Clark Interview, September 10, 2015). Teaching science, Owen explained that "If you teach it right, looking at coming up with questions, looking at either process or data and something like that, and come up your own solutions and then checking it – I just think it's so interesting. I think it's fun…it can apply to so many things" (Clark Interview, September 10, 2015).

At the time of the interview, Owen mentioned that he was working on developing an upcoming unit for thermodynamics. He felt tension between the need to "get through everything" in AP Physics and engaging students in inquiry (Clark Interview, September 10, 2015). Further, his knowledge of instructional approaches before arriving at Middle University was "basically direct instruction. Even when I did labs, you knew what you were looking for" (Clark Interview, September 10, 2015). At this point, Owen had assembled a host of PowerPoint slides to anchor the unit. He grappled with integrating both inductive and deductive teaching approaches into the unit:

> That's what I'm trying to figure out now is when I'm making my unit, I'll start teaching for thermo, is how to do it where it's kind of a mixture of both, especially because Mr. Riggs keeps saying that this [teaching AP Physics] is usually direct instruction. I think thermo is harder to visualize, but that's just a whole different thing in some ways.
> (Clark Interview, September 10, 2015)

This piece of the narrative will continue to develop over the next sections.

Attending to and Interpreting Student Work. For Owen, attending to and interpreting student work focused primarily on "seeing" student answers or broad concepts in student thinking, ultimately identifying what learners understood or had "misconceptions" about. Owen's student work consisted of pre-laboratory predictions, submitted by students on Google forms. Stemming from a unit on the topic of fluids, the overarching goal of the upcoming lab was to construct the relationship between the magnitude of the buoyant force and the weight of fluid displaced by an object (i.e., Archimedes' principle). Owen stated that he would like students to "somehow see that [relationship] through collecting data" (Clark Interview, September 10, 2015).

Prior to the lab, Owen posed two hypothetical situations to students in both visual and written form. Specifically, these situations reflected those "which a lot of people have misconceptions with" (Clark Interview, September 10, 2015). For example, in one scenario, students were asked to predict if the weight of an object before it is submerged in water is *greater than, equal to,* or *less than* the weight of the displaced water. "The right answer is equal to but a lot of people will say greater than or less than because they're not sure how the forces interact" (Clark Interview, September 10, 2015). In looking at students' predictions, Owen referenced a pie chart on his laptop, explaining that: "I see right away which each kid says with their name, and what they decided, which is really cool" (Clark Interview, September 10, 2015). Here, Owen attended to students' choice of a response (i.e., learner selection of *greater than, equal to,* or *less than*), stating that: "It was 50%, over 50% got it wrong" (Clark Interview, September 10, 2015). Making sense of or interpreting what he noticed, Owen explained that these percentages showed him that students had "misconceptions" going into the lab.

In the seminar task, Owen largely attended to broad concepts or pieces of ideas in student thinking (e.g., conduction, what an insulator is), again assessing what students either understood or had "misconceptions" about. For example, in analyzing the totality of responses from a student named Riley, he wrote "Riley has some misconceptions about what an insulator is and how conduction works. He does understand some of the general concepts" (Clark, WS, Q1:3). At one point, Owen provided some insight into how one student, Jon, was working to make sense of ideas: "He understood it through his own experiences and understood a lot of the general concepts. He knows that he needs to look into what makes a good insulator" (Clark, WS, Q1:3).

Owen's interpretations of what he noticed in the student work were evaluative in nature. He made sense of student ideas in terms of generic outcomes such as: "Ana does not understand what an insulator is," or "Jon had a general understanding of conduction" (Clark, WS, Q1:3).

Linking Student Work to "Next Steps" in Instruction. For Owen, students' pre-lab predictions functioned as a numerical indicator of how many students had initial "misconceptions." Throughout the lab, students collected, analyzed, and discussed data in small peer groups - ultimately arriving at the conclusion that "these [weight of an object before it is submerged in water compared to the weight of the displaced water] are equal" (Clark, WS, Q1:3). Here, students' predictions were not used to inform or adjust "next steps" in instruction (e.g., making students' evolving hypotheses public or an object of inquiry, leveraging strengths in students' ways of representing or reasoning about initial hypotheses or models, adjusting how students' participate in this lab or what type of experiences they interact with). Instead, student predictions (i.e., learner selection of *greater than, equal to,* or *less than*) were primarily used to quantitatively monitor whole-class progression toward arriving at the intended scientific relationship.

In the seminar task, Owen explained that: "If I changed anything, I might have the students look at and manipulate all four variables at once to see the effect it has. How are they observing the influence of each variable on heat transfer? Are they able to measure it quantitatively?" (Clark, WS, Q1:3). While potentially a positive modification, Owen's whole-class suggestion was weakly linked to the inferences he constructed from student work, if at all.

Stances. As Owen talked about his student work throughout the interview, he tended to portray science as method for gathering data and grappling with information through interactions with peers and the teacher – ultimately aimed at “discovering” or confirming a scientific concept or relationship. Student learning was depicted as a process of “fixing misconceptions” over time. Owen described his role as organizing instructional activities (e.g., preparing the lab, directions, scenarios) and “walking around the whole lab and making sure that they’re good, that type of thing” (Clark Interview, September 10, 2015). The practices of attending to, interpreting, and responding to student work were largely represented as “seeing,” evaluating, and monitoring student progress from “misconceptions” to normative scientific ideas.

Kate England

Contextual Background. A woman in her early 20s, Kate England had a friendly personality. At the end of the fall 2015 semester, Kate will graduate from Middle University with a Bachelor of Science degree in Biology, a minor in Religious Studies, and a Master of Teaching – Secondary Science with a specialization in Biology. In high school, Kate had an inspiring teacher “who could present the information and cause me to think, not only critically in science, but critically as a life skill and apply it into other fields” (England Interview, September 10, 2015). Kate enjoys working with kids and feels that teaching, as opposed to being in an office all day, was a good fit.

During the fall 2015 semester, Kate student-taught 7th grade science at Hilltop Middle School, a local area school. While she developed a positive relationship with her mentoring teacher, Ms. Willis, Kate often expressed frustration with the sequencing of school and district science curriculum. At the time, the district science coordinator was attempting to integrate common assessments into the 7th grade curriculum and across all middle schools. However, as the assessments were still in development, Ms. Willis was unsure of what scope and sequence to pursue at the beginning of the K-12 school year. In reference to planning lessons and activities, Kate explained:

> We were in the awkward, like, we don't know what the city wants of us versus how we imagined going forward, so we wanted something that we definitely knew could work either way - if we were going to move more into Ecology or if we were going to move more into Evolution, or whatever. (England Interview, September 10, 2015)

Outside of this frustration, Kate repeatedly stated that she enjoyed getting to know her students. Teaching science, Kate wanted students to understand that "science is kind of a tool for you to approach most things in life…It's got some prescriptive things to it, but it's also a way for you to engage in everything around you…Science allows you to just know more and appreciate what you don't know about the world" (England Interview, September 10, 2015).

Attending to and Interpreting Student Work. Kate attended to several aspects of student work, though not consistently within or across the work samples. These include the "quality" of student work, specific student ideas, and a beginning glimpse of how students were working to make sense of the content. To the interview, Kate brought student work from a gravitropism lab that functioned as (a) an introduction to "working with living things and plants" (England Interview, September 10, 2015), and (b) a preassessment of students' process skills. Again, as the scope and sequence of the 7th grade curriculum was still unknown at this point, this lab was selected to provide insights into “what they [students] know, like watching them write down what they thought was a hypothesis, a prediction, and as an opportunity for them to question their scientific knowledge thus far and turn it into more of a process, type of thing” (England Interview, September 10, 2015). That is, subject-matter was a secondary focus to process skills:

> We wanted them to kind of be able to practice observations, inferences, some sort of experimental design, and then just kind of engage in more academic skills of like writing, working through a lab, and thinking critically because some of these kids probably still don’t even know why the plants, the roots grow down and the stems [grow] out...we don’t even talk about this for another month, probably.” (England Interview, September 10, 2015)

The lab questions followed the format of “The Scientific Method,” in its traditional sense (i.e., identifying variables, making a prediction, turning a prediction into a hypothesis, following a procedure, collecting data, drawing a conclusion). Ms. Willis and Kate had graded the labs, deducting points for incomplete or incorrect responses.

Kate first talked about the overarching “quality” of student work. For example, in reference to one student, Kate stated: “The student is neat, as in organizationally, the paper is not ripped, it’s intact…The student didn’t feel like he made a lot of mistakes because there’s not a lot of eraser marks. I notice that more or less, some sentences are complete, that the student has a pretty good understand[ing] of grammar and vocabulary” (England Interview, September 10, 2015).

With further probing (i.e., Is there anything else you noticed or learned from looking at this student work?), Kate pointed out and discussed cross- and within-class aspects of students’ “incorrect” ideas, marked by point deductions. For example, she talked at length about a lab question that prompted students to explain why the seeds grew the way they did. Interpreting student responses, Kate posited:

And certainly some students in the honors classes noticed that the title says, “An

> Introduction to Gravitropism." And when they got to that question, they're thinking about it, and they're like, "Oh!" …But on some of them I returned, I had to write it on the bottom, "Think about the title, Gravitropism." Or some of them, even though verbally I know I talked through it with them, about how the stems grew up and the roots grew down, they would talk about it going outward or inward" (England Interview, September 10, 2015)

As well, Kate was a "little irked" that she did not concretely talk more about gravity and the influence on the seeds (England Interview, September 10, 2015). Here, Kate made sense of and attributed students' "incorrect" ideas to a combination of (a) students' inability to use the lab title as a key clue to explain the central phenomenon, (b) the lack of a "concrete" teacher explanation to students.

In the seminar task, Kate attended to specific student ideas, stemming from pieces of the learning goals, at times. For example, Kate stated: "She [Ana] thinks about heat and temperature as air rather than of molecular particles. She thinks that because the air inside the mitten will be the same as the air in the room, they will be the same temperature" (England, WS, Q1:3). In the second half of her statement, Kate simply repeated what the student, Ana, wrote: *Both thermometers will have the same reading because the end of the mitten is open to the outside classroom air. Air can get in and out of the mitten so the temps are the same.* However, she does offer some insight into Ana's idea, suggesting that Ana could be making sense of heat and temperature as air, instead of at the micro-level of particles. In other student responses, Kate attends less to students' ideas and more to broad ways in which some students were working to make sense of the content: "Jon seems to think very practically and think about things in terms of insulation and type of material used. Jon is also a visual learner" (England, WS, Q1:3). Or, "He [Riley] thinks in application" (England, WS, Q1:3). Making sense what she noticed, Kate pointed out some students have “misconceptions” about conduction, requiring “more depth of knowledge [rather] than quantity of knowledge” (England, WS, Q1:3).

Linking Student Work to “Next Steps” in Instruction. Kate’s student work, stemming from the gravitropism lab, was not used to inform or adapt “next steps” in instruction. Instead, the graded labs were returned to students and placed in their interactive notebooks. Kate explained that, “It’s their first interaction with formulating hypothesis and talking about independent and dependent variables, alongside things like measurement, graphing, and data analysis stuff. So those are in their notebooks for them to reference” (England Interview, September 10, 2015).

In the seminar task, Kate linked her interpretation of student “misconceptions” to “next steps” in instruction, reviewing “missed” ideas. For example, Kate proposed a whole-class review of conduction prior to the introductory activity: “It seems that some students have misconceptions about conduction. It would be better to challenge those misconceptions rather than have the students building and qualifying their misconceptions throughout the lesson (England, WS, Q1:3). Adding to this suggestion, Kate wrote: “I also might have students observe demos rather than working through the lab stations so that the class can work together on making predictions and observing results” (England, WS, Q1:3).

Stances. Discussing this particular student work, Kate largely portrayed science as entities of knowledge and process skills, accumulated from and validated by authoritative sources – the teacher in this instance. Student learning was depicted as a “get it” or “don’t get it” undertaking, grounded in the accumulation of information and skills over time. Consistently, Kate represented teaching as providing students concrete explanations in addition to challenging and correcting students' non-normative ideas – often through whole-class work with her: "It would be better to challenge those misconceptions rather than have the students building and qualifying their misconceptions" (England, WS, Q1:3). The practices of attending to, interpreting, and responding to student work were largely represented as "seeing" and evaluating pieces of student ideas and process skills, ensuring sure that future lessons addressed student "misconceptions."

Summary

Table 5 provides a summary of key findings regarding: (1) what preservice teachers attended to, or noticed when examining student work; (2) how they interpreted, or made-sense of what they identified as important; (3) how and to what extent they took up student ideas and thinking to inform "next steps" in planning and adapting instruction, if at all, during this initial pre-module conversation.

Table 5

Key Characteristics of Preservice Teachers' Initial Repertoire of Practice

PRACTICE	ALLIE	OWEN	KATE
"Seeing" and Attending to Student Work: *What do teachers notice when they examine student work?*	▪ Notices student "answers," sometimes in a quantitative form. ▪ Attends to broad concepts or pieces of student ideas; focuses on "misconceptions," or areas of student struggle. ▪ Unpacks individual student ideas at times.	▪ Notices student "answers," sometimes in quantitative form. ▪ Attends to broad concepts in student ideas; focuses on "misconceptions" ▪ At times, attends broadly to how students are working to make sense of ideas.	▪ Quality of student work. ▪ Attends to specific student ideas and broad ways student work to make sense of ideas, at times.
Interpreting Student Work: *How do they make sense of what they notice?*	▪ Student work is indicative of whether students "understand" or "don't' understand" (evaluative in nature).	▪ Student work is indicative of what students "understand" or have "misconceptions" about (evaluative in nature).	▪ Student work is indicative of student "misconceptions" (evaluative in nature).
Linking Student Work to "Next Steps" in Instruction: *How and to what extent do they take up student's ideas and reasoning to inform instruction?*	▪ Links patterns in student "mistakes" or "misconceptions" to whole-class instructional decisions ▪ "Next steps" largely targeted at reviewing "missed" content or bolstering areas of student struggle.	▪ Student work has little to no connections to "next steps" in instruction.	▪ Links student "misconceptions" to whole-class instruction, largely targeted at reviewing "missed" content.

Notably, while Allie, Owen, and Kate certainly portrayed individual strengths and struggles in how they analyzed and interpreted student work to inform instruction, key areas for growth across all beginning teachers included:

1. "Seeing" multiple dimensions of students' individual and collective ideas *and* their ways of theorizing about, representing, and communicating these ideas.

2. Making sense of the meanings students are working to convey in their work; albeit through differing life experiences, language, and ways of thinking and reasoning.

3. Moving beyond evaluating levels of "correctness" in student work: Seeing holistic and evolving portraits of individual and collective student patterns in strengths, struggles and motivations.

4. Leveraging students' tentative ideas and unfolding hypotheses as objects of continual inquiry over time, and in interactions with peers, with differing experiences, and with differing sources of evidence.

5. Adapting instruction to support and extend evolving lines of individual and collective student thinking and curiosity. Ensuring that all students have the conceptual and material resources needed to access *and* grow in constructing explanatory ideas and models of the world around them.

Guided Rehearsal of Collaborative Analysis and Response to a Researcher-Generated Set of Student Work

Over the next three weeks, Allie, Owen, and Kate collaboratively revisited and examined (a) researcher-generated student work, and (b) case studies of two teachers who planned lessons based on this same set of student work. Consistent with a sociocultural frame, individual teacher thinking and learning in this study was largely situated in a community, inclusive of peers, of pedagogical tools, and of classroom artifacts of practice. Within this community, these teachers talked, they grappled with problems of practice, and they created visible representations of practice (Greeno, 2006). In this joint space of intellectual activity, I offer the reader insights into (a) patterns of teachers' conversational exchanges, and (b) structures of ideas and practice that they co-constructed.

Revisiting and Analyzing Student Work: Interacting Perspectives

In this learning sequence, pedagogies of enactment, or "opportunities to rehearse and enact discrete components of complex practice in settings of reduced complexity" (Grossman, Hammerness, et al., 2009, p. 282) framed teacher work. Within a collegial space, Allie, Owen, and Kate revisited the researcher-generated student work, interacting with a protocol that privileged attention to patterns in students' individual and collective understanding of ideas, as well as their ways of thinking and reasoning about these developing ideas. In this section, I illustrate key patterns of teacher interactions around student work, and insights into individual teacher learning stemming from this initial work.

Patterns of interactions. On a Thursday evening in September, long after the school day was over, Allie, Owen, and Kate made their way to Middle University, congregating around a rectangular table in a large classroom. After ordering pizza, they touched based with the doctoral student in charge of their student teaching observations in the local schools. Finishing up last bites of dinner, we interacted with the protocol, examining Ana's responses (i.e., 7th grade student) to the series of prompts. Early-on, these conversations were typified by the following dialogue:

Owen: Well, I thought she [Ana] had the best understanding.

Amy: Okay, talk a little more about that. What led you to think that?

Owen: I just thought her reasoning was good, it was well thought out…. I thought she was thinking about the reason of it, instead of just like 'this might be a good insulator.' She was looking at more why it is, and she got the first question correct [multiple choice response], which is good.

Amy: Allie, can you add to this?

Allie: I was also impressed with her use of like, 'this will really help slow down heat loss because the molecules of air are far apart.' I think Jon also talked about the molecules, but that use of 'oh, I understand how heat transfer happens between molecules,' that was good. (TD, September 17, 2015).

While it was certainly encouraging to "hear" these teachers beginning to delve into student reasoning, these early conversations were consistent with what Grossman, Wineburg, and Woolworth (2001) described as "congenial conversation." That is, while friendly, these discussions were largely dependent on a facilitator to mediate the conversation, eliciting on-going and often disjointed insights from all participants.

Over time, however, two key patterns in teacher exchanges emerged – exemplifying key features of collaborative inquiry into student work. Marked by interactions of differing perspectives, preservice teachers in these conversations: 1) negotiated elements of and connections between science, student learning, and pedagogical approaches; and 2) inter-contextualized, offering up their own experiences, ideas, and practice across multiple contexts as resources for constructing knowledge at the group level.

In the first pattern of exchange, teachers navigated subject matter, student learning, and teaching approaches together. For example, in the following piece of dialogue, Allie and Owen worked to make sense of what Ana may have meant by her use of the terms "heat" and "heat flow."

Owen: Maybe grabbing onto her use of the word "heat" can kind of…we can dig into what she means by that.

Allie: But she does say later, "heat flow."

Owen: But she's going back-and-forth.

Owen: But heat is not like a quantity, a quantitative thing, I think, in a sense. Take the transfer of heat.

Allie: But you could lose heat, right?

Owen: How do you lose the heat?

Allie: Well, because it transfers but you're still losing it. A piece of a system can lose heat to the rest of the system. Is that incorrect to say it like that?

Owen: That makes sense, I guess.

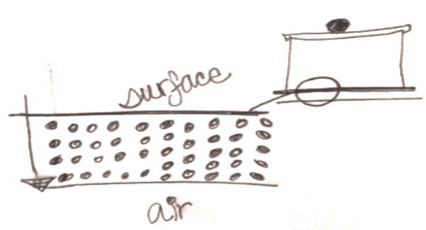
Allie: Yeah, so you need to ask her, "Okay, so where is the heat? What do you mean by heat loss? Where is the heat going?"

Owen: Yeah.

Allie: "Does it just disappear?" (TD, September 17, 2015)

In this exchange, an initial focus on gaining insights into Ana's thinking changed course to negotiating the scientific meaning of "heat flow" and in particular, "heat loss" out of a system. This conversation ultimately catalyzed a series of questions aimed at helping Ana elaborate on or further her thinking.

In other exchanges, preservice teachers re-interpreted student ideas and reasoning – working to better understand the meanings that students were trying to convey. In the following conversation, Allie, Owen, and Kate contemplated what one student, Riley, meant by her suggestion to add a thick layer of cardboard to the floor of the solar cooker as a means of minimizing thermal energy transfer out of this system, to the surroundings (see Figure 4).



With a thick layer of cardboard, the molecules are close by eachother [sic] but there are more of them. The molecules will still wiggle and bump into eachother [sic] and then pass thermal energy along, but there are just more of them to pass through. So, this will keep the temperature hot longer in the cooker.

Figure 4. Riley's response: Minimizing thermal energy transfer out of the solar cooking system.

Owen: Wiggle and bump. I like the wiggle and bump.

Kate: Maybe she's thinking about the school dance.

Owen: I think it's good.

Allie: 'There are more of them to pass through,' is that incorrect?

Owen: I don't think she is completely off with that.

Kate: What molecules are close by each other?

Allie: Okay, so…

Kate: She's saying that cardboard, it's a thicker material, so the molecules…there are a lot of molecules in a small space, so heat can't go through them.

Owen: Or, she's just saying to make it [cardboard] thicker.

Allie: That would increase the insulation.... Because, a thick layer of cardboard wouldn't increase the spacing of the molecules. (TD, September 17, 2015)

As this dialogue continued, Allie, Owen, and Kate grappled with *how* Riley was thinking about the rate of thermal energy transfer at a molecular level (e.g., the language Riley is using, the diagram she uses to express her ideas, alluding to material thickness vs. density).

In a second pattern of interaction, teachers "offered up" and made visible ideas and experiences from multiple contexts (e.g., student teaching context, personal experiences as a high-school student) as resources for making sense of teaching and learning science on a social plane. For example, in talking about the importance of eliciting and "seeing" student reasoning, Owen stated:

> Obviously, it's different because it's not at the same level [middle school students vs AP students], but you can relate this to an AP student using a formula and just plugging everything in. Like coming up with a formula for the rate of conduction, and deciding to make something thicker, but not really understanding why you would make it thicker. (TD, September 17, 2015)

In this excerpt, Owen used his experiences with AP students as another lens for the team to "see" the importance of pressing for student reasoning. Throughout engagement with student work, a bi-directional "transparency of ideas and practice," across multiple contexts, afforded teachers another way of relating to or making sense of "problems of practice" stemming from complex interactions of subject matter, students, and pedagogical decisions. In follow-up interviews, all three participants described these perspective-seeking conversations as particularly influential in shaping their individual thinking and practice (WS, 2.1).

Digging deeper: "Seeing" student ideas *and* their ways of thinking and reasoning. With support from collegial conversations and the protocol, teachers' on-going interactions with student work in this cycle most notably reflected growing attention to and consideration of students' reasoning - used to support learners' evolving ideas at the macro- and micro-level. Preservice teachers' developing capacity to attend to this additional dimension of student learning was evident across team discussions, across teachers' reflections on personal growth, and across one additional analysis of student work – originating from middle school student named Jack.

For example, in analyzing Jack's responses, Allie pointed out that while Jack may be understanding the phenomena at the macro-level, he lacks "depth in his understanding" at the molecular level of *how* and *why* (Evans, WS, Q1.4). As well, she recognized that Jack is working from his "backyard" experiences to make sense of thermal energy and heat transfer. In reflecting her own learning after this inquiry into student work, Allie pointed out the importance of looking at: (a) if students have seemingly repeated something that they heard, or if students have put something in their own words; (b) if students are able to connect the material to their own lives or something outside the classrooms; and (c) areas of individual student struggles *and* strengths (Evans, WS, Q1.5 and 1.6).

Likewise, Owen attended to specific ideas in Jack's work that were "correct," but lacked a depth of reasoning. For example, Owen stated: "Jack seems to have a simple understanding of heat flow…but all of his reasoning is based on his idea of a coat being an insulator, and more specifically, a coat being a good insulator due to its thickness" (Clark, WS, Q1.4). Making sense of what he noticed, Owen explained that: "Jack says things that are technically correct but he does not understand why these things are correct. He does not really provide details at the micro- or macro-level. He needs to be asked questions that better show his understanding and uncover any misconceptions he might have" (Clark, WS, Q1.4). In reflection, Owen explained that he has started to ask himself: "Does their reasoning show that they have a strong conceptual understanding of the material? How strong of an understanding are the students showing with this work? What do they really seem to understand and what can they understand better?" (Clark, WS, 1.6).

And finally, Kate also noticed that while Jack has some understanding of heat transfer, "whether or not this is because of an in-depth understanding…is unknown" (England, WS, Q1.4). That is, "Jack understands layers and insulators, but perhaps not at the molecular level" (England, WS, Q1.4). Working to "see" past "right or "wrong" in student work, Kate shared:

> It's been good practice for me…. The middle school mindset is, oh we're still talking about capitalizing the first letter of your sentence and putting questions marks at the end of questions. And so actually going beyond that and seeing the student, or picturing the student trying to explain that, it has been a challenge for me. I look at it [student work] and I tend to tell by the fact that they did do this or

> they didn't do that, that this is going to be a right or wrong answer, as opposed to forming a working, informative response. (TD, September 17, 2015)

Case Studies: "Seeing Possibilities"

Coupled with analysis of student work, case studies or "representations of practice" were intended to make visible and represent images of the HLTP under study (Grossman, Compton et al., 2009; McDonald et al., 2013). In this next sequence of learning experiences, framed by pedagogies of investigation (Grossman, Hammerness, & McDonald, 2009), Allie, Owen, and Kate analyzed two case studies, focusing on "seeing" and learning about key aspects of teaching that are dually (a) accountable to disciplinary rigor (i.e., the pursuit of increasingly coherent and evidence-based explanations of the natural world) and (b) responsive to students' evolving strengths, struggles, and motivations. As depicted below, these case studies surfaced teachers' ideas about teaching and student learning in addition to affording them an opportunity to "see" differing possibilities.

Case study one. In the first case study, Allie, Owen, and Kate expressed concern with the way the teacher in this scenario had analyzed the student work (i.e., seeing broad levels of "correctness" in student ideas). Kate explained that this teacher interpreted student responses as "either right or wrong, it wasn't a spectrum of understanding" (TD, October 1, 2015). In breaking students into groups based on this analysis and interpretation of student work (i.e., students with below level understanding, students with above level understanding), and remediating or extending, both Allie and Owen expressed concern. Owen noted that he was "confused" by how this teacher broke them into groups, based on a shallow interpretation of work. Further, Allie stated that she was "on the fence" (TD, October 1, 2015). Elaborating, she explained that the teacher had most likely “misconstrued” or “poorly placed students” (TD, October 1, 2015). For Allie, this type of teaching and learning approach resembled tracking: “I’m also, I don’t really like tracking and I know that this is not tracking but splitting kids based on ability, I don’t like that. I have personal feelings against that” (TD, October 1, 2015).

From a differing perspective, Kate worried about the students in one group working more independently: “It’s hard to monitor that too. Because it’s like what if your perception of a student having an average understanding was an under-developed understanding and then they communicate to another student a misconception” (TD, October 1, 2015). As shown, these conversations often surfaced teachers’ tacit ideas about how students learn, and corresponding teaching approaches.

Case study two. The second case study afforded Allie, Owen, and Kate a differing vision of what science teaching and learning could “look” like in classrooms:

Owen: I like the claim thing, I guess. The claims she [teacher] came up with from the student work, and then kind-of breaking them down. That’s awesome. She’s asking them to really look at their misconceptions.

Allie: And, relating that to their everyday life experiences, because they have to bring those to the table.

Kate: Also, I just thought about this, if you’re doing this with the entire class and the above average learners are looking at both of them, then even if they technically got it correct, they can be looking at perhaps why other people’s responses may or may not make sense and further develop their understanding on perhaps what they got correct in the first place.

Owen: Well, or, isn’t there [*sic*]different levels of evidence that they [students] could use too? You could go into more depth with some of your evidence, more involved than just using a pot and a spoon. Like you could go into a lot more depth.

Allie: She also included just so many ways for students to learn, a simulation, drawing, discussion.

Amy: Sure, here the teacher's role is to direct students to differing sources evidence and resources to interact with, not answers. (TD, September 24th, 2015)

In the conversation they pursued, teachers "tried on" this approach, sharing potential advantages and challenges. For example, Allie cited two strengths in this approach: (1) relevance to how science is actually done, and (2) normalizing error in learning, helping students understand that their ideas will evolve (vs. being "right" or "wrong"). Owen noted value in having all students work on "thermodynamics, the processes, and how they work," albeit with scenarios that ranged in levels of complexity: "I could find something really simple, or something very complex depending on their level of thinking and understanding…. once again, if you're coming back to a test they are still understanding the same process" (TD, September 24th, 2015).

For Kate, coming up with everyday experiences or phenomena that related to her content area, while meaningful in her opinion, was an area of challenge for her. As well, this approach seemed more feasible with her honors class:

> My hesitation with different types of science instruction in general as I'm learning with my students, some of my academic and collab kids have really hard time with discussion. This guiding and building on ideas is much more feasible in an honors class for me because they can follow through with conversation. Some of my other kids can't last two minutes of discussing out-loud because one student doesn't talk loud enough for the entire class to hear, or says something funny. Sometimes we plan around limited opportunities for distraction. (TD, September 24th, 2015).

Allie articulated challenges in the form of questions. For example, she asked a series of questions related to how to implement this type of approach (e.g., levels of scaffolding, how to work on a model over time). Collectively, these case studies were particularly productive in (a) portraying differing representations of practice, giving teachers an opportunity make sense of how teachers linked differing practices (i.e., analyzing, interpreting, and respond to student work) to a systematic approach to teaching and learning science, (b) affording teachers opportunities to relate to or "try on" different elements of practice, and (c) "seeing" differing areas of teacher strength and struggle, potentially informing future "next steps" with teachers (e.g., tools for scaffolding equitable discourse in science classrooms). Many threads of these conversations continued into cycle two.

Cycle Two: Rehearsals of Collaborative Analysis and Response to Student Work Generated in Preservice Teachers' Secondary Science Classrooms

Allie Owens: "Common Streams of Thought"

Context and description of student work. At the end of cycle one, Allie expressed a personal interest in learning how to engage students in constructing explanations of an anchoring phenomenon, originating from a brief pre-module introduction to designing units grounded in "big ideas" and causal explanations of phenomena over time (Field Notes, October 1, 2015). After a short brainstorming session at the end of seminar class and sharing some resources, she developed a series of questions over the next week that prompted students to predict and explain, on a macro- and micro-level, what happens when a light bulb with two metal prongs is placed a beaker with tap water, in a beaker with a salt solution, and a beaker with a sugar solution - and plugged in. Specifically, Allie asked students to write a prediction of what they thought would happen on a macro- or observable level (e.g., the bulb in the salt solution will light up, the bulb will slowly light up in the salt solution, the light bulb in tap water will not light up). After conducting the experiment, students noted if their predictions were correct or incorrect. In the final part of the prompts, Allie created an empty diagram of each of the three beakers and light bulbs. She asked students to "draw what you think is happening on molecular level in each beaker" (TD Artifact, October 7, 2015). Her overarching goal was to "gauge how much they knew about ionic and covalent bonding and what was actually going on" (TD, October 7, 2015). Anchoring a portion of her bonding unit specifically related to ionic and covalent bonding, Allie stated that "we're going to reassess this [over time], and they're going to come up with explanations of what's actually happening," (TD, October 7, 2015).

Attending to and interpreting student work. Discussing her student work, Allie largely attended to and talked about (a) nuances in individual student "theorizing" about what was happening on a molecular level and why; and (b) emerging questions of student curiosity. Interpreting or making sense of what she noticed, Allie identified four patterns of student thinking, or what she characterized as "common streams of thoughts" (TD, October 7, 2015). Elaborating on each pattern, Allie cited specific evidence from individual student work to support her inferences. For example, referencing the student diagrams, she stated:

> But she, for instance, thought the saltwater was more saturated and that sugar water was too dilute, and so that's why it didn't happen [bulb did not light up]. Some of my students, after observing this, went on and started asking questions about, "Well what if we mix salt and sugar? What if we add more sugar? What if we add more salt? What if we were using different liquids? Would it change?" So this really sparked their curiosity. (TD, October 1, 2015)

Further, Allie pointed out that "the level of understanding definitely varied…. But, I think that the biggest question was, 'Why does this happen?' None of them were like, 'Oh, I know this,' and I didn't tell anyone why because I want them to draw that conclusion" (TD, October 7, 2015). She also noted that while students had some ideas of what was happening at the molecular level (i.e., the underlying causal mechanism), only "one or two of my students, whose work I don't have here, actually showed positive/negative

[ions], but they didn't really get further than that…. I didn't expect anyone to know exactly what's going on" (TD, October 7, 2015). Reflecting on the original prompt, however, Allie noted that she should have added a text box, offering students a space to express or further expand on their thinking in writing as well.

Guided by the consultancy protocol, further conversations centered on helping Allie expand on what she "noticed" in student work. Again, these discussions often veered toward interrogating subject matter:

Owen: This one's interesting because, "dissolves sugar." They almost think that they're seeing that.

Allie: Yeah, so they don't see it, but they think the sugar dissolves better or something like that.

Owen: I don't even know. Does sugar dissolve quicker or anything?

Allie: No. Covalent compounds are worse at dissolving.

Kate: Well, did you use regular table salt and sugar?

Allie: Mm-hmm (affirmative).

Kate: Sorry, you're saying that covalent bonds should dissolve?

Allie: No. Sugar dissolves in water, but the ionic bonds are better at dissolving in water than covalent bonds. (TD, October 7, 2015)

This conversation continued as Allie and Kate worked to clarify the underpinning mechanism of the light bulb phenomena. At other times, as reflected in the exchange below, preservice teachers worked together to re-interpret what meanings students were working to convey:

Kate: Because they seem to be not thinking about like, what is it about the compounds that are causing it, rather than something about the amount.

Owen: Yeah, have you learned about charges at all?

Allie: No. Well, electrons and protons, but…

Owen: It's pretty hard for them to realistically think they would get this, right?

Allie: Oh yeah. This is the pre-test to the unit, well not a pre-test. It was a pre-hook. I spent a day long like "get interested about bonding" type of thing, and then we're going to further investigate this.

Owen: Okay, yeah. I think they're focusing on the explanation of a complete circuit. I think they're trying to go for that…. In a sense they're not completely wrong.
(TD, October 7, 2015)

Linking student work to "next steps" in instruction. Moving forward, Allie explained that while she hadn't fully decided, she was contemplating posting the four explanations on the board, "kind-of what that teacher did in that previous example [case study]" (TD, October 7, 2015), engaging students with further information and evidence to support, refute, or modify these explanations in "next steps." As well, she aimed to offer students opportunities to conduct their own experiments, exploring questions of interest that they were developing:

> They could extend this and say, 'Okay, what if I used different substances or different liquids?' And think about the bonding that occurs in the liquids and substance and try and predict something. Or they could do something with melting point, or something else, just to explore properties of covalent and ionic bonds. (TD, October 7, 2015)

In the conversation that followed, Allie elicited input from the team as to "next steps" in student learning activities, grappling with potential information or experiences students could interact with to help them compare, refine, or add to explanations over time (e.g., points of direct instruction, simulations, student designed experiments). Notably, this conversation spurred differing ways of thinking about teaching and learning science:

Owen: It'd be cool to be like, 'Now let's go back to this [students' initial ideas and models]. What's going on here with what you just said' type of thing, since you already have their thoughts on it. It's like…coming back to, what do you call it, your big?

Amy: Your big idea?

Owen: Yeah, the big idea. Like this [specific learning activity] is a small idea, but you could keep going back to it, like, 'How does this fit into here?"

Kate: Especially because…you've normalized error several times in this, so they're not going to be afraid to go back and do it because you talk about how it's only a prediction.

Allie: Yeah. Some of them were annoyed that I didn't tell them after [what was happening].
(TD, October 7, 2015)

Stances. As Allie talked about her student work in this instance, she tended to represent science, or development of scientific knowledge and practice, as a theory-building endeavor. Student learning was depicted as a process of actively proposing and refining explanations of phenomena over time, anchored in interactions with peers, with differing experiences, and with differing sources of information. Allie emphasized that she "didn't expect them [students] to know exactly what's going on" (TD, October 7, 2015), stating frequently that students would keep coming back to and refining their thinking. In parallel, Allie represented teaching as eliciting and making student thinking visible – an object of continual inquiry. In this instance, attending to and interpreting collective patterns in student reasoning or "theorizing" and emerging questions functioned a key resource for Allie to think about *how to* support students' evolving lines of thinking - grounded in epistemic activity reflective of the discipline.

Owen Clark

Context and description of student work. Owen "borrowed" the structure of his cycle two prompts from Allie's presentation of student work. Noticing her use of a phenomenon to elicit students' ideas and reasoning, in both visual and written form, Owen asked if we (i.e., the team) could help design his prompts at the end of her presentation. The overarching goal of these prompts, or set of questions, was to elicit students' understanding of thermal energy transfers in everyday situations - as related to conduction, convection, and radiation. Specifically, he proposed that students select an everyday life situation that involved "increasing the transfer of thermal energy through two of these processes or reducing it. I want [students] to draw it…and, actually show the molecular transfer" (TD, October 7, 2015). In a short working session around a whiteboard, every team member chimed in to help Owen develop, expand on, and refine the final set of questions (see Figure 5).

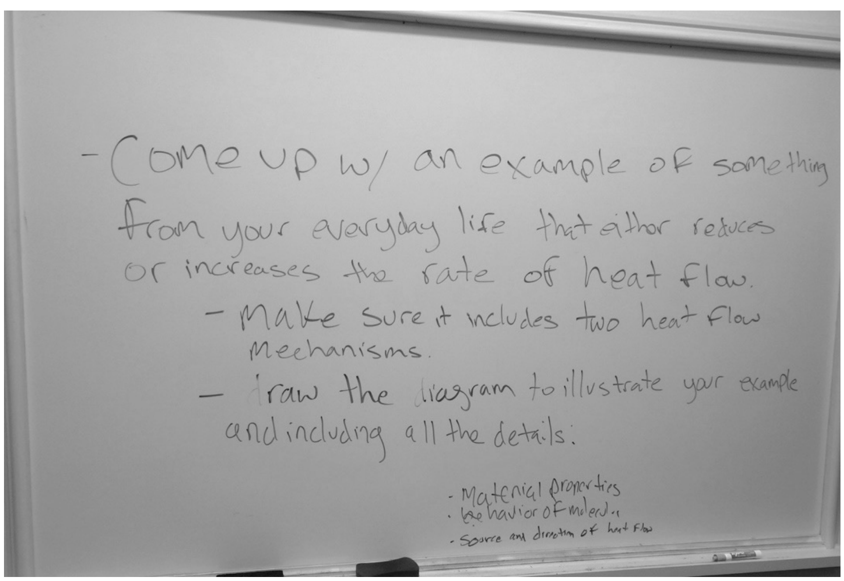


Figure 5. Owen's final prompt, developed in collaboration with the team.

Beginning his presentation of student work, Owen explained that in the class before, he had "gone over thermal energy transfers, so we've gone over conduction, convection, and radiation" (TD, October 15, 2015). Namely, his general teaching approach involved (a) introducing a concept such as conduction through a presentation; (b) giving students everyday examples of objects to grapple with (e.g., down jacket, wood stove, thermos), and encouraging them to explain what was happening in terms of thermal energy transfer to peers; and (c) going over "what happened" with the whole-class. In regard to this specific prompt, Owen stated that:

> the idea with this prompt was for them to come up with their own [example], and they would draw a picture that would have to involve two energy transfers, convection or radiation or conduction. Then, they would have to include details in the description and the details should include material properties, behavior of the molecules, and the direction of heat flow. (TD, October 15, 2015)

Owen brought three samples of student work for the team to examine, representing a "wide range of understanding" (TD, October 15, 2015).

Attending to and interpreting student work. Talking about his student work, Owen consistently attended to (a) individual student ideas, often restating or describing students' responses; and (b) detail in and depth of student reasoning. For example, referencing one student with "a middle level understanding" (TD, October 15, 2015), Owen stated:

> He's [Student A] talking about sleeping on a bed with a down comforter, so he draws a bed and a person, and has arrows pointed toward the middle of the comforter, and he says 'stopping, decreasing conduction.' He said, 'made of feathers to trap warmth, thermal energy that my body is radiating. Feathers are good at stopping convection.' I think this also really doesn't show much a firm understanding, sadly. He talks about feathers trapping the thermal energy for radiation and he says they're good at stopping convection, which is true, and I guess he is basing that off our discussion in class, but he doesn't really talk about why it's good or what's occurring. (TD, October 15, 2015)

Making sense of or interpreting what he noticed, Owen (a) described each student's level of understanding (e.g., no understanding of the concepts, middle level of understanding, stronger understanding), and (b) reasons underpinning students' differing levels of understanding. These reasons ranged from a lack of student effort to the structure of an AP course to his teaching approach. For example, in reference to a student who demonstrated a "low" understanding of the concepts, Owen explained that this "kid's definitely struggling, kind-of sits in the back and doesn't do his homework half the time. I don't know why he's in the class sadly" (TD, October 15, 2015).

Guided by the consultancy protocol, further conversations centered on helping Owen expand on what he "noticed" in student work. In the following exchange, Allie pressed for further insights into what Student A was working to convey:

Allie: How do you feel about the way his arrows are going [pointing up and down within the comforter]?

Owen: I don't really know what they are saying, to be honest.

Allie: Okay, because I was thinking maybe the heat from the body is trapped in the blanket.

Kate: Yeah. I think it's [heat] is not escaping, so it's just bouncing around in There.

Owen: Maybe, I'm not sure. He's showing them going in both directions, which is incorrect. (TD, October 15, 2015)

The conversation continued as Owen, Allie, and Kate re-interpreted this student's thinking. At one point, Owen noted that his students had minimal experience sharing their thinking in drawings or in writing. Contextualizing this statement through his experience as a high-school student, Owen stated:" I was like one of those kids, I think, scared to put their own thoughts down…. I remember having feeling in high school, for sure, not confident enough, thinking 'This teacher is going to judge me a lot with this type of thing" (TD, October 15, 2015). In terms of writing, students had only worked on describing, in written-form, scientific relationships and theories that may appear on the AP exam.

Describing collective patterns in student thinking, Owen characterized the class as "confused." Part of this, according to Owen, stemmed from a problematic learning progression to AP Physics: "A lot of them haven't taken physics since freshman year, and they are grasping at these misconceptions" (TD, October 15, 2015). Elaborating on his conceptualization of "confused," Owen further explained that "a lot them [students] were understanding the difference between conduction, convection, and radiation, but they really didn't delve into the details of the molecules" (TD, October 15, 2015). Upon reflection on his own teaching, Owen shared: "I maybe just didn't do a good enough job teaching. I don't know. I spend a lot of time going through the three processes with them, so it's tough. Maybe they weren't paying attention."

Linking student work to "next steps" in instruction. Owen did not use this student work to inform "next steps" in instruction. In this case, students "spent time explaining it [their responses] to each other and talking through it with each other…. then, I talked through it again" (TD, October 15, 2015). In the conversation that pursued, Kate, Allie, and Owen reflected on what could have been differently with students to this point:

Owen: I think in my head, thinking, it's like you have to have them practice this type of thinking. They have to be able to, it's what makes science interesting, it's what makes science fun. It's one thing to walk them through a demo or walk them through an example and have them explain it, but to actually be able to come up with their own ideas and thoughts, I think that just takes practice.

Kate: Yeah. And you think I've given them every opportunity, so like, the next step is just to connect all of these ideas, but sometimes, you have to make sure that either it's really explicit, or that everybody understands the connection.

Allie: Have you been able to put a coat on the board and be like, 'Okay, show me where the heat is coming from. Now show me…'

Owen: I haven't. To be honest, and maybe I should have done it more, and this is more me being comfortable, and the biggest thing Mr. Riggs ways to me is, 'You have to give them more time to think.'

Allie: Wait time?

Owen: Wait time. That's all he [Mr. Riggs] says to me, 'Wait time, wait time.' The problem is there's really smart kids that will answer it right away, and then I'll move on, because I think I've given enough time for everyone else to think about it, so there's always kids in the class that know what's going on. (TD, October 15, 2015)

Exemplified in this short excerpt of dialogue, Owen begins to think about affording learners more agency in coming up with and making sense-of their own ideas and thinking. Moving forward, the team "imagined" pedagogical possibilities, such as gathering small teams of students around whiteboards to draw models, to facilitate discussion, and to make on-going thinking more visible to peers and the teacher. Sharing her approach, Allie explained that during her lesson that day,

> I called different groups of students up to just work one on one with me in small groups with me on bonding, because some students…. they just needed more guided practice. You just need to make sure that all of the other students are doing something of value while you are working with a small group. (TD, October 15, 2015)

As well, we discussed the possibility of anchoring a sequence of learning experiences in a common set of learning goals, and engaging students with situations or phenomena that represent a range of complexity. Adding his own insight, Owen explained that his "dream" (TD, October 15, 2015) would be to add a space on his Google forms (referring back to the Archimedes' principle lab) for students to explain their thinking in addition to selecting an "answer" that best matches students' ideas at a given point in time. Importantly, while Owen saw value in these ideas moving forward, he wasn't sure this was possible as a student teacher: "It's one of those things, we are very behind already…. I don't even know [that] this would be on our test or that he [Mr. Riggs] would do it" (TD, October 15, 2015).

Stances. As Owen talked about his student work throughout the majority of the discussion, he tended to portray science as acquiring information from an authoritative source over time (i.e., the teacher). Following linearly from teaching, student learning was largely depicted as accumulating and processing information over time – at times with peers. Notably, it was encouraging to "hear" about the importance of peer discussion in Owen's classroom. However, the primary purpose of these peer interactions was aligned with "reaching" a canonical understanding. Correspondingly, Owen portrayed his primary role as monitoring and validating individual and collective student thinking – "correcting misconceptions" along the way. Representing his teaching practice, Owen repeatedly used the language of "I talked with them about…," reflecting his primary role as arbiter of science content. Typifying this pattern, Owen explained, "it [time for students to respond to the guiding prompt] took ten minutes, and then we spent time explaining it to each other and talking through it with each other…and then I talked through it again" (TD, October 15, 2015). At several points, Owen seemed surprised that students were struggling, given the quantity of time he had spent "presenting" information to students. Perhaps consistently, in this instance, the practices of attending to and interpreting student work were largely represented as "seeing" students' ideas and reasoning for the purpose of assessing student learning outcomes (i.e., broad levels of understanding). Student work played a minimal role in adapting "next steps" in instruction.

Kate England

Context and description of student work. Kate struggled to find a place in her student learning experiences to elicit, collect, and examine evidence of student thinking. After two email exchanges, and working to "see" differing possibilities, she settled on bringing samples of student work stemming from their homework - a pre-exam review packet. Kate identified the learning goals as "levels of organization, abiotic factors, biotic factors, water cycle, carbon cycle, photosynthesis, and respiration" (TD, October 15, 2015). Narrowing this down, Kate indicated that she would like to focus on the portion of the packet related to photosynthesis and cellular respiration.

Leading up to this review packet and throughout her analysis of student work, as described in the next section, Kate discussed teaching and learning experiences in relationship to two distinct types of classes: (a) honors class, and (b) academic and collaborative classes. Elaborating, Kate stated: "collab, or collaborative [classes], a lot of them have IEPs and then academic is our base" (TD, October 15, 2015). For all classes, in regard to photosynthesis and cellular respiration, students took Cornell-style notes with summarizing and formulating questions. She emphasized the importance of reactants and products, paralleling reactions to a mathematical equation. In a follow-up "sense-making activity," she gave students a piece of paper with an equation skeleton, "hardly any ink on this paper, and it was writing out the equation as a class, filling in the blanks" (TD, October 15, 2015). Kate explained that it was helpful for both groups of students (i.e., honors and academic/collab) to color-code the reactants and products in both processes, answering questions such as: "Is water on the right-hand side or left-hand side of photosynthesis, and where else do you see water on the page?" (TD, October 15, 2015). Finally, students worked with a plants and snail gizmo to better "see" the relationships between these processes.

The focal portion of student work was framed by two questions. The first question prompted students to describe the difference between photosynthesis and cellular respiration. Characterizing this question as "really open-ended," Kate explained that "they [students] could say it happens in different organisms. They have different products and reactants, which they do, and they involve different types of energy" (TD, October 15, 2015). The second question prompted students to explain the relationship between photosynthesis and cellular respiration.

Attending to and interpreting student work. Discussing her student work as related to these two questions, Kate largely attended to individual student ideas, often restating what students had written in their short-answer responses. Drawing attention to one student in a collaborative class, Kate stated:

> She says, 'what plants take in and what animal plants take in,' so again, just in English, I don't really know what that means but something about plants and animals, different organisms utilizing different processes. And, what is the relationship between the two? 'To help plants and to help them breathe.' (TD, October 15, 2015)

Making sense of what she noticed, Kate consistently followed up her restatements of student answers with her thoughts regarding (a) what each student understood, was confused about, or did not understand, and at times (b) potential reasons why:

> This is an honor student, 'Photosynthesis is the process of plant making food. Cellular respiration is when all living things use food and water to release energy,

> carbon dioxide, and water.' She's a little confused with the water aspect of it, which we didn't talk about it too much. (TD, October 15, 2015)

Exemplified in the previous and following passages, reasons for differing levels of student "understanding" primarily centered on what was addressed or not addressed within learning experiences leading up to this review packet. For example, in pointing out how one student explained the difference between photosynthesis and cellular respiration, Kate stated:

> 'Photosynthesis is plain algae and some bacteria. Cellular respiration, plants and animals, and they both use energy from the sun,' which is, I would just say, say a little more about that, because photosynthesis uses the sun's energy, that cellular respiration produces it. I think maybe because they don't know about it at the micro level they don't understand why, like, you don't put energy into breaking apart glucose to make energy. (TD, October 15, 2015)

Flipping through the student work from both classes, Kate shared four additional student responses. Identifying collective patterns in student thinking, Kate noted that there "weren't a ton of kids who really did an in-depth analysis of photosynthesis and cellular respiration" (TD, October 15, 2015). That is, "students could either say what goes in and what comes out [of photosynthesis and cellular respiration] but couldn't talk about it" (TD, October 15, 2015). In particular, she expressed frustration that students didn't seem to "get" that cellular respiration happens all the time, especially since she had "explicitly debunked" (TD, October 15, 2015) many misconceptions about photosynthesis and cellular respiration (e.g., photosynthesis occurs during the day and cellular respiration at night). She conveyed equal frustration with the district pacing guide. As the topic of cells was slotted for next semester, Kate felt that she couldn't help students understand the "why" of cellular respiration.

Noticing a large range of student ideas across classes, Allie inquired into her overarching question for learners:

Allie: Do you teach around big questions?

Kate: Yeah.

Allie: Like, what was your big question for photosynthesis and cellular respiration?

Kate: It was more like, "How do we get energy?" or "How do we make food?" …. If you think about it, just conceptually, if you put all of the concepts that we've touched on just in the first unit on a map, it's scattered; it's all over the place. For some students, it works, because they get bored really easily, so the more scattered it is, the more opportunities they have to engage each time. (TD, October 15, 2015)

Kate described the large amount of information she had to "cover" for the collaborative and academic classes. However, she also noted that "it's different for the honor students, and I don't mean to generalize, but that's the trend that I see. For some of the honor students, it's not a lot of new information to download and upload. They can go more easily into processing" (TD, October 15, 2015). Steering the conversation back toward a focus on student thinking, I asked Kate to think about one class, sharing her thoughts on "next steps" in instruction.

Linking student work to "next steps" in instruction. Kate's student work was not used to inform "next steps" in instruction. The homework packet was due the next day, the same day as the unit test. Further, she explained that "I don't know how much we'll remediate after this, because on this test, this isn't going to show up as much, because they will talk about it and mention it again and reiterate again when they talk about cells" (TD, October 15, 2015). Probing further:

Owen: There's a test tomorrow?

Kate: Yeah, yeah, yeah…we have to move pretty quickly. The reason why last week I was like, I can't do it [eliciting and collecting evidence of student thinking], is, this past week, they have had a week of biomes…. We just did tundra, taiga, rainforest, temperate, deciduous forest, grassland, and desert.

Owen: Wait, you're doing photosynthesis at the same time?

Kate: They learned about is last week, a week and a half ago. So for the past five, six days, I've been working on biomes. (TD, October 15, 2015)

As the conversation continued, Owen asked Kate if she could have just worked with students on the "big picture" (e.g., plants give off carbon dioxide), leaving the details to the next semester when cells would be introduced (TD, October 15, 2015). Kate seemed to agree, emphasizing that this was not her unit plan. She further explained that if she had more time, she could have probed more student thinking: "If had had probed them last week, it probably would have been like, 'try to name all of the biomes.' They need to be able to actually download new information" (TD, October 15, 2015).

Stances. As Kate talked about her student work, she tended to portray science as distinct entities of knowledge and process skills, accumulated from authoritative sources – the teacher in this case. In her classes, students seemed to engage with (a) a collection of knowledge (e.g., abiotic factors, biotic factors, water cycle, carbon cycle, photosynthesis, and respiration), or (b) experimental design. In thinking about "better" unit planning at one point (referencing the district mandated pacing guide), Kate noted that teaching with and through explanations of real-life phenomena was not possible at this point: "I actually think I would lose my middle schoolers if I did something like that" (TD, October 15, 2015). However, she did see value in guiding a unit with a concept such as "food." Elaborating, she explained that "they love food…. part of the reason why they can't think about how our cells have to undergo cellular respiration is because they don't know anything about their cells. You know what I'm saying?" (TD, October 15, 2015).

Images of how students learn in this instance were depicted as a "get it" or "don't get it" undertaking, grounded in the accumulation of information and skills over time. For example, in reference to students' process skills, Kate stated: "We interact with these kids on a daily basis, and we know. We've assessed them several times, and we're shocked, and we've assessed them again, and we know that they don't know it. They just don't know it [experimental design]" (TD, October 15, 2015). Consistently, Kate represented teaching as ensuring that students receive organized and detailed information, often in the form of "prescriptive Cornell style notes" (TD, October 15, 2015). Further, she made distinctions between what types of activities students should interact with, based on perceptions of students' background experiences:

> For the collab-academic students, it's sometimes nicer to go big than small [scope and sequence of curriculum], because they don't have those previous experiences with animals and living things, so you have to give those experiences to them before they can apply it. With honors students, for the most part, I like to start small and then go big.… A good chunk of my honors students, their parents are involved in the science community, they have interacted with stuff a lot. Just being outside, they have a lot more experiences than other students. (TD, October 15, 2015)

The practices of attending to, interpreting, and responding to student work here were largely represented as "seeing" pieces of student ideas, evaluating student outcomes (e.g., levels of understanding), and if time allows, remediating. Cycle two characteristics of preservice teachers' repertoires of practice are depicted in Table 6.

Table 6

Cycle Two Key Characteristics of Preservice Teachers' Repertoire of Practice

PRACTICE	ALLIE	OWEN	KATE
"Seeing" and Attending to Student Work: *What do teachers notice when they examine student work?*	▪ Notices individual ways of theorizing about the central phenomenon. ▪ Notices emerging questions of student curiosity.	▪ Notices individual student ideas and details in and depth of reasoning about these ideas.	▪ Notices disjointed aspects of student work: quality, fragments of ideas, some insight into student thinking.
Interpreting Student Work: *How do they make sense of what they notice?*	• Developed patterns or "common streams of thought" in students' ways of theorizing about the phenomenon. ▪ Makes substantive reference to student work in explaining each pattern.	▪ Student work is indicative of student learning outcomes – or broad levels of understanding (evaluative in nature).	▪ Student work is indicative of student learning outcomes – or broad levels of understanding, or "misconceptions" (evaluative in nature
Linking Student Work to "Next Steps" in Instruction: *How and to what extent do they take up student's ideas and reasoning to inform instruction?*	▪ Adapts instruction based on students' collective patterns of student theorizing. ▪ Makes visible and leverages student thinking as an object of continual inquiry.	▪ Student work has no connections to "next steps" in instruction. • Hypothesized differing links between student learning and pedagogical approaches.	• Student work has no connections to "next steps" in instruction.

Learning in, from, and for Practice: Individual Storylines

This study situated novice teacher learning in the interactive and relational work of teaching (i.e., analyzing and responding to student work) to help teachers build three primary teaching practices: (1) attending to substance of student thinking, (2) interpreting the substance of student thinking, and (3) linking patterns individual and collective student thinking to "next steps" in instruction. In this final section, I offer the reader insights to each teacher's interactions with peers, with pedagogical tools, and with classroom artifacts over time. By attending to each teacher's shifting participation in activities, as well as their stances toward science, toward student learning, and toward teaching as depicted in conversations, I offer a nuanced portrait of how individual teacher learning unfolded in, from, and for practice.

Allie Evans: "Re-imagining approaches to teaching and learning science"

Attending to and interpreting student work: Seeing dimensionality. While Allie certainly had the capacity to analyze student work, her early practice privileged more attention to student "answers" or fragments of ideas – with a keen eye towards areas of student struggle. For Allie, looking at student work gave her insights into student learning outcomes, often in terms of broad levels of understanding (e.g., what students "understood" or "did not understand"). Largely summative in nature, Allie positioned student ideas as a private entity – shared only between a student and teacher primarily for evaluative purposes and remediation. In her reflections of this early work, Allie pointed out that she "didn't have much of a critical eye" (Evans, WS, 1.6).

Perhaps consistently, Allie's stances toward science, toward student learning, and toward teaching in beginning conversations were largely unproblematized (i.e., didactic approach to teaching science that centered on the accumulation of knowledge over time). Coupled with lessons framed by collection of knowledge-level learning goals, there was seemingly little room for (a) engaging students in the authentic sense-making practices of the discipline, in which students' evolving ideas and lines of thinking are made visible and worked on over time, and (b) eliciting, "seeing," and leveraging the rich repertoires of thinking, reasoning, and communicating that students bring to learning science.

Over time, Allie's attention to student work started to shift in two key ways. First, her on-going interactions with peers, with the protocol, and with the researcher-generated student work reflected growing consideration of students' ways of reasoning at the macro- and micro-level. As depicted in earlier sections of this chapter, Allie took an active role in later conversations, probing for deeper insights into how students were representing and making sense of their ideas. For Allie, these collegial discussions were especially influential in helping her "see" differing dimensions of student learning: "I found it really helpful to look over student work together. Everyone's slightly different perspectives helped validate my own train of thought while introducing me to new ways of looking at things" (Evans, WS, 2.1). Secondly, Allie "took up" the language of the protocol, identifying individual areas of student struggle *and* strength. On several occasions, she emphasized the importance of identifying and elaborating on strengths in individual student work, signaling to learners that there is always "a further place to go" (TD, September 24, 2015). Now, Allie explained that she tries to take more time analyzing student work, seeing beyond answers and "find[ing] something positive and strong about the work the student has produced" (Evans, WS, 2.1).

An expanding repertoire: Eliciting student thinking. For Allie in particular, this early work together catalyzed thinking about how to more effectively elicit student ideas and reasoning in tasks and questions. That is, she felt that it was important to better "structure [her] assessments to allow students to explain their thinking" (Evans, WS, 2.1). In an effort to support this emerging interest, I modified the upcoming case studies to include a representation of an "easily replicated" task that (a) was anchored in the development of an explanation for a phenomenon over a series of lessons, and (b) elicited and revealed a broad range of student thinking, theorizing and communicating. As indicated in the next section, Allie "borrowed" the structure of this task, re-designing a portion of her upcoming bonding unit to elicit a range of student ideas *and* theorizing about "why" a phenomenon happens.

"Borrowing" a representation of teaching and learning science: **Shifting stances.** Comparing and contrasting case studies, Allie resonated with the second case study (i.e., teacher attends to multiple dimensions of student learning; identifies, makes visible, and adapts instruction based lines of student theorizing; considers resources that ensure continued engagement with and challenge in disciplinary activity). Prior to this activity, as evidenced in team conversations and in personal reflections, Allie shared with us her goal of better connecting chemistry to the everyday lives of her students (Evans, WS, 2.1). For example, in grappling with teaching quantum, she shared with the team: "The hardest thing for me, well, quantum is very relevant to our lives, it's around us all the time, but how can I make them see that relevance? Make them more excited to learn about it…. What's the point of them [students] doing this besides it's on the SOL?" (TD, September 24, 2015). Perhaps shedding light on this articulated "problem of practice," Allie viewed this particular representation or "vision" of teaching and learning science as one conduit of connecting subject matter to the real world and student experiences (Evans, WS, 2.1). Further, she noticed value in (a) relevance to how science is actually done, and (b) normalizing error in learning, or helping students understand that their ideas will evolve over time (vs. being "right" or "wrong") (TD, October 1, 2015). Moving forward, Allie "borrowed" (a) the task structure, and (b) the teaching and learning approach represented in the second case study. Anchoring a portion of her bonding unit specifically related to ionic and covalent bonding in the light-bulb phenomenon, Allie elicited student thinking in regard to what was happening and why.

She explained that "we're going to reassess this [over time], and they're [students] going to come up with explanations of what's actually happening," (TD, October 7, 2015).

Importantly, our conversations here indicated that Allie may have started to access a more problematized stance towards science and student learning. Stemming beyond content knowledge, a more problematized stance toward science privileges careful attention to how scientific knowledge is constructed, refined, and validated over time on individual and social plane (Smith, Maclin, Houghton, & Hennessey, 2000). That is, teachers taking this stance largely represent science as a theory building endeavor, framed by "big ideas," and inclusive of tentative hypothesis that are revised over time in light of new ideas, evidence, and argument. In parallel, Allie began to portray student learning as a process of building and revising explanatory ideas over time – using students' ideas and ways of thinking and theorizing as key resources in developing and refining scientific explanations over time. In reflection, Allie identified this portion of the teacher learning experiences as most formative in shaping her thinking and practice (Evans, WS, 2.1).

Attending to, interpreting and responding to student work: Re-positioning student thinking and imagining possibilities. Discussing her student work in cycle two, Allie largely attended to and talked about (a) nuances in individual student "theorizing" about what was happening on a molecular level and why; and (b) emerging questions of student curiosity. Allie's interpretation of student work was more consistent with an interpretive stance. That is, she worked to make sense the meanings that students were trying portray with the purpose of improving (vs. proving) student learning and adapting "next" steps in instruction (Slavit et al., 2013). In this instance, Allie shared (a) four “common streams of thought,” or student ways of theorizing about what has happening on molecular level in relationship to the central phenomenon (TD, October 7, 2015). Importantly, she made substantive references to student work about each pattern. In moving forward, her plan was to make these explanations visible to the class as objects of continual inquiry.

Here, I draw the reader’s attention to how she positioned student thinking. Contrasting her earlier practice (i.e., answers or ideas are a private entity – shared between a student and teacher primarily for evaluative purposes and remediation), Allie positioned students’ ideas and their ways of thinking and theorizing about these ideas in shared space by teacher and students – tentative explanations to be worked on, modified, assessed in ways that are consistent with the discipline of science. In team conversation, Allie framed “problems of practice” in terms of imagining differing pedagogical approaches, grounded in student thinking, with the team. More specifically, she grappled with the types of learning experiences that would support students’ evolving lines of thinking. And, while adaptations to instruction at an individual level were “out of reach” as of yet (i.e., thinking about the types of tools or resources – conceptual, social, or epistemic – that may support access to, engagement with, and continued growth in genuine disciplinary activity), she certainly showed growth in adapting “next steps” in instruction based on collective patterns in student thinking.

Moving forward: Being a part of a Professional Learning Community. To the last interview, Allie excitedly brought in myriad questions of student curiosity that she had gathered - extending from their class work on ionic and covalent bonding (e.g., Do ionic compounds have to be dissolved in order to conduct electricity? Which compounds have a higher melting point – ionic or covalent?). She realized that, while she wanted to give students an opportunity to explore these questions in an open-inquiry lab, she needed (a) a converging point, and (b) a better focus on "What did you do? and Why did it happen?" (Evans Interview, October 22, 2015). In a short working session, we talked through relationships between prior class activities and student questions:

Amy: If you could frame all of these questions into one "how" or "why" question, what might that be?

Allie: Hmm, well, How do the ways chemicals bond affect the properties that they have? Or, how does the way that atoms bond affect the properties of compounds?

We worked to revise a "big idea" question that, combined with an anchoring phenomenon, could potentially frame and provide structure not only to this lab, but an entire unit on bonding. Moving forward, Allie's goals are to (a) develop units framed by "big ideas" and anchored in the development of scientific explanations, and (b) become "better at analyzing student work and establishing how best to move forward given the data that I have collected" (Evans Interview, October 22, 2015). Further, she stated that: "It is really important to me to be a part of a professional community so that I can ask for the advice of my coworkers and figure out new ways to look at student data" (Evans Interview, October 22, 2015).

Owen Clark: "Seeing past plug and chug student responses"

Attending to and interpreting student work: Seeing dimensionality. Beginning our work together, Owen's attention to student work focused on "seeing" student answers or broad concepts in student thinking. For Owen, looking at student work gave him insights into student learning outcomes, specifically in terms of what students either "understood" or had "misconceptions" about. Largely summative in nature, Owen positioned student ideas as a private entity – primarily visible to teacher as a means of monitoring student progress from "misconceptions" to normative scientific ideas. For Owen, the goal of analyzing the student work was to "see where the weaknesses might show through where they wouldn't in a normal activity" (Clark, WS, 1.6).

In parallel, Owen's stances toward or representations of science, of student learning, and of teaching in beginning conversations were largely unproblematized. Productively, Owen valued the use of peer discussion in his AP Physics class. However, these peer interactions were primarily used as a means of processing information, ultimately reaching a scientific concept or relationship. Combined with carefully designed PowerPoint presentations, Owen portrayed teaching and learning as a process of "fixing" misconceptions over time and interaction with peers and accumulating ideas and concepts (e.g., collection of PowerPoint slides). Driving learning with (a) a collection of knowledge stemming from the topic of thermodynamics, and (b) a race to get subject matter ideas "covered" by the AP exam, there was little space for making visible, leveraging, working on evolving lines of student thinking.

Over time and in interactions with peers, with the protocol, and with the researcher-generated student work, Owen started to privilege attention to students' ideas and their ways of thinking and reasoning. In fact, "seeing" and pressing for student reasoning was Owen's biggest "take-away" from the module learning experiences. He recognized that the capacity to "see" student reasoning was important in gauging conceptual understanding of physics – past a "plug and chug" response (Clark Interview, October 22, 2015). Reflecting on his own learning and growth, he emphasized the importance of determining if students' "reasoning show[s] that they have a strong conceptual understanding of the material, or are they just saying things because they know they are right" (Clark, WS, 1.5).

An expanding repertoire: Eliciting student thinking. For Owen, examining student work catalyzed thinking about how to better structure tasks and question to elicit a wide range of students' ideas and their underlying reasons for these ideas (Clark Interview, October 22, 2015). "Borrowing" the structure of Allie's elicitation prompts, Owen worked with the team to design his cycle two prompt. In particular, his goal was to elicit students' thinking about thermal energy transfers in everyday situations:

> The idea with this prompt was for them to come up with their own [example], and they would draw a picture that would have to involve two energy transfers, convection or radiation or conduction. Then, they would have to include details in the description and the details should include material properties, behavior of the molecules, and the direction of heat flow. (TD, October 15, 2015)

Attending to, interpreting, and responding to student work: Static stances. Discussing his student work in cycle two, Owen largely attended to and talked about individual student ideas *and* the character of reasoning underlying these ideas – a visible and productive area of growth in his teaching repertoire. Once again, however, his interpretations of what he noticed were consistent with an evaluative stance. That is, student thinking is primary positioned as private entity – a check on student learning outcomes. Further, in team conversations, Owen framed "problems of practice," or in this case, differing "levels" of student understanding in terms of problems with students (e.g., lack of effort, lack of preparation for AP). For Owen, it was perplexing that his students didn't "perform" better, as he "spent a lot of time going through the three processes with them…. Maybe they weren't paying attention" (TD, October 15, 2015). In this cycle, student work was not used to inform "next steps" in instruction.

Perhaps consistently, Owen retained simplified stances toward and representations of science, of student learning, and of teaching in team conversations (i.e., didactic approach to teaching science that centered on the presentation and accumulation of knowledge over time). For Owen, it's possible that these stances, collectively at this point, constrained the perceived utility of student work beyond an evaluative indicator of what students had learned. That is, without re-envisioning how science operates as a discipline, and orchestrating learning around the development of explanatory, or "big ideas" over time, it may be difficult to see how students' ideas and their diverse ways of thinking, reasoning, and communicating can play a substantial role in learning science.

Moving forward: Possibilities and tensions. In a conversation that followed, Owen and team worked to hypothesize differing links between student learning and pedagogical approaches (e.g., giving students more time to think, ways to make thinking more visible to peers, using more real-life phenomena). It was encouraging to "hear" teachers discuss pedagogical possibilities in ways that (a) were entangled with consideration of subject matter, and (b) stemmed directly from and were connected to manifestations of students' "real-time" ideas and reasoning (vs. thinking about strategies in the abstract).

Moving forward, Owen left this particular experience thinking more carefully about how to cultivate a deeper understanding of physics. In particular, he seemed to realize the importance of driving student learning through real-life phenomena: "I guess to truly understand physics and to truly get it, like I'd never really get it until it's related to real world situations. That's when you really [are] able to think through other situations, which we've been talking about" (Clark Interview, October 22, 2015). At this point, however, he struggled with: (a) a more complex understanding of not only subject matter but of how science operates as a discipline, and (b) *how* to structure meaningful student engagement with subject matter: "It [thermodynamics] just became this confusing puzzle. That's the tough thing about it too. It's hard in themo to relate this to anything, in terms of the real world in a lot of ways" (Clark Interview, October 22, 2015). He also shared that "with this stuff [thermodynamics], it will take time with me just being more comfortable with the content too. The first time though, I was just like, oh, I just got to get through this" (Clark Interview, October 22, 2015). Certainly, navigating these struggles in an AP class that was chronically behind, lacked a clear framework and direction of student learning, and was focused on "covering" content in preparation for the end-of-year AP exam also influenced his developing repertoire of practice. Looking forward, however, Owen was able to "see" possibilities for improving teaching and learning in his own classroom. For example, one of Owen's goals is to

> incorporate the type of questions into my physics class that allow me to truly asses the understanding of the students…. A good question would allow a student with a deeper understanding to delve much deeper into the content. This takes a little more time to think up questions like these but I'm excited for the challenge to do this when I have my own class. (Clark, WS, 2.1)

In direct application, he added a space on his Google forms for students to submit their responses and thinking during "live-time" teaching and learning (TD, October 15, 2015).

Kate England: "Small steps towards seeking dimensionality in student learning"

Attending to and interpreting student work: Seeking dimensionality at

times. In early conversations, Kate primarily attended to disjointed aspects of student work: the quality of student work (e.g., no ripped pages); fragments of student ideas, often marked by point deductions; and some insights into these ideas, noting broad ways that students might have been making sense of content. Summative in nature, these insights functioned as indicators of student learning outcomes – especially as related to areas of student struggle or "misconceptions." In her reflections at this point, Kate explained that she was approaching student work very concretely. Did they understand it? Did they say what I expected? Did they hit the right targets?" (England, WS, 1.6). Here, Kate positioned student ideas as a private entity – shared only between a student and teacher primarily for evaluative purposes and remediation.

Perhaps consistently, Kate's stances toward science, student learning, and teaching in beginning conversations were largely unproblematized. Kate portrayed science as distinct entities of knowledge and process skills, accumulated through and validated by an authoritative source – the teacher. Her role as a teacher was depicted as providing students concrete explanations, often through structured whole-class work with her. Coupled with the pursuit of concrete facts, that students either "got" or "didn't get," there seemed to be little space "seeing" and leveraging a wide range of student ideas and reasoning.

Over time, and in interactions with peers, with the protocol, and with the researcher-generated student work, Kate's showed some progress in attending to student ideas and their reasoning behind these ideas – especially as related to the researcher-generated work. She described collaborative inquiry into student work as productive, "helping [her] better understand how to approach student work in a different way"

(England, WS, 2.1). In particular, Kate openly shared her own struggle to "see" beyond "right" and "wrong" in students' answers, describing the middle school mindset as a focus on "capitalizing the first letter of your sentence and putting question marks at the end of questions" (TD, September 17, 2015).

Notably, Kate voiced assumptions about students that may have restricted her perception of what students were capable of. That is, she often talked about students in terms of fixed and unproductive labels: low IQ kids, honor students, average learners, low kids. Further, these labels tended to function as a filter for grappling with teaching and learning possibilities. For example, discussing the notion of working on students' evolving lines of thinking, Kate disregarded this approach with her academic and "collab kids," stating that students in these classes "can't last for more than two minutes of discussing out-loud…. we plan around limited opportunities for distraction" (TD, September 24th, 2015). Discussing the potential advantages of peer discourse in science, Kate worried about monitoring this process as students with an "average understanding" may communicate misconceptions to students with "under-developed" understandings (TD, October 1, 2015). Even with the suggestion of trying an exit card or prompt, Kate "closed down" the conversation, stating that "They [students] just sit there, and at that point, you are like, Wow, you still don't have a pencil? You can't help yourself? Just get to work" (England Interview, October 22, 2015). Notably, these patterns of response to problematizing teaching and learning typified Kate's participation and thinking throughout much of this work. Kate struggles to understand what students *are capable of doing* with the appropriate inspiration, support, and guidance.

Attending to, interpreting, and responding to student work: Static stances. Kate had difficulty with finding a place to elicit, collect, and examine evidence of student thinking for cycle two. In our final interview, she explained that students in her classes in do not engage in "a lot of independent work…. We guide them through work in their notebook" (England Interview, October 22, 2015). After two email exchanges, Kate settled on bringing in samples of student work from a pre-exam review packet. Discussing a portion of this work, Kate largely attended to and talked about individual student ideas, often restating what each student had written. Collectively, she recognized that while students had a general idea of photosynthesis and cellular respiration, they "couldn't really talk about it" (TD, October 15, 2015). As cells were not introduced until the next semester, Kate felt like she could not help students understand the "why" underpinning these processes.

Once again, Kate's interpretations of what she noticed were consistent with an evaluative stance. That is, student ideas were primary positioned as private entity – a check on student learning outcomes. Further, Kate framed "problems of practice," or in this case, differing "levels" of student understanding largely in terms of problems with students. She expressed frustration that students didn't seem to "get" the content, as she felt like she had "explicitly debunked" many misconceptions about these processes (TD, October 15, 2015). In this case, student work was not used to inform or adapt "next steps" in instruction. In fact, while the exam was the next day, the class was well into another unit.

Perhaps consistently, Kate retained unproblematized stances toward or representations of science, of student learning, and of teaching in this team conversation.

In her role as a teacher, Kate focused on presenting clear and organized information (e.g., prescriptive Cornell style notes, fill-in-the blank organizers), correcting misconceptions, and engaging students in activities to "discover" information. Kate talked about student learning as "downloading new information" (TD, October 15, 2015). As of now, accessing science as a theory-building endeavor was seemingly impossible to Kate: "I actually think I would lose my middle schoolers if I did something like that" (TD, October 15, 2015). Collectively, these stances may work to constrain the perceived utility of student thinking beyond an evaluative indicator of what students had learned.

Moving forward. In our final interview, Kate explained that she has:

> started to think about strengths and weaknesses. I think a lot of times for grading, you either add up the points or you deduct the points, and for the most part I just deduct points or don't deduct points, and then just ask for clarification. I need to figure out what the strengths are and what the weakness are. (England Interview, October 22, 2015).

Working to see more dimensions of student learning is certainly a step forward. Kate also explained that she is grappling with how to elicit student thinking more effectively. Asking her to tell me a little more about that, Kate explained that she has learned that to move forward, her student work "must provide specific opportunities for me to learn from their responses" (England Interview, October 22, 2015). Into her first year of teaching, she would like to use student work to better inform and guide instruction – but in ways that "do not hinder my instructional pacing" (England Interview, October 22, 2015). As of now, she explained that her practice looks more like direct instruction and remediation – consistent with the prevailing transmission-acquisition pedagogical approach, or "cultural script" (Skyles et al., 2010) seemingly shared by her mentoring teacher. Moving forward, Kate's goal is to create "learning opportunities that are inquiry-based, perhaps presenting data that contradicts or challenges students' misconceptions" (England Interview, October 22, 2015).

CHAPTER 5: FINDINGS, DISCUSSION, AND IMPLICATIONS

In this chapter, I discuss relevant insights stemming from analysis of similarities and variations across teacher learning trajectories (i.e., cross-unit analysis). Consistent with single embedded case study (Yin, 2014), these insights illuminate the larger case phenomenon, or relationships between practice-based pedagogies and novice teacher learning. Specifically, I offer the reader five insights into the following research questions:

1. How do preservice teachers participate in pedagogies of practice, grounded in tool-supported analyses of student work, to attend to, interpret, use student thinking to adapt secondary science instruction?
2. What features and conditions of a practice-oriented pedagogical approach seem to shape how preservice teachers attend to, interpret, and use student thinking to adapt secondary science instruction?

Insight One: *Situating novice teacher learning in tool-supported analyses of student work, integrated with representations of practice, helped prospective science teachers "see" dimensionality in students' ideas and their ways of thinking and reasoning about these ideas.*

Allie, Owen, and Kate's initial patterns of participation in examining student work reflected attention to student "answers," fragments of ideas, or superficial aspects of learner work (e.g., question completion, torn pages). Consistent with the literature (e.g., Levin & Richards, 2011; Windschitl et al., 2011; Talanquer et al., 2015), without guidance, these novices struggled to "see" a more nuanced and dimensional portrait of student learning – focused on strengths and struggles in students' ideas as well as the underlying character, representation, and rationality of these ideas. Often coupled with lessons framed by a corpus of knowledge-level learning goals, Allie, Owen, and Kate's initial repertoire of practice as related to *attending to student thinking* most likely constrained (a) substantial inferences about individual and collective student learning, and (b) pedagogical possibilities that make visible, build on, and support students' evolving lines thinking as objects of inquiry in developing explanatory accounts of natural phenomena.

Over time, and in interactions with peers, with pedagogical tools, and with the case studies, Allie, Owen, and Kate's participation in multiple rehearsals of examining student work reflected growing attention to (a) the disciplinary substance of students' ideas (i.e., the nature and character of student reasoning underlying student ideas), and (b) strengths and struggles in student thinking. Notably, the protocol used to analyze student work focused collegial conversation on these dimensions of student learning in science. These discussions, in particular, were identified by all three novices as especially influential in helping them expand recognition of differing facets of student learning (WS, 2.1). Additionally, collegial analyses of the case studies (i.e., representations of practice), appeared to further shape teachers' thinking. For example, all three novices recognized differences between attending to "right" or "wrong" in student ideas and, as Kate stated, "a spectrum of understanding" (TD, October 1, 2015) in students' ideas *and* their ways of thinking and reasoning.

Throughout teacher conversations and within individual teacher work, it was apparent that Allie, Owen, and Kate "took up" the language of the protocol – privileging attention to details in and the depth of students' macro- and micro-levels of explanation about phenomena. For example, in discussing her student work in cycle two, Allie primarily talked about nuances in students' individual and collective ways of theorizing about how and why a central phenomenon happens. Further, she felt that it was important in her own practice to "see" (a) beyond answers, "find[ing] something positive and strong about the work the student has produced" (Evans, WS, 2.1), and (b) areas of student curiosity, leveraging these as further access points into learning chemistry. Owen identified the capacity to attend to student reasoning as the biggest "take-away" from the module learning experiences. And for Kate, even though her student work in cycle two reflected student responses to knowledge-based questions, she recognized that her curriculum structure constricted space for thinking about the underpinning mechanisms of and reasoning about differing scientific processes. As well, she identified need in her own practice to look for strengths and struggles in student work, instead of solely deducing points – a step forward for Kate.

Productively, interactions of *practice-centered pedagogies*, or pedagogies of investigation and enactment (Lampert et al., 2010; McDonald et al., 2013), supported novice teachers' developing readiness to attend to the substance of students' ideas and reasoning. That is, situating novice teacher learning in interactive "slices" of the day-to-day activities of the profession (i.e., recurrent cycles of analyzing student work), coupled with representations of practice, or visons of "what is possible," helped Allie, Owen, and Kate (a) re-envision the repertoire of resources that students bring to learning science, and (b) expand the types of "evidence" that they used to construct inferences about student learning and pedagogical approaches. Notably, all three teachers started to consider students' ideas and reasoning in ways that are more continuous with the disciplinary practices of science: "They make sense; they are supported by the available evidence; [and] they have explanatory and predictive power" (Coffey et al., 2011, p. 1122).

Additionally, for Allie and Owen, framing formative assessment as persistent attention to the disciplinary substance of students' ideas generated a purpose and need for crafting tasks and questions that elicited a wide range of student thinking and scientific sense-making - an unexpected but welcome "change of route" in the teacher learning experiences. In their review of the formative assessment literature in science, Coffey et al. (2011) argued that formative assessment in teacher education primarily focuses on myriad strategies and techniques, undermining "attention to the *very ideas those strategies were supported to make visible*" (p. 1120). In parallel, this study suggests that assessment approaches may have more meaning and purpose when connected to and embedded in the development of HLTPs, such as *attending to the substance of students' ideas and reasoning to adapt instruction*. Supporting teachers' evolving pedagogical visions, the case studies used in this study were adapted to include an "easily replicated" representation of task that elicited a range of student thinking about an anchoring phenomenon. Notably, both Allie and Owen "borrowed" the structure of this elicitation task, re-designing a portion of their respective lessons for cycle two in an effort to elicit a range of student ideas *and* theorizing about "why" a phenomenon happens – a visible area of teacher growth.

This research, in concert with a growing number of studies (e.g., Barnhart & van Es, 2015; Kang & Anderson, 2015; Kazemi & Franke, 2004), indicates that preservice teachers can learn how to attend to the substance of students' ideas *and* their ways of thinking and theorizing about these ideas with targeted support and guidance. In particular, engaging novices in multiple "opportunities to rehearse and enact discrete components of complex practice in settings of reduced complexity" (Grossman, Hammerness, et al., 2009, p. 283) bolstered Allie, Owen, and Kate's capacity to attend to strengths and struggles in students' ideas and reasoning. As Barnhart and van Es (2015) posited in their study of preservice teachers' capacities to analyze and respond to student thinking within a video-based course, learning to "see" nuances in students' ideas and reasoning with respect to content appears to function as a cornerstone for more sophisticated interpretation of and response to student thinking. However, also consistent with similar studies (e.g. Barnhart & van Es, 2015; Kang & Anderson, 2015), learning how to better "see" the disciplinary substance of students' ideas did not guarantee that preservice teachers would interpret and respond to student work in increasingly sophisticated ways - leading to the second study insight.

Insight Two: *Novice teachers' developing readiness to make sense of and adapt instruction based on student thinking was shaped by their stances toward science, toward student learning, and toward teaching – as depicted in collegial conversations.*

A growing number of studies have suggested that teachers' "critical pedagogical discourses" (Thompson et al., 2013), or evolving stances toward "what counts" in productive teaching and learning may shape or be shaped by their developing repertoires of practice (e.g., Kazemi & Franke, 2004; Thompson et al., 2013; Warren et al., 2001).

More specifically, these studies lend support to the instructional triangle, or the complex interactions between teachers, students, and subject matter that systematically function to support the complex work of teaching and learning (e.g., Cohen, Raudenbush, & Ball, 2003; Tomlinson, 2014). In this study, I used the instructional triangle as a lens for understanding Allie, Owen, and Kate's stance-taking patterns toward or representations of science (i.e., *How are scientific ideas developed and validated*?), of student learning (*How do students learn science*?), and of science teaching (i.e., *What images of science teaching do novices portray*?), as depicted in conversations over time. These patterns afforded insights into how preservice teachers grappled with and made sense-of their practice as they participated in collaborative inquiry into student work. Notably, in this study, teachers' stance taking patterns were consistent with and connected to their developing instructional practices as related to attending to, interpreting, and using student thinking to adapt instruction.

Novice teachers' initial thinking and repertoire of practice. As described previously, Allie, Owen, and Kate's initial patterns of participation in examining student work reflected attention to student "answers," fragments of ideas, or superficial aspects of learner work. Making sense of or interpreting what they noticed, all three preservice teachers positioned student answers or ideas as a private entity, shared between a teacher and a student for evaluative purposes (i.e., determining "levels of correctness" against canonical ideas as represented in the curriculum). Further instructional moves, if any, were in primarily in service of remediating areas of student struggle. Consistently, in these early conversations, preservice teachers largely portrayed unproblematized or simplistic notions of science, student learning, and teaching. For example, Allie depicted teaching as ensuring that students receive the “proper information” (Evans Interview, September 10, 2015). This stance towards teaching was consistent with her practice of making sense of student work in terms of her teaching effectiveness:

> “I like to look cross-classes, because then I think about, okay, what was going on in that class. Did I word something differently? Is it later in the day so I had already taught it and it dissipated? I like to see that.” (Evans Interview, September 10, 2015)

Owen portrayed student learning as a process of “fixing misconceptions” through interactions with peers and the teacher. Likewise, this stance toward student learning was consistent with his attention to and tracking of class percentages of student “misconceptions” throughout a lab. And all preservice teachers portrayed science as a vast body of knowledge to be acquired and validated by an authoritative source, or the teacher. Problematically, this stance toward science afforded little space for making visible and leveraging a diversity of student’s evolving lines of thinking as key resources, within disciplinary talk and activity, to develop increasingly sophisticated explanatory accounts of natural phenomena over time (NRC, 2012).

As Allie, Owen, and Kate interacted with peers, with pedagogical tools, and with classroom artifacts of practice across cycle one and two, two primary patterns in teachers’ stance-taking patterns emerged: (1) shifting stances, becoming more problematized, and (2) static stances, consistently unproblematized. These patterns varied along dimensions of (a) how teachers positioned student thinking, and (b) how teachers framed “problems of practice.” I offer the reader insights into each stance-taking pattern, connections to instructional practices, and emerging questions.

Shifting stances: Becoming more problematized. Allie’s patterns of participation in examining student work across cycle one and two reflected growing attention to (a) the disciplinary substance of individual student's ideas, or ways of theorizing about the underpinning mechanism of the phenomenon; and (b) student curiosities. Making sense of or interpreting what she noticed in cycle two, Allie identified and positioned four patterns of student theorizing in a shared space by teacher and students – tentative explanations to be worked on, modified, and assessed over time and in light of observation and evidence. Moreover, she framed "problems of practice" in terms of hypothesizing differing pedagogical possibilities that provided students opportunities to revisit and refine their tentative explanations over time. These insights are similar to Windschitl et al.'s (2011) findings. That is, these scholars found that beginning teachers who interpreted student work with the aim of inquiring into and understanding differing facets of student learning also developed evidence-based hypotheses that connected student learning with pedagogical decisions. Positioning dilemmas of practice as "puzzles of practice," Windschitl et al. (2011) also indicated that teachers maintained high expectations of all students, and used the language of "support and scaffolding" to ensure that all students had access to and support in evolving disciplinary learning. And while adapting instruction to support individual student access to and continued participation in disciplinary activity was "out of reach" at this point, Allie showed growth in modifying "next steps" in instruction based inquiry into patterns of student thinking and theorizing.

Notably, in cycle two, Allie's developing repertoire of practice as related to attending to, interpreting, and linking patterns in student thinking to "next steps" in instruction was consistent with a more problematized representation of science, student learning, and teaching. For example, Allie started to depict student learning as developing evidence-based explanations over time. Consistently, interpreting student work, she identified four "common streams of thoughts" or patterns in students' tentative explanations, making these visible on a social plane. While sharing her student work with the team, Allie noted that she "didn't expect them [students] to know exactly what's going on" (TD, October 7, 2015), emphasizing that students would keep refining their evolving lines of thinking over time. Likewise, Allie portrayed teaching as cultivating student sense-making and reasoning. As such, Allie worked to link patterns in students' tentative explanations to "next" steps in instruction, grappling with the types of learning experiences that afforded students agency in modifying their thinking over time. While promising, however, one key question of interest emerged from the study data: Why did Allie's repertoire of practice shift over time?

Motivated by her underlying goal of "find[ing] more ways to relate chemistry to the everyday lives of my students" (Evans, WS, 2.1), Allie resonated with (a) a "pre-study" seminar class focused on orchestrating student learning around "big ideas" and casual explanations of phenomena over time, sharing that she "got a huge amount out of connecting the content to the real world" (Evans, WS, 2.1); and (b) the second case study. In specific reference to analyzing the case studies, Allie noted that she "found it most helpful to manipulate and organize ideas in new ways to find new connections and establish new approaches that will help improve my teaching of the content. The work we did together really helped widen my perspective" (Evans, WS, 2.1). In particular, the second case study offered Allie a different representation of "what is possible" in teaching and learning science. In seminar class, Allie expressed interest in learning how to anchor a portion of her bonding unit in a central phenomenon (Field Notes, October 1, 2015). “Borrowing” the structure of the prompt in case study two, Allie elicited student thinking in regard to the light-bulb phenomenon, with the intention of having learners work on refining a model of this phenomenon over time.

Here, Allie started to access a more problematized stance toward science. A more complex representation of science privileges careful attention to how scientific knowledge is constructed, refined, and validated over time on an individual and social plane (Smith et al., 2000). In classrooms, this means that student engage with science as a theory-building endeavor, grounded in the pursuit “big ideas.” As such, students’ diverse and nascent ideas and ways thinking, theorizing, and communicating are necessarily leveraged as rich intellectual and social resources in building increasingly sophisticated evidence-based explanations on and individual and social plane (e.g., Warren & Rosebery, 1995; Warren et al., 2001). For Allie, this shifting stance toward science afforded a differing purpose for attending to and interpreting student ideas and reasoning – beyond a sole focus evaluating levels of “correctness” against a canon of knowledge. Like Thompson et al. (2013), who found that beginning teachers who appropriated ambitious practices over time developed critical pedagogical discourses focused intensely on how students thinking about and make sense of science, Allie used the disciplinary substance of students’ ideas as a resource for adapting instruction in ways that built on and fostered continued student participation in disciplinary activity. And while she would certainly benefit from continued support in aspects of teaching such as (a) shifting the goal of science instruction from portraying facts and skills to explaining phenomena; and (b) supporting students in developing arguments, explanations, and explanatory models (i.e., discourse practices of science), her growing capacity to *attend* *to and interpret the disciplinary substance of students' ideas to adapt instruction* reflected positive "first steps" towards teaching in ways that are rigorous and responsive to all students.

Static stances. Across cycle one and two, Owen and Kate demonstrated growth in their readiness to attend to the disciplinary substance of students' ideas. While encouraging, however, their interpretations of what they noticed in student work were consistent with an evaluative stance. That is, they continually positioned student thinking as a private entity – a check on student learning outcomes shared only between a teacher and student. Further, student work was not used to inform "next steps" in instruction, and "problems of practice" were largely framed as problems with students. For example, to Owen, it was perplexing that his students didn't "perform" better on the elicitation task he had designed, especially given the amount of time he had spent going through thermodynamic processes with them (TD, October 15, 2015). Likewise, Kate expressed frustration that her students didn't seem to "get" the content, as she had explicitly "debunked myriad misconceptions about these photosynthesis and cellular respiration (TD, October 15, 2015

Owen and Kate's patterns of stance-taking toward science, toward student learning, and toward teaching, as depicted in conversations across cycle one and two, were consistently unproblematized (i.e., didactic approach to teaching science centered on the presentation and accumulation of knowledge and skills). That is, while Owen and Kate's repertoire of practice demonstrated growth in relationship to attending to disciplinary substance of students' ideas, they struggled to see the potential contributions of students' ideas and their ways of thinking, reasoning, and communication to learning science - beyond a check on student learning outcomes. Consistent with Thompson et al.'s (2013) assertion, and reflected in similar studies of preservice science teachers' attention and response to student thinking (e.g., Kang & Anderson, 2015; Windschitl et al., 2011), critical pedagogical discourses, or stances developed "around the execution of instructional strategies (even strategies aimed at supporting student reasoning) result in trajectories that do not readily incorporate ambitious practice" (p. 607). Further, Ball and Cohen (1999) suggested that teachers who hone their skills within frame of reference rooted in "conservatism of practice" may struggle with thinking about teaching and learning in more complex ways. From this piece of the study, I am compelled to think about the types of learning experiences that would potentially support on-going teacher growth in relationship *attending to the substance of students' ideas and reasoning to adapt instruction.* I offer the following hypothesis.

In their work with beginning secondary science teachers, Windschitl and his colleagues (2012) found that only novices who reconceptualized subject matter around the "big ideas" appropriated some form of ambitious teaching during the course of a unit (e.g., eliciting a range of student thinking, pressing for evidence-based explanations). It is possible that Allie, Owen, and Kate may need support in re-envisioning science as theory-building endeavor, grounded in the pursuit "big ideas," or "substantive relationships between concepts in the form of scientific models that help learners understand, explain, and predict a variety of important phenomena in the natural world" (Windschitl, Thompson, Braaten, & Stroupe, 2012, p. 888). In science classrooms, this means that teachers elicit and pay persistent attention to the substance of students' ways of making sense of science - leveraging student thinking as a key resource, within disciplinary talk and activity, to build “big ideas” (Thompson et al., 2013). Notably, prior to this study, Allie, Owen, and Kate had minimal experience in (a) planning for student engagement with the “big ideas” to develop explanatory accounts of phenomena over time, and (b) supporting students in developing models, arguments, and explanations. I conjecture that cultivating the development of these science-specific practices in teacher preparation pathways, within practice-oriented learning experiences, *may* help novices better learn to appropriate ambitious practice. Two key features of practice-oriented learning experiences that have the potential to support this endeavor include: (a) the development of preservice teacher discourse communities, and (b) a system of tools mediate and scaffold novice teacher learning.

Insight Three: *Collegial conversations prompted productive problematization, helping teachers re-examine current practice and thinking while “seeing” new possibilities.*

A situative perspective on teacher learning draws attention to the social nature of learning and the central role of teacher learning communities in cultivating what and how people learn in authentic activity (Greeno, 2006). Traditionally, Putnam & Borko (2000) pointed out that teacher preparation programs have focused more on the development of individual knowledge and competencies, rather than the establishment of rich discourse communities. With respect to teacher education, situative theorists emphasize the value of creating opportunities for teachers to work together on developing and improving repertoires of practice, and locating these opportunities in the day-to-day challenges and practices of ambitious teaching – regardless of the venue (Ball & Cohen, 1999; Putnam & Borko, 2000).

In this study, within a collegial space, prospective science teachers engaged in multiple cycles of tool-supported inquiry into artifacts of classroom practice. Interacting around student work and the case studies, Allie, Owen, and Kate negotiated elements of and connections between science, student learning, and pedagogical approaches. For example, I once again illustrate Allie and Owen's efforts to make sense of what a seventh-grade student may have meant by her use of the terms "heat" and "heat flow."

Owen: Maybe grabbing onto her use of the word "heat" can kind of…we can dig into what she means by that.

Allie: But she does say later, "heat flow."

Owen: But she's going back-and-forth.

Owen: But heat is not like a quantity, a quantitative thing, I think, in a sense. Take the transfer of heat.

Allie: But you could lose heat, right?

Owen: How do you lose the heat?

Allie: Well, because it transfers but you're still losing it. A piece of a system can lose heat to the rest of the system. Is that incorrect to say it like that?

Owen: That makes sense, I guess.

Allie: Yeah, so you need to ask her, "Okay, so where is the heat? What do you mean by heat loss? Where is the heat going?"

Owen: Yeah.

Allie: "Does it just disappear?" (TD, September 17, 2015)

In this exchange, an initial focus on gaining insights into a student's thinking changed course to negotiating the scientific meaning of "heat flow" and in particular, "heat loss" out of a system – a core idea that traverses many fields of science. In other conversations, Allie, Owen, and Kate re-interpreted features of student thinking, sometimes agreeing and sometimes disagreeing, but continually working to understand students' ideas and the underlying reasoning for and rationality of these ideas. Enriching these exchanges, novices often "offered up" or made visible ideas, assumptions, and experiences from multiple contexts (e.g., student teaching context, experiences as a university student, experiences as a high school student) as a resource for further making-sense of teaching and learning approaches. For example, using his experiences with AP students as a "lens" to further help the team grapple with the importance of pressing for student thinking and reasoning, Owen explained:

> Obviously, it's different because it's not at the same level [middle school students vs AP students], but you can relate this to an AP student using a formula and just plugging everything in. Like coming up with a formula for the rate of conduction, and deciding to make something thicker, but not really understanding why you would make it thicker. (TD, September 17, 2015)

And finally, Allie, Owen, and Kate inquired into or "imagined" pedagogical possibilities stemming from analyses of student work. For example, in reference to Kate's corpus of knowledge-level student responses within a pre-exam review packet, Allie probed her learning goals for students:

Allie: Do you teach around big questions?

Kate: Yeah.

Allie: Like, what was your big question for photosynthesis and cellular respiration?

Kate: It was more like, "How do we get energy?" or "How do we make food?" …. If you think about it, just conceptually, if you put all of the concepts that we've touched on just in the first unit on a map, it's scattered; it's all over the place. For some students, it works, because they get bored really easily, so the more scattered it is, the more opportunities they have to engage each time. (TD, October 15, 2015)

In this discussion that followed, Kate "closed down" this particular exchange, describing the large amount of information that she had to "cover" with students. However, Owen picked this line of exchange back up, inquiring into the "big picture" of the content. I use this particular example to depict the complex nature of some of these interactions as Allie, Owen, and Kate grappled with and negotiated "dilemmas of practice." However, the majority of dialogue invited continual teacher interrogation and imagination. For example, in response to Allie's student work in cycle two, the team brainstormed and weighed potential learning experiences that provided students opportunities to modify or refine their tentative explanations of the light-bulb phenomena. Similarly, in cycle two, the team worked with Owen to critically reflect on and hypothesize ways of affording AP Physics students more agency in developing and making-sense of their own ideas and thinking.

All three preservice teachers identified these "perspective-seeking" conversations as influential in shaping their developing readiness to "see," attend to, and respond to strengths and struggles in the disciplinary substance of students' ideas (WS, 2.1). As Allie described, "I found it really helpful to look over student work together. Everyone's slightly different perspectives helped validate my own train of thought while introducing me to new ways of looking at things" (Evans, WS, 2.1). Further, collaborative inquiry into "problems of practice," located in interactions of students and subject matter, engaged novices in "thinking like a teacher" (Hammerness et al., 2005). That is, this collegial learning space became a place not just for acquiring teaching models, strategies, and techniques, but also for grappling with science itself; with how students think about and learn science; and with pedagogical approaches - in ways that approximate the complex work and continual sense-making that the profession necessitates. Ball and Cohen (1999) identified these exchanges as promising means of supporting significant teacher learning, arguing that: “Some disequilibrium is required for such learning. It is not sufficient simply to see what one already assumes about students, learning, and content; one would also need to see others' assumptions, differences in their content and effects, or unexpected effects of one's own ideas and practices" (p. 14).

In concert with a growing number of studies that situate teacher learning in intellectual and social communities (e.g., Horn, 2010; Little, 2002; Windschitl et al., 2011), this study posits that novices’ “perspective-seeking” discussions, grounded in attention to students’ scientific thinking, can function as key resource in building teachers’ (a) interconnected knowledge of science, student learning, and teaching; (b) development of instructional practice (e.g., attending to the disciplinary substance of students’ ideas); and (c) capacity to learn from another, breaking down traditional isolation of teachers’ work (Ball & Cohen, 1999). Importantly, this intellectual work was mediated by a system of tools – leading to the fourth study insight.

Insight Four: *A shared system of tools mediated preservice teacher participation in collegial work, framing attention to “what counts” in appropriating ambitious practice.*

A host of research has indicated that simply gathering teachers together to look at artifacts of classroom practice does not ensure that meaningful learning will occur (Little, Gearhart, Curry, & Kafka, 2003; Slavit, Nelson, & Deuel, 2013). Guidance and support, in the form of pedagogical tools, appears to be a key element of cultivating collegial construction and critique of ideas and reasoning (e.g. Levin et al., 2009, Star & Strickland, 2008; Windschitl et al., 2011, Thompson et al., 2013). In this study, two types of pedagogical tools mediated preservice teachers' intellectual work: (1) protocols that facilitated analysis and discussion of student work, and (2) WISE, an online learning platform that I used specifically for teachers.

First, a disciplinary-specific protocol, consistent with a vision of science-as-practice (Lehrer & Schauble, 2006; NRC, 2012), was used to analyze student work. This protocol made visible and afforded explicit attention to (a) strengths and struggles in students' ideas as well as their ways of thinking and reasoning about these ideas at a macro- and micro-level; (b) students' everyday language, experiences, and (c) connections to designing "next steps" in instruction (see Appendix B). Productively, Allie, Owen, and Kate took up the "language" of this pedagogical tool over the weeks - especially as related to thinking and talking about facets of students' evolving ideas *and* reasoning. Notably, Coffey et al. (2011) pointed out that attention to the disciplinary substance of students' ideas is largely overlooked in the literature underpinning responsive science teaching and learning. As such, it was encouraging to observe preservice teachers attend to student work in ways that more effectively balance (a) accountability to science, and (b) accountability to learners. Likewise, the team consultancy protocol was particularly beneficial in eliciting preservice teacher thinking and practice, expanding what teachers noticed in the student work, and scaffolding in-depth inquiry into and discussion of student learning and teaching approaches. Moving forward, Windschitl and colleagues (e.g. Windschitl et al., 2011; Thompson et al., 2013) illuminated the potential of these of disciplinary-specific tools to (a) embody the ideas, reasoning, and language congruent with a community of teachers deliberately working to take up ambitious teaching; and (b) cross multiple contexts, including university courses, field experiences, and full-time teaching settings - affording a shared system of tools.

As well, scholars have noted that novices need substantial support in making sense of and reflecting on participation in reform-based work (Davis, 2004) - narrating their own stories of struggles and growth across a learning trajectory (Sfard and Prusak, 2005). In this study, Allie, Owen, and Kate used WISE, an online learning platform, to "narrate a storyline" of their learning progressions over time and through practice-centered learning experiences. This pedagogical tool supported novice teacher learning in two important ways. First, novices used myriad embedded tools in WISE (e.g., questionnaires, reflection notes, short answer prompts and tasks) not only to log their thinking, but to reflect on and add, integrate, and modify earlier thinking related to analyzing, interpreting, and suggesting "next steps" in instruction. In essence, Allie, Owen, and Kate developed and revised a working model of their thinking and practice over time. Used primarily as a teacher reflection tool, WISE helped teachers critically reflect on areas of learning and growth. Secondly, within WISE, I was able to monitor developing teacher "storylines," providing individual preservice teacher feedback as the learning experiences unfolded. In future studies, studying this additional layer of feedback would afford a more nuanced understanding of teacher learning processes and the role of feedback loops. And finally, across team discussions and individual teacher reflections, it was apparent that Allie, Owen, and Kate's involvement in multiple "learning-to-teach" contexts shaped developing thinking and practice – leading to the final insight.

Insight Five: *The development of practice was influenced by membership across learning-to-teach contexts.*

Prospective science teachers have been and continue to negotiate membership across multiple "learning-to-teach" discourse communities. Teachers' interactions with actors, artifacts, tools, and institutional messages within and across these communities have influenced and continue to influence "what counts" in developing pedagogical visions, instructional repertoires, and ideas about learners and learning in science (Lortie, 1975; Kennedy, 2010; Sykes et al., 2010). In this study, Allie, Owen, and Kate were members of the seminar class and their student teaching communities. Data from interviews and team discussions showed that both of these contexts shaped on-going teacher thinking and practice, albeit in differing ways.

Allie talked positively about her cooperating teacher, forging a positive relationship with Mrs. Jones. Notably, Allie appreciated the freedom she had to design her own lessons. As Allie started to access a more problematized stance towards science, student learning, and teaching, she was afforded space to "try-out" new ideas and practice with her chemistry students (e.g., anchoring a portion of an upcoming unit in a phenomenon, eliciting a range of student ideas and reasoning with a new formative assessment structure). And while Allie didn't necessarily receive active support from her mentoring teacher in *attending to the substance of students' ideas and reasoning to adapt instruction*, she was able work on this HLTP across learning-to-teach contexts. Further, Allie felt that it was important to seek out and participate in professional learning community into her first year of teaching (Evans Interview, October 22, 2015). Moving forward, this may help Allie "teach against the grain," learning to skillfully interact with students over high standards of disciplinary learning.

In contrast, Owen and Kate student taught in classrooms that were rooted in a "conservatism of practice" (Ball & Cohen, 1999). That is, the day-to-day pedagogies of their mentoring teachers remained rooted in "teacher-dominated discourse, textbook-based lessons, and [coverage] as the main curricular principle" (Sykes, Bird, & Kennedy, 2010, p. 465). Speaking about the influence of a testing culture, Owen stated that "It's all about just passing tests and moving on…. It's just frustrating" (TD, October 15, 2015). Likewise, Kate expressed frustration with her school's disorganized curriculum structure and pacing guide (England Interview, September 10, 2015). Most likely, the institutional norms in these contexts worked against the development of innovative practice. In their work with beginning science teachers, Thompson and her colleagues (2013) argued that without robust stances towards science, towards student learning, and towards teaching, prospective teachers are readily swayed by discourses centered on coverage and control. Perhaps consistently, Kate seemed to take up the ideas and practices of her mentoring teacher. Positively, however, as Owen focused more on privileging student reasoning in AP Physics, he started to "imagine" possibilities for improving student learning in his own classroom. For example, one of his future goals is to

> incorporate the type of questions into my physics class that allow me to truly asses the understanding of the students…. A good question would allow a student with a deeper understanding to delve much deeper into the content. This takes a little more time to think up questions like these but I'm excited for the challenge to do this when I have my own class. (Clark, WS, 2.1)

Historically, the development of *enacted* teaching practice has been left to the idiosyncrasies of student teaching experiences (Clift & Brady, 2005). However, these experiences may work against the development of ambitious teaching. Thus, this study lends support to situating preservice teacher learning, at times, in the interactive and relational teaching practices that that afford opportunities to weave together knowledge of responsive teaching with teachers' evolving readiness to *enact* these knowledge (McDonald et al., 2013). Positively, practice-based pedagogies may help beginning teachers learn to "teach against the grain" – in student teaching or into the first years of teaching.

Study Implications

As coursework in teacher preparation makes a shift from a primary focus on what teachers know and believe to a greater focus on what teachers do (Ball & Forzani, 2009), insights from this study suggest potential directions for the design of teacher learning trajectories. Broadly, these implications related to (1) what we teach, or the curriculum of science teacher preparation; and (2) how we teach, or the pedagogies of science teacher preparation.

Implication one: High-leverage teaching practices work systematically to support significant teacher and student learning. To date, the field of teacher preparation lacks a core set of professional knowledge, skills, and language that orient a cohesive vision and progression of what novice teachers learn, how they learn, and how they demonstrate what they have learned across preparatory experiences (Ball & Forzani, 2009; Cochran-Smith & Zeichner, 2005; Darling-Hammond, 2006; Levine, 2006; NRC, 2010). In response, a growing number of teacher educators have worked on organizing preparation of preservice teachers around a "learning-to-teach" core of teaching practices that underpin that day-to-day work of rigorous and responsive teaching (e.g., Boerst, Sleep, Ball, & Bass, 2011; Kazemi, Lampert & Franke, 2009; McDonald et al., 2013; Windschitl et al., 2012). Importantly, these HLTPs collectively function as a "framework of meaning" (Sousa & Tomlinson, 2011), entangling the development of teacher knowledge, skills, and dispositions. And while the composition of this core set of practices is under debate among scholars, this study illuminated two HLTPs that seemed to work in tandem with bolstering novice teacher capacity *attend to substance of students' ideas and reasoning to adapt instruction.*

First, *orchestrating student learning around the big ideas to develop explanatory accounts the natural world* appeared to function as an "umbrella" practice. In science, the big ideas can be understood as "substantive relationships between concepts in the form of scientific models that help learners understand, explain, and predict a variety of important phenomena in the natural world" (Windschitl, Thompson, Braaten, & Stroupe, 2012, p. 888). Importantly, this practice opens a conceptual space and purpose for rigorous science learning – affording students great capacity to access, construct, and explain a coherent storyline of the world around them.

For beginning teachers, the capacity to plan around "big ideas" (vs. a topic or collection of facts) seemed to be a critical stepping stone for (a) building coherence across core ideas of science, (b) "seeing" and leveraging the diversity of conceptual, epistemic, and social resources that students bring to learning science, and (c) motivating on-going and substantial student learning within disciplinary activity. Consistent with the literature (e.g., Davis et al., 2006; Larkin, 2012; NRC, 2012; Reiser, 2013; Thompson et al., 2009), Allie, Owen, and Kate struggled to refocus goals of student learning from a collection of ideas and skills to the development of "big ideas." Instead, student learning sequences were often framed by a seemingly endless sea of knowledge and skills - a dead end for working on learner ideas and thinking over time. In reflection, Allie and Kate noted that they would have benefitted from learning how to design units that (a) are framed by big ideas, and (b) orchestrate student learning around the development evidence based explanations for a phenomenon over time. In agreement with Windschitl and colleagues (Windschitl et al., 2012; Thompson et al., 2013), this study suggests that helping preservice teachers reconceptualize subject matter around the "big ideas" in planning practices is central to cultivating early-career development of ambitious teaching.

Second, a primary goal of science education reform is to shift instruction from knowledge and process skills to supporting student participation in the *development of evidence-based explanations* over time. A key knowledge-building practice of science (Reiser, 2013), this science-specific HLTP also worked cohesively with *attending to substance of students' ideas and reasoning to adapt instruction.* While preservice teachers in this study grew in their capacity to attend to the disciplinary substance of students' ideas, they struggled with interpreting and knowing how to leverage and respond to student thinking - beyond a check on learning outcomes. This study posits that rigorous and responsive teaching, in part, hinges on teacher capacity to leverage students' everyday ideas, reasoning, and interests as terrain for co-constructing, negotiating, refining explanatory accounts of the world around them. As another core practice, bolstering preservice teacher capacity to support the *development of evidence-based explanations* in science is central to (a) learning how to engage students in disciplinary work (i.e., modeling, argumentation) to build explanatory accounts of the world around them (Berland et al., 2015; Windschitl et al., 2012; Thompson et al., 2013) and in turn, (b) "seeing," interpreting, and using students' diverse ideas and ways of thinking and participating in science as key resources in learning science.

Implication two: Situating teacher learning in practice. As part of a core set of "learning-to-teach" practices (Windschitl et al., 2012), the HLTP of *attending to the substance of students' ideas and reasoning to adapt instruction* is intended to ascend in depth and complexity across preparatory experiences and into the initial years of teaching (Grossman, Hammerness, et al., 2009). In its most sophisticated form, teachers attend to strengths and struggles in multiple dimensions of student learning in relationship to the learning goals; they look carefully at how students, individually and collectively, are expressing their ideas and the meanings that they are trying to convey; and they use students' scientific thinking to adapt instruction in ways that ensure access to, continued growth in, and participation in disciplinary talk and activity. Positively, situating preservice teacher learning in recurrent cycles of analyzing and responding to student work (i.e. approximations of interactive, relational, and day-to-day practices of teaching) cultivated teacher reasoning and decision-making at the boundaries of science, students, and teaching. That is, practice-centered learning afforded opportunities to rehearse, revise, and retry interactive "slices" of larger HLTPs, such as attending to the disciplinary substance of students' ideas, with targeted feedback and reflection (e.g., Lampert et al., 2013; Windschitl, Thompson, & Braaten, 2011). Treated as a one-time activity, however, there is little hope that preservice teachers will start down an early-career trajectory toward teaching *in response to what students do*.

In this study, introducing novices to this intellectual work as they were student teaching was overwhelming at times. In a preassessment of their initial repertoires of practice, I found that while Allie, Owen, and Kate had taken courses that addressed curriculum design, models of instruction, assessment, and differentiation, this was the first time that they had coordinated these elements in a critical activity of teaching (i.e., analyzing and responding to student work). In agreement with Allie, Owen, and Kate's primary suggestion for improving this module, I recommend that this HLTP be introduced early and revisited "in practice" frequently – allowing preservice teachers ample time to build and demonstrate increasingly sophisticated instantiations of this core practice. For example, opportunities to *attend to the disciplinary substance of students' ideas and reasoning* through analysis of classroom data (e.g., student work and thinking) can be worked on repeatedly, and in increasingly sophisticated ways through preparatory experiences and into the initial years of teaching to (a) gain insights into a wide range of students as evolving learners of science, (b) make sense-of and grapple with the efficacy of formative assessment strategies and data in teaching and learning, and (c) link individual and collective student thinking to proposing, assessing, and innovating differing instructional adaptions that further individual and collective student growth. As Owen pointed out, starting this work before student teaching would have afforded him "more time incorporating this more naturally into practice" (Evans, WS, 2.1). That is, student teaching is an ideal time for preservice teachers to repeatedly inquire into student work, spending more time grappling with emerging "problems of practice" (vs. exploring "first steps" to looking at student work). Beginning this work with teachers, I offer the following "lessons learned:"

- Begin with 3-5 samples of student work that contain substantial student responses to 1-2 prompts that elicit students' ideas and scientific sense-making. Be sure that the work selected reflects a range and varied types of student thinking, and is aligned with clear set of learning goals.

- Talk about the scientific explanation underpinning the student work. These were some of the most productive discussions, as core ideas and concepts cross fields of sciences (e.g., fluxes of energy and matter into, within, and out of systems). Importantly, these discussions (a) normalized inquiry into subject matter for teachers, and (b) cultivated deeper understanding of subject matter.

- Seek out student struggles *and* strengths in each sample of student work. Prompt teachers to "pose" two *questions* back to each student – one that extends an area of strength, and one that scaffolds an area of struggle. This simple activity was identified by all three novices as influential in shaping their thinking and practice.

- Analyze the formative assessment prompt and dimensions of student learning elicited. What works? What could be improved?

- Use varied type of student work: exit cards, a "Do Now," a drawing or model.

- Be sure that potential adaptations to instruction are dually (a) accountable to science, and (b) accountable to learners.

Study Limitations and Directions for Future Research

In this final section, I draw the reader's attention to three primary limitations of this study and related directions for future research. First, a primary limitation of case study research is often depicted as a lack of generalizability. This study in particular reflects one instantiation of pedagogies of practice, situated in a one science teacher education course, with three preservice teachers. Further, these teachers' developing repertoires of practice were undoubtedly shaped by their experiences in the Middle State University teacher preparation program, inclusive of the program's orientations to teaching and learning in classrooms today. As such, it is impossible to posit that "what happened" in terms of teacher learning during this collection of learning experiences will happen elsewhere. However, Stake (1995) argued that "the real business of case study is particularization, not generalization" (p. 8). In affording readers a nuanced depiction of how teacher learning "came to life" within these practice-oriented learning experiences, I am hopeful that the study insights will resonate with (a) the scholarly literature, and (b) practitioners who are working to re-imagine and improve the pedagogies of higher education that support the development and enactment of responsive teaching practices. In future studies, situating teacher learning in multiple cycles of tool-supported inquiry into records of classroom practice (a) within and across preparatory experiences; (b) with larger cohorts of prospective science teachers; and (c) spanning multiple teacher preparation programs would expand insights into how preservice science teachers learn to *attend to the substance of students' ideas and reasoning to adapt instruction* over time and in interactions with peers, with supporting pedagogical tools, and in conjunction with other HLTPs. Furthermore, tracing preservice teachers' stances toward science, toward student learning, and toward science teaching throughout these endeavors seems to be a promising method of understanding of teachers' pedagogical reasoning that shape or is shaped by their developing instructional repertoires.

Secondly, this study was situated within the contextual boundary of the university seminar class. I did not follow teachers into their respective classrooms to ascertain how they (a) elicited student thinking and collected student work on a more regular basis, (b) used pedagogical tools introduced in the seminar class, or (b) implemented "next steps" generated from collegial conversations. Thus, the study insights were limited to teacher participation in seminar activities. In future studies, tracing preservice teachers' stance-taking and enacted practice across the university and classroom setting would better inform pedagogies of practice that closely link and support co-evolutionary teacher participation in and learning across coursework and fieldwork contexts.

A final limitation of this study concerns my dual role as a facilitator and researcher of preservice teacher learning experiences. In ways, these roles were complimentary. That is, my role as a researcher prompted an in-depth, rigorous, and continual examination of how teachers participated cycles of collaborative inquiry into classroom artifacts of practice. In turn, these insights informed "next steps" in supporting teacher learning during the module learning experiences. However, as a facilitator of these teacher learning experiences, I was unable to adequately examine the influence of facilitation practices. These facilitation patterns certainly had the potential to shape and be shaped by teachers' on-going interactions with classroom artifacts of practice.

More broadly, as systems of teacher preparation shift from a dominant focus on distilling a collection of knowledge for teaching (e.g. philosophies, models of instruction, strategies) to helping preservice teachers develop *and* enact HLTPs across learning-to-teach settings (McDonald et al., 2013), the field would benefit from studies that explore the central role, work, and expertise of teacher educators necessary to mediate and support this endeavor. To date, very few studies across the literature have examined teacher educators' classrooms, including nuanced portraits of university instructors' stance-taking and instructional practice. Such studies have the potential to (a) contribute to a more holistic understanding of how teachers learn in, from, and for practice (Lampert, 2010); (b) illuminate how teacher educators define and develop a professional vision for rigorous and responsive teaching in higher education; and (c) detail the communities, structures, or tools that support or hinder the development and growth of teacher educators' evolving thinking and repertoires of practice – central to inspiring and cultivating ambitious teaching in science classrooms today.

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APPENDIX A

Student Work Probes

1. Let's imagine that in our classroom, you have two thermometers, labeled A and B. You place thermometer A completely inside a mitten and thermometer B on the classroom table next to the mitten. Three hours later, you come back to read the temperature on thermometer A and B. During the time you were away, the temperature of the classroom stayed the same.

   a. *What do you think will happen? Circle the response that best matches your thinking.*

      A. Thermometer A (inside the mitten) will have a lower temperature than thermometer B (on the classroom table).

      B. Thermometer A (inside the mitten) will have a higher temperature than thermometer B (on the classroom table).

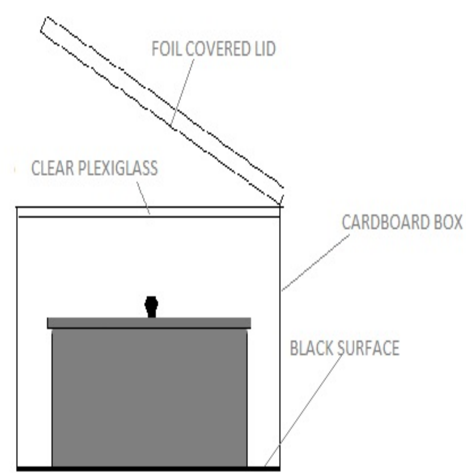
      C. Both thermometers will have the same temperature reading.

   b. *Why do you think this will happen?*

Probe modified from: Keeley, P., Eberle, F., & Farrin, L. (2005). Uncovering student ideas in science. 1: (pp. 103-108). Arlington, VA: NSTA Press.

2. Describe one way that you could minimize or reduce thermal energy transfer (or heat loss) through the bottom wall or floor of the solar cooking system to the surrounding air.

3. Clearly represent and explain WHY you think your idea would reduce heat loss out of this system – so that your peers can understand your thinking!



4. Make a list of any other ideas you have about reducing thermal energy transfer (or heat loss) through the bottom of the wall or floor to the surrounding air.

APPENDIX B

"SEEING" MULTIPLE DIMENSIONS OF STUDENT LEARNING IN SCIENCE: GUIDE FOR ANALYZING AND INTERPRETING STUDENT WORK

Looking for patterns in individual and collective student ideas and their ways of making-sense of, reasoning about, and communicating these ideas.

LEARNING GOALS:

1. What understandings or partial understandings did you see or notice students' developing ideas? *Be prepared to talk about evidence for your findings from the student work.

Common Student Strengths	Common Student Struggles
Individual Student Strengths	Individual Student Struggles

2. How are students working to make-sense of, support, represent and communicate explanations of these ideas (*look at the micro- and macro-level!)?

Common Student Strengths	Common Student Struggles
Individual Student Strengths	Individual Student Struggles

PATTERNS:

3. What 2-5 student-generated ideas, claims, hypotheses, or questions about the phenomenon might you make visible and have students continue to pursue in the next lesson?

4. List the following (as applicable):

Everyday terms or language you that could potentially leverage:	Related phenomena or contexts interest that students could explore or extend the big ideas/core ideas through:

BRAINSTORMING POSSIBILITIES FOR "NEXT STEPS" IN STUDENT LEARNING

- What type of experiences, information, or sources of evidence might students interact with next? Adaptations for individuals or teams? Why?

- What types of resources can you make available to students (e.g., materials, tools that support student discussion, explanation building scaffolds) to support them in making sense of, talking about, or building explanations for themselves?

This protocol, "Seeing Multiple Dimensions of Student Learning in Science," was designed by Amy Germundson-Sneed (amygvirginia@gmail.com).

APPENDIX C

Collaborative Inquiry into Student Work and Planning "Next Steps" in Science Instruction: Team Consultancy Protocol

Preparation: Please bring a lesson that you taught and 4-5 representative samples of anonymous student work to seminar class. Become familiar with this protocol and be prepared to talk about/reflect on your student work and thinking with your colleagues!

Overview of Lesson and Student Work	*2 minutes*	Presenting teacher offers a brief overview of the lesson, including: • the learning goals (big ideas, core knowledge/ideas, and focal practices) that the student work targets, and • the purpose of eliciting student thinking at this point in the unit.
Scientific Explanation	*8 minutes*	Presenting teacher guides the team though an explanation of the underlying scientific ideas/phenomenon/practices. *What would an evidence-based explanation for this phenomena "look" or sound like?*
Summary of Student Work Analysis and Interpretation	*5 minutes*	Presenting teacher provides: • summary of his/her analysis and interpretation of the student work, describing patterns of individual and collective student ideas and ways of thinking, reasoning, and communicating: addresses strengths, struggles, motivations. *What did you learn or notice in this work?* • resulting questions or dilemmas from analysis and interpretation of student work. *I am wondering about…, What I find puzzling is….*
Participant Reflection	*5 minutes*	Colleagues silently read & review the student work samples, focusing on the presenting teacher's questions as well as patterns in ideas AND ways of thinking, reasoning, and communication within and between student responses. Student strengths? Struggles? Motivations?
Probing Questions: "Seeing Students' Ideas and Reasoning"	*10 minutes*	Colleagues ask probing questions to *expand* the presenting teachers thinking about the analysis of interpretation the student work. The presenter responds to the questions.
Consultation: Linking Patterns in Student Work to "Next Steps" in Instruction	*15 minutes*	Presenting teacher describes current thinking on "next steps" in instruction <u>linked</u> to analysis of student work and resulting questions or dilemmas - then becomes a silent listener while peer discussion begins. Colleagues confirm and/or suggest <u>evidence-based ideas</u> about next instructional steps based on the student work and the presenting teacher's comments and questions. May think about: scaffolds, extensions, working in contexts of interest, ways to make subject matter and reasoning more accessible, etc.

Reflection	*5 minutes*	Presenting teacher reflects on new perspectives and ideas, providing insights into and a rational for "next steps" in instruction.
Debrief	*5 minutes*	Facilitator reflects on the process of attending to student work, analyzing student thinking and reasoning for understanding, and using this information to inform responsive science teaching as presented through the team process. For example: • The facilitator shows how teacher ideas around student understanding of and reasoning/communicating about phenomenon changed throughout the discussions. • The facilitator describes how "next steps" in instruction evolved through the discussions. • The facilitator elicits reflections from team.

This protocol was adapted from The Consultancy Protocol, developed by Gene Thompson-Grove, Paula Evans, and Faith Dunne as part of the Coalition of Essential Schools National Re: Learning Faculty Program. This protocol was designed by Amy Germundson-Sneed (amygvirginia@gmail.com).

APPENDIX D

Pre-Module Interview Questions

GENERAL QUESTIONS	• Briefly tell me a little bit about your academic background and experience. • If you had to explain to a student in your class what science is, how would you respond? • Today, we talk a lot about student diversity in classrooms. What does "student diversity" mean to you?
PLANNING	*Let's talk about how you planned the lesson that you have with you today.* • What were your goals for this lesson when you were planning it? • Describe how you went about planning this lesson. o What information or resources, if any, informed your planning process? • What types of teaching approaches did you use and why? • How did you try to make sure that this lesson was effective for all of your students? Can you give me an example? • How did you plan to gauge the effectiveness of this lesson?
REFLECTION	*Let's talk about how you thought the lesson went.* • Did you meet your goals? How do you know? • Let's look 2-3 samples of the generated student work. Tell me what you see in each student work sample. • What did you notice or learn from looking at the student work? • Talk about your "next steps" in instruction? How did you decide this? • Is there anything else you would like to share with me about your impressions about this lesson?

APPENDIX E

Post-Module Reflection Questions

INTERVIEW QUESTION	1. What are your "walk away ideas" from our time together over these past weeks? PROBE: Can you explain more about that. PROBE: Can you give me an example of that?

WISE QUESTIONNAIRE	1. What 2-3 areas do you feel you have grown the most in (e.g., how you look at student work, how you made sense of student work, how you link patterns in student work to your own curriculum design/instructional decisions. Explain each and if possible, provide specific examples. 2. What 1-2 goals do you have moving forward into your career - related to practice of attending to substance of students' ideas and reasoning to inform or adapt instruction? 3. What parts of our work together over the past weeks did you find most helpful in shaping your thinking and practice (e.g., collaborative analysis of student work and discussion with peers, protocol of analyzing student work, using student work from your own individual classrooms, WISE reflection prompts....)? Why? 4. What 1-2 things could we improve for next year (e.g., more/less of some activities, ideas for alternative activities, what worked for you, what didn't)?

APPENDIX F

Attending the Substance of Students' Ideas and Reasoning in Adapting Instruction: Observation and Analysis Guide

TEACHER PRACTICES: INDICATORS OF TEACHER GROWTH

"Seeing" and Attending to Student Thinking		**Notes**
Dimensionality	*Can "see" and uncover multiple dimensions of student ideas and reasoning: conceptual, epistemic, and social.*	
Level of Specificity	*Uncovers details and nuances in individual and collective student thinking. Makes specific claims about a learner's strengths, struggles and motivations in relationship to the learning goals– supports claims with evidence.*	

Interpreting Student Work		**Notes**
Stance	*Takes an interpretive stance toward student thinking: looks for and interprets meaning behind student thinking (in lieu of "correctness").*	
Profiles of Learning	*Develops patterns in individual and collective student thinking with attention to strengths, struggles, and motivations.*	

Adapting "Next Steps" in Instruction (Planning)		**Notes**
Accessibility	*Leverages differing resources students bring to learning as access points into and conduits of high-level intellectual and disciplinary activity.*	
Type	*Proactively plans for student differences in strengths, struggles, and motivations – in relationship to the learning goals. As students build increasingly sophisticated causal storylines, develops conceptual, epistemic, and social scaffolds and extensions to ensure that learning is relevant, accessible, and challenging for every learner.*	
Reasoning	*Links patterns in individual and collective student struggles, strengths, and motivations to evidence-based instructional decisions, on a daily basis.*	

TEACHER STANCES: INDICATORS OF TEACHER GROWTH

> Stance: *"a worldview and a habit of mind –a way of knowing and being in the world of educational practice that carries across educational contexts and various points in one's professional career and that links individuals to larger groups and social movements intended to challenge the inequities perpetuated by the educational status quo" (Cochran-Smith & Lytle, 2009, p. viii).*

Stance Towards Science	Notes
Science is a knowledge-building, social endeavor that occurs through building, testing, negotiating and refining evidence-based explanations and models over time.	

Stance Towards Student Learning in Science	Notes
All learners have an abundance of nascent, albeit diverse, intellectual, epistemological, and social resources for making sense of the world around them. These resources function as access points into and conduits of high-level intellectual and disciplinary activity.	

Stance Towards Teaching Science (Images of Science Teaching)	Notes
Teachers facilitate sense-making activities within a working community of learners in ways that help them build a coherent "storyline" of the world around them. They elicit, probe, build on, and support students' diverse ideas, curiosities, and ways of knowing and participating in science as the raw materials of learning science.	