

“Students drive where I go next”: Ambitious practice, beginning teacher learning, and classroom
epistemic communities

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Abstract

“Students drive where I go next”: Ambitious practice, beginning teacher learning, and classroom epistemic communities

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Curriculum and Instruction

This study examined the learning, practice, and classroom communities of five beginning secondary science teachers for one school year. To varying degrees, the participants attempted to enact ambitious practice, a framework for instruction focused on providing students with opportunities to engage in rigorous and responsive science activity. The purpose of the study was twofold. First, this study investigated the resources beginning teachers recognized, generated, and used to shape and learn from practice. Second, this study examined the epistemic classroom community and science practice negotiated between the participants and their students. By analyzing teacher and student interactions in a classroom context, this study filled important gaps in the field’s understanding of teacher learning and classroom communities as spaces for students to engage in authentic science practice. This study pursued answers to two groups of guiding questions:

- What resources for instruction do beginning teachers recognize, generate, and use in their school contexts? How do beginning teachers' differing use of resources shape their particular trajectories of practice and professional learning?
- How and why is science framed as a “public” or “private” practice? Over time, how and why does the public or private framing of science influence actors' (teachers, students) participation in the epistemic work in classroom spaces? How do teachers and students negotiate “what counts” as a science idea in classroom spaces? How is value assigned to science ideas and by whom? How do teachers and students work on science ideas over time given the kind of epistemic community they negotiate?

Using a situative framework, this study traced both beginning teacher learning and the negotiation of their classrooms as epistemic communities over time. Analysis of discourse during classroom interactions, artifacts created by participants and students, and interviews with participants afforded insights into how and why novices learned from practice using resources, and how their classroom communities supported particular kinds of opportunities for students to participate in authentic science activities.

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Dedication

To my family

Introduction

This dissertation is an attempt to address a dominant image of teaching in American science classrooms, of which the primary activity is an individual's delivery of subject matter information to students (Papert, 1993; Saywer, 2008). The norm of "teacher dominated" instruction appears in large-scale observational studies in American classrooms, which note, "teacher discourse, textbook based lessons, and coverage [are] the main curricular principles" shaping instruction (Sykes, Bird, & Kennedy, 2010, p. 465). In many science classrooms, "teacher dominated" instruction focuses on the completion of numerous activities rather than sense making, rarely takes into account students' prior knowledge, seldom presses for explanations, and treats students' ideas as incongruent with canonical science (Alexander, Osborn, & Phillips, 2000; Banilower, Smith, Weiss, & Pasley, 2006; Barton & Tan, 2009; Horizon Research International, 2003; Maskiewicz & Winters, 2012; Roth & Garnier, 2007; Weiss, Banilower, McMahon, & Smith, 2001; NRC, 2011; Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001; Warren & Rosebery, 1995).

To move beyond the teacher-dominated framework of most science classroom instruction, I turned to researchers who redefined "what counted" as teaching and learning. For example, Smylie and Wenzel (2006) constructed a report to improve Chicago's public schools, noting that "intellectually ambitious instruction" – teaching that fostered deep student learning – changed the role of the teacher from information delivery system to facilitating students' authentic work in a discipline. Recent studies from mathematics, literature, and science education have continued the work of Smylie and Wenzel (2006), framing the teaching profession around *ambitious practice*. Teachers enacting ambitious practice support students' leaning across ethnic,

racial, class, and gender categories while scaffolding their legitimate participation in the conceptual, epistemic, social, and material processes of science. A key feature of ambitious instruction is that teachers' work is guided by a repertoire of instructional practices that enable them to *adapt and innovate pedagogical routines and tools to meet students' emerging needs* (Ball & Forzani, 2011; Ball, Sleep, Boerst, & Bass, 2009; Duschl, 2008; Kazemi, Franke, & Lampert, 2009; Lampert & Graziani, 2009).

In this dissertation, I wanted to better understand ambitious practice through two lenses. First, I examined how beginning teachers try out and learn from attempts at ambitious practice. Specifically, I followed five novices as they navigated the tensions, challenges, and dilemmas that arose when attempting to enact ambitious practice when such instruction did not align with their school's norms, valued practices, and expectations for science teaching. Second, I wanted to add to a growing body of research that demonstrates why ambitious instruction could provide students with opportunities to learn science through legitimate participation in disciplinary practices.

My study can hopefully inform literature on teacher learning, teacher education, instructional leadership, and professional development by illuminating aspects of how and why beginning teachers make decisions about instructional priorities, and the outcomes those decisions have on students' opportunities to learn science (Grossman & McDonald, 2008; Lampert, et al., 2011). I hope to contribute to this theory-building effort by seeking answers to the following groups questions:

- 1) What resources for instruction do beginning teachers recognize, generate, and use in their school contexts? How do beginning teachers' differing use of resources shape their particular trajectories of practice and professional learning?

2) How is science framed as a “public” or “private” practice? Over time, how and why does the public or private framing of science influence actors’ (teachers, students) participation in the epistemic work in classroom spaces? How do teachers and students negotiate “what counts” as a science idea in classroom spaces? How is value assigned to science ideas and by whom? How do teachers and students work on science ideas over time given the kind of epistemic community they negotiate?

Summary of Study Design

In this qualitative multi-case study, I investigated two aspects of ambitious practice that are undertheorized in science education literature. First, I examined the resources that beginning teachers recognized, generated, and used to shape and learn from practice over time. Second, I investigated the classroom epistemic community and science practice negotiated between the participants and their students over time.

Findings from this study were drawn from four different data sources. First, I engaged in requested or informal planning communication with participants. For example, a participant emailed me and asked if I could review a test she prepared for her students. As I discussed practice with the participants, I both collected artifacts and recorded conversations for transcription and coding. Second, I observed participants during their first year of instruction. I conducted observations of each participant during three timeframes throughout the 2011-2012 school year: October, 2011, January – April 2012, and May/June, 2012. The purpose of the observations was to observe the development of teacher learning and science activity over time. Third, I conducted three types of semi-structured interview: A unit interview with a resource card sort, a reflection on the first year teaching, and a personal epistemology of science interview. A semi-structured approach allowed me to adapt the protocol to probe participants’ comments,

ideas, and theories about practice while still focused on the overall goal of a one-hour interview. Finally, I collected data from participants at professional development sessions called Critical Friends Groups (CFGs). The purpose of the CFGs was for the participants to share puzzles of practice that were focused on student thinking and learning.

This study constructs a picture of beginning science teacher learning and classroom science practice across one school year to better understand how contextual features, such as resources and students' science ideas, shape novices' instructional decisions and their participation in the classroom epistemic community.

Synopsis

This dissertation consists of three essays written in the style of stand-alone sections. As such the reader may find areas where concepts are given shorter treatment in one section but more elaborated treatment in another section. There may also be some redundancy as ideas from one section are summarized in another section. My goal with this dissertation was to explore different aspects of my data and write about these for different audiences ranging from teacher leaders or teacher educators looking for information about supporting teacher learning through resources, to researchers specific to science education looking to advance scholarship on science teaching and learning, to an audience within the educational research community looking to explore methodological issues concerning research on teachers and pedagogy. Your flexibility as a reader – who may or may not be a member of any of these audiences – is greatly appreciated. The structure of the dissertation is as follows:

Section 1: Beginning science teachers' use of resources to shape and learn from practice

In this section, I discuss how teachers recognized, generated, and used resources to shape and learn from practice during one school year. Specifically, I examined how novice teachers

navigated tensions about the role resources should play to support ambitious practice or more conservative forms of science teaching. While all participants in this study recognized and used the same resources to shape instruction, including students' science ideas, how the novices used resources over time provided them with different kinds of opportunities to learn from practice. This study provided insight into how teachers who readily enacted ambitious practice learned differently than teachers who frequently engaged in more conservative forms of science teaching.

Section 2: Examining secondary science classrooms as epistemic communities fostering science-as-practice

In this section, I examined how teachers enacting ambitious practice provided opportunities for students to learn science-as-practice. Providing students with such learning opportunities required different forms of instruction rather than the “inquiry” or “hands on” approaches in many classrooms, which feature teachers as the sole authority of knowledge. Since the field of science education understands little about students' roles and ideas in shaping classroom activity (see Minstrell, 1982; Warren et al. 2001 for examples), I investigated how teachers and students negotiated epistemic classroom communities as students took up the role of epistemic agents. The ideas of epistemic communities and epistemic agency come from Science, Technology, and Society (STS) studies and the History and Philosophy of Science (HPS) literature. These fields have converged on similar ideas about how science practice is negotiated between actors with and without power. I examined three aspects of epistemic communities in classrooms that relate to students' learning opportunities: The distribution of cognitive authority, the geography of science ideas, and whether science is presented as an individual or community-driven practice.

Section 3: Theoretical, methodological, and practical considerations for practice-based teacher education and research

In this essay, I reflect on both the literature and my experiences as a researcher studying how beginning teachers learned from attempts at ambitious practice. Based on my work, I argue that redefining the teaching profession around ambitious practice has four implications for research that could be done with regards to beginning teachers. First, the timescale for studying beginning teacher learning from practice needs to extend in order to see their “fits and starts” across contexts and over time. Second, beginning teachers may try out different “grain sizes” of practices, from “elemental” moment-by-moment talk moves to larger planning and instructing routines. Researchers need to theorize about the grain size of practice they are studying when examining the talk, tasks, and tools at play in the classroom. Third, beginning teachers constantly experiment with practices in order to be responsive to their students. Researchers need to ask about and pay attention to what novices experiment with and why. Fourth, many studies of beginning teachers use binary language to characterize novices’ learning and practice: for example, teachers are “ambitious” *or* “conservative”, “effective” *or* “ineffective”, have *or* do not have subject matter knowledge. Researchers need to better tell the complex stories of beginning teachers’ learning and practice as the novices make sense of a variety of competing messages about “what counts” as instruction in their school contexts.

SECTION 1

Beginning science teachers' use of resources to shape and learn from practice

Beginning teachers learn their practice in a variety of contexts, including teacher preparation courses, early field experiences in schools, and internships (Cobb, Zhao, & Dean, 2009; Grossman, Hammerness, & McDonald, 2009; Zeichner, 2010). In each setting, beginning teachers interact with the actors, materials, and historic expectations for teaching and learning (i.e., the instructional cultural scripts, see Sykes, Bird, & Kennedy, 2010). Rarely however, do settings share a common language of practice or a vision of teaching to act as anchors for supporting beginning teacher learning (Edwards, 2010; Grossman et al., 2009bb; Kennedy, 2010; Putnam & Borko, 2000; Sykes et al., 2010). Therefore, novices often experience tensions when learning to teach as they try to make sense of competing messages about “what counts” as practice in their varied contexts (Gainsburg, 2012; Grossman & McDonald, 2008; Wilson & Berne, 1999; Zeichner, 2010).

One possible area for accord is to provide novices with opportunities to use and learn from a similar suite of *resources* across contexts. Resources are physical and intellectual commodities that teachers recognize, generate, and use to solve problems of practice. Resources can be *conventional* and provided to teachers (e.g., books, facilities, time, and planning tools), *social* and emerge from teachers' interactions with other people (e.g., students' knowledge that is elicited in the classroom, peers' stories of practice, tools generated by colleagues to address problems of practice), and *intellectual* that change over time (e.g., teachers' evolving understanding of subject matter and pedagogy, conceptual frameworks for teaching) (Cohen et al., 2002; Lampert et al., 2011).

While resources are central to teachers' learning and professional work, researchers often make an assumption that if beginning teachers have opportunities to use and learn from similar sets of resources, they will recognize them as foundational for making instructional decisions to solve problems of practice regardless of where they teach (Gainsburg, 2012). However, different contexts often provide varied messages to novices about how similar sets of resources should be used to shape and learn from practice (Lampert et al., 2011; Thompson et al., 2013). Therefore, how and why novices learn from practice using resources could depend on where they teach and how they how they make sense of varied instructional expectations in a setting.

Problem Framing

This study describes how and why five beginning secondary science teachers used resources to shape and learn from practice during their first year teaching. In their preservice setting, the course instructors told the five participants that resources should support *ambitious practice* – an instructional framework that supports students' leaning across ethnic, racial, class, and gender categories while scaffolding their legitimate participation in the conceptual, epistemic, social, and material processes of a discipline (Ball & Forzani, 2011; Ball, Sleep, Boerst, & Bass, 2009; Duschl, 2008; Kazemi, Franke, & Lampert, 2009; Lampert & Graziani, 2009). The beginning teachers' school contexts, however, promoted similar sets of resources as supports for more conservative forms of teaching, the primary activity of which is an individual teacher's delivery of subject matter information to students (Papert, 1993; Saywer, 2008). The five participants thus encountered different messages about how and why they should use a similar set of resources to learn from and shape practice.

Research questions

In this study, I use a multi-case approach and a situative theoretical framework to study five beginning teachers' learning during their first year of teaching in a school that promoted resources as important for conservative forms of practice. I defined learning as teachers' changing participation in teaching activities (planning, instructing, and reflecting) over time. Understanding how and why beginning teachers used resources to learn from and shape practice required insight into two features of teachers' learning – their pedagogical reasoning and critical discourses. Pedagogical reasoning describes the consequential instructional decisions teachers make about student learning (Horn, 2007; Horn & Kane, 2012; Lampert et al., 2011; Thompson et al., 2013). Critical discourses describe an individual's developing personal theories about “what counts” as productive teaching and learning (Flores, 2006; Rex & Nelson, 2004).

Specifically, I asked:

- What resources for instruction do beginning teachers recognize, generate, and use in their school contexts?
- How do beginning teachers' differing use of resources shape their particular trajectories of practice and professional learning?

Background

In this section, I theorize about the idea of resources that could support beginning teacher learning. Next, I give examples of research that focus on teacher learning and resource use in mathematics education, and discuss how such ideas are undertheorized in science education. Finally, I describe the situative theory framework I use to study how and why beginning teachers recognize, generate, and resources them to learn from practice.

Defining resources and their importance for teacher learning

I use a sociocultural perspective to define resources and describe their importance for beginning teacher learning. Resources are physical and intellectual commodities that teachers recognize, generate, and use to solve problems of practice. By using resources, teachers engage in complex forms of intellectual activity that might otherwise be too difficult without some form of assistance. Central to understanding how and why teachers use resources is the concept of mediation—the idea that resources function “between” an individual practitioner and the accomplishment of a complex task. Resources thus enable novices to leverage, organize, and use various contextual features to complete valued goals (Rogoff, 2003; Wenger, 1998).

Teachers do not use resources absent of a context. As teachers use resources in their school, the community reciprocally re-shapes the resources and their function to better serve valued goals (Cole & Engestrom, 1993). This interplay between how teachers use resources and how the school shapes resources can lead to learning tensions for beginning teachers as they try to solve problems of practice over time in their instructional context.

Support for teachers in the form of resources is not new to teacher learning research or instructional reform efforts. Historically, studies claim that *conventional* resources, such as money, facilities, books, and time play an important role in the kinds of instructional decisions teachers make. Such resources are typically provided to teachers by other actors in the institutional system – a department chair, methods instructor, principal, or school district (Cohen et al., 2002). Another form of support, *social resources*, emerge from teachers’ interactions with other actors and are deployed when planning, instructing, and reflecting. Such resources include students’ knowledge and discourses, as well as other teachers’ stories of practice. A third form of resource support could include teachers’ *intellectual* resources – their science knowledge for teaching (an understanding of content, how it is represented, how to best to teach it to their

students), and conceptual frameworks for teaching (the vision of instruction and pedagogical infrastructure teachers use to plan, enact, and reflect on practice) (Cohen et al., 2002).

Intellectual resources evolve over time as novices learn more about their subject matter and pedagogy through interactions with students.

Research about resources and teacher practice

Studies of teacher learning often describe how practitioners use, or “misuse” conventional, social, and intellectual resources (see Cohen et al., 2002; Lampert et al., 2011). In mathematics education, for example, Gainsburg (2012) summarizes research focusing on characteristics of individual mathematics teachers that influence why they may or may not recognize and use resources. These characteristics include the “amount” of teachers’ subject matter and pedagogical knowledge, teachers’ values and goals and their congruence with the culture promoting particular resources, and teachers’ beliefs about the purpose of resources and their use. Gainsburg notes that such studies have not produced a substantive theory as to why individuals use resources in particular ways. Therefore, she advocated for studying teacher actions by looking at how they navigate tensions about teaching and learning across learning contexts. Like Gainsburg, I argue that placing responsibility solely on beginning teachers for using resources does not consider how contextual features support, or discourage, novices’ learning.

Other researchers focus on how an entire department of teachers used resources to support ambitious practice. For example, Lampert et al. (2011) note that the prevailing use of resources occurs across three teaching activities in an Italian language school: 1) planning: i.e., how teachers prepare for practice; 2) instruction: i.e., what teachers do in interaction with subject matter and diverse students across time; 3) reflection: i.e., how teachers think about, talk about,

learn from, evaluate and capture their insights about students. How teachers use resources during each of these activities are shaped by their school's vision of "what counts" as teaching and learning. Lampert et al. (2011) argue that when a school promotes ambitious instruction as the foundation for teachers' work, individual practitioners and departments' use of resources to learn and shape future instruction is informed by pedagogical principles focused on students' intellectual and pedagogical needs.

While teachers' use of resources to shape and learn from practice has been a topic of interest in mathematics education, such work is undertheorized in science education. Typically, research in science education mirrors mathematics education: science teachers seem more "successful" if they have access to conventional, social, and intellectual resources (Abell, 2007; Avraamidou & Zembal-Saul, 2010; Gess-Newsome, 1999; Gess-Newsome & Lederman, 1995; Hashweh, 1987; Luft & Roehrig, 2007; Magnusson et al., 1999; Maskiewicz and Winters, 2012; May, Hammer, & Roy, 2006; Nilsson, 2008; Nilsson & van Driel, 2010; van Driel et al., 1998; van Driel et al., 2002). However, recent research in science education demonstrates both that teachers use a broader range of resources than previously imagined, and that the field does not understand *how* beginners use resources to shape and learn from practice (Windschitl et al., 2012).

One example of a resource that all teachers use, yet is undertheorized in the literature, are students' science ideas. The recognition of students' science ideas as a resource emerges from research demonstrating that students enter school with a multitude of ideas about the world from their everyday experiences that can emerge during various classroom activities (Donovan & Bransford, 2005; NRC, 2007). Frequently, studies claim that novices treat students' ideas as "misconceptions", believing that their role as the instructor is to replace students' "incorrect"

information with canonical knowledge (Abell, 2007). In such cases, teachers devise instructional strategies to better deliver information to students (Sawyer, 2008).

Other teachers frame students' ideas as resources to foster deeper and more meaningful science learning opportunities for the class and the instructor (Larkin, 2012; Lehrer, R., & Schauble, L., 2001; Levin, Grant, & Hammer, 2012; Minstrell, 1982; Scott, Asoko, & Leach, 2007). Cohen et al. (2002, p. 92) explain:

“Students that have learned to reflect on their ideas, listen carefully, and express themselves clearly are likely to be better users of materials, teachers and other contributions. They are also likely to make it easier for other students and teachers to use their ideas. How students and teachers organize their interactions also shapes resource use. Students and teachers whose classroom cultures support the respectful expression, explanation, and scrutiny of ideas are likely to generate more usable material for instruction, and thus to have more resources to use than classrooms in which conventional lecture and recitation are the rule.”

Two examples of using students' science ideas as resources for learning stand out in science education research. First, Minstrell conducted a series of self-studies in which he examined how student thinking shaped his own physical science instruction. Minstrell argued that the role of teacher was to learn from student thinking and let their ideas drive both in-the-moment discourse and the trajectory of the unit (Minstrell & Kraus, 2005). He found that when he provided students with continual opportunities to publically test and revise their ideas, they learned complex concepts. A second example comes from the Chèche Konnen Project. This longitudinal research program involved teachers and students from grades K through 12 working

towards fostering sense-making of science ideas through inquiry and argumentation in classrooms with culturally, linguistically, and socioeconomically diverse populations. Chèche Konnen Project teachers used students' intellectual, cultural, and linguistic resources to center the class' scientific inquiry on questions and phenomena that arise from students' lived experiences using the community's sense-making discourses (Warren & Rosebery, 1995).

Both Minstrell and the Chèche Konnen Project illustrate how teachers can use students' science ideas as resources to support ambitious practice. Rather than hear students' ideas as "misconceptions" and adapting information delivery to change the "incorrect" thoughts, a teacher's role is to orchestrate scientific sense-making in the classroom by helping students think through scientific practice using their ideas and experiences (Warren et al., 2001; Warren & Rosebery, 1995). To do so, teachers must constantly make instructional adaptations based on students' evolving disciplinary understanding, not using their ideas as "misconceptions." While most science teachers likely use students' ideas, *how and why they use* those ideas could vary greatly. Therefore, I pay particularly close attention to how and why teachers use students' science ideas as a resource in this study.

Theoretical framework: Reframing teacher learning with situative theory

I use situative theory to address the complexity of examining how and why teachers recognize, generate, and use resources to learn from practice. Situative theory is a hybrid analytical lens framing individuals' learning through their participation in activities that occur through interactions with actors, tools, and institutional cultural scripts (Greeno, 2006; Peressini, Borko, Romagnano, Knuth, & Willis, 2004; Putnam & Borko, 2000; Sykes et al., 2010). This perspective on teacher learning helps refocus researchers' analytical lens to, as Peressini et al. (2004) propose, "guide our decisions about data to collect" and to offer a way of disentangling -

without isolating - the complex contributions of these various contexts to novice teachers' development" (p. 71). In other words, a situative perspective helps researchers make sense of why beginning teachers' learning differs as they make sense of the varied norms and expectations for participation across contexts (see Cobb, 2000; Fairbanks, Duffy, Faircloth, He, Levin, Rohr, & Stein, 2010; Peressini et al., 2004; Putnam & Borko, 2000).

Using situative theory, I define learning as an individual's *changing participation in teaching practice – planning, instructing in-the-moment, and reflection – over time* (Greeno, 2006; Rogoff, 2003). Note that in the situative view, practice is co-constructed by teachers *and* students; in other words, teachers and students, through their interactions, shape learning opportunities and instructional practice in their classroom over time. It is important to note that since ambitious and conservative forms of teaching differ about what counts as practice, the frameworks also disagree about what, how, and why beginning teachers *should* learn over time. Ambitious practice implies *generative learning* – constantly using resources to adapt instruction to both support students' disciplinary thinking and to enable opportunities to unearth students' emerging and changing ideas (Franke, Carpenter, Levi, Fennema, 2001). Instructionist practices, however, assume teacher learning involves using resources to make increasingly efficient instructional decisions to better deliver subject matter information to students. From a more conservative perspective, students' disciplinary ideas are treated as "correct" or "misconceptions" that teachers can learn about and fix over time (Papert, 1993; Sawyer, 2008).

One reason I use a situative perspective and generative learning is to problematize an acquisition model of teacher learning in which "gaining more" intellectual resources, such as content and pedagogical knowledge, results in teachers making "better" instructional decisions (see Carlsen, 1999; Sawyer, 2008). Hill et al. (2008), researchers from mathematics education, categorize such

literature as *affordance* and *deficit* studies. Affordance studies examine what “high-knowledge” teachers could do when planning, teaching, and reflecting that “low-knowledge” teachers cannot accomplish. For example, high-knowledge teachers were better able to work on students’ misconceptions and stimulate their reasoning (see Crawford, 2007; Nilsson & van Driel, 2010). Deficit studies examine the low quality of planning, teaching, and reflection when teachers lacked “adequate amounts” of content and pedagogical knowledge. Researchers often note that low-knowledge teachers were more likely to rely on textbooks, teach incorrect information, and have reduced student achievement (see Carlsen, 1991; Gess-Newsome & Lederman, 1995; Lee, 1995).

Such studies also suggest that researchers can compartmentalize teacher learning into separate time segments: looking for the earliest time a teacher “has” content and pedagogical knowledge, determining how they retrieve it for use in present planning and teaching, and unpacking how they reorganize the knowledge when reflecting for future practice (see Abell, 2007; Heaton, 1992; Nilsson, 2008; van Driel et al., 2002). I argue that framing teacher learning primarily as “gaining” and “reorganizing” knowledge separates one aspect of teachers’ development from the other intellectual work inherent in practice (Fairbanks et al., 2010; Kazemi et al., 2009; Kennedy, 1987, 2010; NRC, 2007). I acknowledge the importance of content and pedagogical knowledge development in teacher learning, and frame its significance through the lens of how teachers use and learn from such knowledge, as a resource, in practice.

To unpack how and why novices learn from practice with support from resources, I use two overlapping lenses – pedagogical reasoning and critical discourses – to understand the kinds of instructional decisions beginners make about student learning, what they frame as problems of practice, and how they think they should solve such dilemmas. I define pedagogical reasoning as

the purposeful coordination of ideas, information, and values about subject matter, curriculum, learners, and instructional context to plan for, enact, and reflect upon instructional practice. My definition draws from research (see Flores, 2006; Grossman, Valencia, Evans, Thompson, Martin, & Place, 2000; Nolen, Ward, Horn, Childers, Campbell, & Mahna, 2009; Shulman, 1987) suggesting teachers' instructional decisions shapes opportunities to learn over time (Greeno, 2006; Sykes et al., 2010). Teachers enacting ambitious or more conservative forms of practice may make different kinds of instructional decisions using the same set of resources, thereby providing themselves with different learning opportunities.

Critical discourses describe an individual's developing personal theories about "what counts" as productive teaching and learning (Flores, 2006; Rex & Nelson, 2004). What makes these internal discourses "critical" is that they are consequential to an individual's actions and learning, and mediate learning and can influence how novices think about practice and resource use across contexts (Sfard & Prusak, 2005). For this study, I use critical discourses to understand teachers' pedagogical reasoning and resource use – why novices make particular instructional decisions using resources depends on what they see as problems or opportunities in practice. Using resources also adds an element to critical discourses that is underdeveloped – the theory can broaden its explanatory appeal when the field understands *why* beginning teachers select particular resources to reason with and about, how their personal theory of teaching and learning shapes their resource use, and why their critical discourses helps them mediate contextual pressure to teach in specific ways.

Opportunities for beginning teachers to use and learn from a suite of resources in a context can differ *depending on how practitioners use resources to support valued teaching practices in a given setting*. Though novices could have opportunities to use and learn from the

same set of resources across contexts, how and why beginning teachers use resources to shape and learn from practice could vary greatly given their pedagogical reasoning and critical discourses.

Methods

Participants and context

In this multi-case study, I investigated five first-year teachers' learning during the 2011-2012 school year. Each participant holds a bachelor's degree in a science field and was a full-time secondary science teacher in the Pacific Northwest (See Table 1 for descriptions of the participants). All participants completed a master's degree in teaching from a large public university in the northwest United States, and during their time at the university, were students in the same secondary science methods class.

I first interacted with the participants as the co-instructor for their secondary science teaching methods class. My duties included planning with the participants, observing their instruction during student teaching, and reflecting with them about their practice. Such interactions with the participants helped build rapport and trust (Merriam, 2009; Patton, 2003).

For this study, I selected participants based on two criteria: their practice history during methods class and student teaching, and their current school's instructional cultural scripts (the historic norms and messages about what counts as teaching and learning – see Sykes et al., 2010). I purposefully selected a range of participants with varied practice histories – three of whom readily attempting ambitious practice, and two of whom typically enacted more conservative forms of practice. I characterized the participants' initial practice histories based on artifacts (methods class assignments, and any student teaching-related documents such as lesson plans, assessments, and tools and scaffolds created by participants and their students), semi-

structured interviews with participants about their methods class and internship experiences that occurred during another research project, classroom observations of participants' instruction, and observation debriefs. I also selected participants based on their first year teaching contexts. I searched for schools whose cultural scripts focused on conservative forms of teaching, which often included pressure to improve students' achievement on standardized tests. The ultimate purpose of both selection criteria was to help develop a theory of teacher learning, and not to generalize unproblematically to similar "populations" of teachers, students, and classrooms.

Table 1.

Description of Participants

Pseudonym and Education	First Year Teaching Assignment	Reasons for Selection in Study
Maria (BS in biology)	8 th grade general science in urban middle school	<ul style="list-style-type: none"> • History of planning for, enacting, and reflecting about ambitious practice during student teaching • Teaching some content (physics) outside of college major • First year teaching assignment different than student teaching assignment (high school biology)
Joseph (BS in chemistry)	Biology and algebra teacher at new project-based learning suburban high school	<ul style="list-style-type: none"> • History of planning for, enacting, and reflecting about ambitious practice during student teaching • Teaching content (biology) outside of college major • First year teaching assignment different than student teaching assignment (high school chemistry)
Karen (BS, MS, PhC. in biology)	Biology at urban high school	<ul style="list-style-type: none"> • History of planning for, enacting, and reflecting about ambitious practice during student teaching • Teaching content in college major (biology) • First year teaching assignment different than student teaching assignment (high school chemistry and physics)

Rebecca (BS in biology)	Biology at urban high school	<ul style="list-style-type: none"> • History of planning for, enacting, and reflecting about conservative instruction during student teaching • First year teaching assignment same as student teaching assignment (high school biology)
Lucy (BS in biology)	9 th grade physical science at suburban high school	<ul style="list-style-type: none"> • History of planning for, enacting, and reflecting about conservative instruction during student teaching • Teaching content (physics and chemistry) outside of college major • First year teaching assignment different than student teaching assignment (high school biology)

Participants' university-based science methods class

The participants' learning cannot be understood without some background into their university-based science methods course. One goal of the secondary science methods class in promoting ambitious instruction was to frame-shift how the participants thought about organizing instruction, and to socialize them into new visions of “good teaching.” This socialization included scaffolding the participants' recognition and use of resources to shape and learn from their ambitious practice. As a co-instructor for the methods class, I promoted the use of conventional, social, and intellectual resources as commodities for pedagogical reasoning that led to generative learning – *adapting and innovating instruction, tools, and routines to meet students' emerging disciplinary thinking* (Ball & Forzani, 2011; Kazemi, et al., 2009; Lampert & Graziani, 2009).

I also helped organize the class around four core practices considered to be central to ambitious teaching: constructing the “Big Idea”, eliciting students' ideas to adapt instruction, helping students make sense of material activity, and pressing students for evidence-based explanations. Throughout the methods course, the participants had opportunities to approximate the four practices using a suite of planning tools and through microteaching – attempting one practice with peers and a methods instructor (Grossman et al., 2009a). The purpose of approximating the practices was for the participants to try out the practices in a safe and collegial environment with peers and instructors and to receive immediate and principled feedback about their work. I will now describe the four practices.

To *construct a Big Idea*, teachers confronted the limits of their own understanding of the science topic, and then investigate their topic, connecting new information to state and national standards. Second, teachers situated a science topic among other ideas to determine how

foundational the original topic is. Third, they determined a relevant, observable, and puzzling phenomenon for the students to explain, and construct a causal explanation for the observable phenomenon involving unseen processes or characters. Finally, teachers predicted what student success looked like as the unit progressed. For example, a teacher could decide for a unit about sound to focus on energy, force, and motion as fundamental ideas. They could then select a puzzling phenomenon, perhaps asking why windows shake when a car playing loud music drives by. The teacher then constructs a causal explanation, involving molecules hitting each other. Finally, the teacher anticipates what students might think about sound and what kinds of experiences students may have had with this phenomenon.

When *eliciting students' ideas*, teachers planned a rich task that can reveal a broad range of student thinking about the target big idea, elicit observations from students about the phenomenon of interest to them, encourage the students to offer initial causal hypotheses about the phenomenon, assist students in synthesizing what they think they know and what they want/need to know, and after class, analyzing students' contributions to shape instruction.

When teachers helped students *make sense of material activity*, they designed conversations with students that allow them to connect various kinds of activity with the big idea. This practice helped students understand how activities related to the observable phenomenon they have been puzzling over, assisted students in using the observations or data collected during the activity with the big idea, support the development of students' academic language as a resource for communicating concepts and making sense of scientific ideas within the classroom community.

The final practice, *pressing students for evidence-based explanations*, required that the teacher help students co-construct evidence-based explanatory models for the puzzling

phenomenon illustrating the big idea. These models depict students' reasoning, linking their observations and information from a variety of sources students had experiences with to unobservable events, structures, or processes. Teachers re-oriented students to the possible explanatory models and hypotheses that could have been proposed up to this point, coordinated students' tentative explanations with available evidence, prompted students to talk about the strength of the evidence and the reasoning that links evidence with explanations, write a final explanation, and had students apply the new explanatory model in contexts beyond those previously discussed.

After methods class ended, the participants were placed in schools for six months of student teaching experience during the 2010-2011 school year. All the participants in this study were student teachers in different high schools in the Pacific Northwest. During student teaching, the participants moved from a secondary to primary instructor role in their classroom, planning, teaching, and reflecting on lessons with their assigned mentor teacher and other influential actors – their methods class peers, instructors, and university-sponsored “site” and “content” coaches. In addition, the participants were required to use the ambitious planning tools from methods class, and had access to the methods class website, which provided sample lessons, units, and reflection materials. The participants' attempts at enacting ambitious instruction in their student teaching context often resulted in tensions between the participants' vision of practice and their mentors' vision, which was frequently framed by a vision of typical instructional practices.

Participants' school contexts: A push for testing

During the 2011-2012 school year, each participant taught in a school that provided a unique set of circumstances for their instruction. While each context was unique, one common

narrative from each school on the participants was to increase students' achievement on standardized assessments.

Maria's Title I middle school focused securing more funding from the school district. To gain administrative attention, Maria's school targeted specific objectives on standardized tests, such as mastery of disciplinary vocabulary. The main press on Maria, therefore, was to help her students demonstrate increased proficiency in the reading and vocabulary sections of the tests. Like Maria, Karen's school also wanted a boost in standardized test scores. However, their motive was different – as a newly designated STEM high school, Karen's school wanted to “justify the title and money” from the district (observation debrief). Karen, therefore, felt constant pressure to “make sure my classroom reflected the STEM goals of the school” – having high test scores on math and science assessments. Like Maria and Karen, Rebecca's school wanted to increase standardized test scores in order to “entice other kids away from schools in the district” (observation debrief). Rebecca noted that her assistant principal frequently attended department meetings to review test score data and to “identify students to target for tutorials” (observation debrief). Lucy's school also targeted students for tutorials; however, her department chair took on the role of “data analyzer” for the other teachers. Lucy had to attend one-on-one meetings with the department chair to “review the students I needed to focus on during a specific week” (observation debrief). Of the five participants, only Joseph's school had a history of high standardized test scores. However, this history resulted in a constant press to maintain the scores in order to “uphold the prestige” of the district (observation debrief).

Data sources and collection

During the 2011-2012 school year I collected and analyzed multiple forms of data from four different types of episodes: requested or informal planning communication, classroom

observations, semi-structured interviews, and professional development sessions. In this section, I describe the data collection and the features of each episode.

Data sources

Requested or informal planning communication

The first category of data sources I used for this dissertation involved requested or informal planning communication that was initiated by the participants. When engaged in planning communication with participants, I paid attention to their pedagogical reasoning, critical discourses, and how they framed problems of practice. For example, in August, 2011, two participants requested to meet with me to discuss their upcoming plans for science teaching. During these planning sessions, a participant and I used their school resources (textbook and curriculum) as well as methods class resources (ambitious planning tools) to plan for the upcoming year. We first discussed a framework for the school year, considering the fundamental science ideas students should know by the end of the year. We then broke the fundamental ideas into units, attempting to create yearlong story of science ideas for students. I audio recorded and transcribed each conversation. As a researcher, I recognized my potential influence on the participants' learning and practice. However, as an advocate of ambitious practice and a teacher educator, I chose to act as a resource for the participants if they requested my assistance (see section about my stance as a researcher of ambitious practice for more information).

While some planned conversations occurred at the beginning of the 2011-2012 school year, the most frequent form of participant-initiated planning communication was through email. Participants often sent emails, requesting that I help them prepare or review their unit planning, assessments, or activities. For email requests, I replied with questions and comments, and I then saved the original email from the participant and my own reply.

During planning communications, participants frequently discussed science teaching and learning in relation to their school's cultural scripts about teaching and learning. Participants discussed a multitude of school-related topics, such as department requirements, results from planning sessions with colleagues, successes and struggles with students, upcoming standardized assessments, and student learning. I scripted notes or audio-recorded such details and saved them in the participants' folders, keeping track of their perceptions about what the school valued as teaching practice.

Classroom observations

The second set of data sources I used for this dissertation was classroom observations. I observed each participant teach during three timeframes throughout the 2011-2012 school year: October, 2011, January – April 2012, and May/June, 2012. In October 2011 and mid-May – June, 2012, I observed one lesson. The purpose of the October and May/June lessons was to get a snapshot of the participants' practice at the beginning and end of the school year, and to see evidence of both the development of classroom science activity and the participants' learning over the school year. In the time period of January 2012 – April 2012, I observed each participant teach one entire unit, meaning that I was in the same class each day. The purpose of the unit-long observations was to observe the development of science activity in a short time, and to see evidence of the participants' daily learning while teaching a unit.

Video record classroom observations

One purpose of classroom observations was to capture as much discursive interaction between all the actors as possible. To capture discursive interactions, I video recorded all classroom observations using a hand held camera. The primary subject on camera was the

teacher and their interactions with students during class time – “between the bells.” I turned the camera on when the class bell rang, and turned the camera off when the dismissal bell sounded.

Observation notes

During each classroom observation, I wrote down questions and notes as the class unfolded, highlighting instructional moves and aspects of classroom practice to ask the participant about during our daily debrief. For example, I recorded and asked about moves that I knew were planned and moves that appear spontaneous, such as skipping over an item on the daily agenda listed on the board. I also recorded any learning objectives, warm-ups, and closing statements written on the board.

Daily debriefs

I informally debriefed with teachers after each lesson. During these 10-15 minute conversations, I scripted notes as the participant described the successes and failure of the lesson to me. In addition, I asked them about particular pedagogical moves they planned (for example, why they use a powerpoint lecture) and moves that are unplanned or spontaneous (for example, why they skipped over an episode listed on the daily agenda). Since this lesson replay occurred immediately after class ends, the participant remembered specific moves and their pedagogical reasoning, which informed their instructional decision (see Horn, 2007, 2010). When engaged in daily debriefs with participants, I paid attention to their pedagogical reasoning, critical discourses, and how they framed problems of practice.

Teacher and student-created artifacts

I collected teacher and students-created documents related to planning, instruction, and reasoning for each unit I observed, and all work associated with the classroom context, including:

- lesson plans
- assessments
- instructions for activities/tasks
- the participant's analysis of student work
- tools (created, modified, or adapted by participants to solve problems of practice)
- various forms of communication, such as email

Such artifacts, triangulated together, can be useful when making sense of teachers' reasoning and instruction in their particular context (Penuel & Gallagher, 2009; Borko, Stecher, Martinez, Kuffner, Barnes, Arnold, Spencer, Creighton, and Gilbert, 2006).

Photographs of tools and scaffolds in the classroom

After classroom observations, I also took photographs of five categories of objects that teachers and students created: graphical inscriptions produced by teachers and students, subject matter representations, scaffolding, directions, norms for participation. I photographed these objects each day I was there to document how they changed during the long unit. I also wanted a record of how the participants' used their pedagogical reasoning and critical discourses to provide opportunities for students to share ideas using physical representations of their thinking.

Semi-structured interviews

The third set data sources I utilized for this dissertation were semi-structured interviews. A semi-structured approach allowed me to adapt the protocol to probe participants' comments, ideas, and theories about practice while still focused on the overall goal of a one-hour interview (Merriam, 2009; Patton, 2003). These interviews provided the participants an opportunity to describe their understandings about teaching and learning (Dilley, 2000). Interviews were recorded using two digital recorders and were sent to a professional transcriptionist. I conducted

three types of semi-structured interviews during this study: A unit interview with a resource card sort, a reflection on the first year teaching, and a personal epistemology of science interview.

Semi-structured interview one: Unit interview including resource card sort

During the January – April 2012 daily unit observations, I conducted three fifteen-minute semi-structured interviews, which include a resource card sort. I asked each participant to answer questions about their unit planning, content understanding, pedagogical reasoning, and classroom activity just before their unit begins, in the middle of their unit, and at the end of their unit (See Appendix A for questions). Included in this semi-structured interview was a resource card sort, which asked participants to discuss what resources informed their pedagogical reasoning processes during planning, instruction, and reflection (Lampert et al., 2011). I asked the participants: “For this unit, you have several resources to draw on as you plan and teach lessons—such as your department, curriculum, ideas from university-based science methods class, the tools from methods perhaps some others I did not name. How would you rank the influence of these on your planning, teaching and reflecting? Did this change over time? Why?” I also asked the participants how they used resources when planning, teaching, and reflecting. I video recorded participants as they sorted cards with those potential resources as well as blank cards that they could have added resources on to. This task provided a lens into a) what participants’ thought were resources to use when planning, teaching, and reflecting, b) how and why participants view certain contextual factors and ideas as resources but not others, and c) how and why participants used resources to learn from and shape practice.

Semi-structured interview two: Reflection on first year teaching

The second semi-structured interview occurred during June 2012, the week after school ends in the participants’ school districts. I asked the participants to reflect on their planning and

instruction, to describe the details of teaching science in their school context, and their experiences of working with various actors. These questions allowed me to characterize the participants' perceived contextual affordances and constraints on their practice as they made sense of teaching in their school context (see Appendix B for the questions). I audio-recorded all interviews and sent them to a professional transcriptionist.

Semi-structured interview three: Personal epistemology of science

The third semi-structured interview asked the participants about their personal scientific epistemology – an individual's understanding of the ways science knowledge is made a treated and vision of scientific work – and experiences as a science learner. While few researchers ask teachers' about their personal epistemologies of science, studies in science education of students' epistemologies (e.g., Sandoval, 2005; Smith, Maclin, Houghton, & Hennessey, 2000), STS, and HPS literature claim that an individual's personal epistemology of science influences both how they learn science and how they shape the actual science practice in spaces where they hold cognitive authority (Harkness, 2007; Hannaway, 1986; Knorr-Cetina, 1999; Owens, 1985; Rudolph, 2002; Shapin, 1988). The questions in the third semi-structured interview (see Appendix C for the questions) allowed me to a) make sense of the circumstances under which the participants revisit and reassess their understanding of subject matter and pedagogy, b) better understand the role of participants' conceptual understanding of science and epistemology on their pedagogical reasoning and practice throughout the year, and c) describe possible associations between teachers' personal epistemology of science, how they set up science practice, and how the science practice shapes teachers' understanding of science. I conducted this interview once, at the end of the school year.

Professional development sessions: Critical friends' groups

The fourth set data sources I utilized for this dissertation came from the participants' participation in three professional development sessions – called “critical friends groups” (CFGs) – throughout the 2011-2012 school year: one in October 2011, one in February 2012, and one in May 2012. Each CFG lasted for one hour, and occurred at the university where the participants were students in their teacher preparation program. The purpose of the CFGs was for the participants to share puzzles of practice that were focused on student thinking and learning. To illustrate the problem of practice, participants shared samples of student work and their analysis of student thinking with a small group (4-5 people) of their teaching peers and a university researcher (myself, the methods instructor, or another secondary science research assistant). At each CFG, I purposefully placed 2-3 participants in the same group, with my faculty adviser or myself as the facilitator. The group then engaged in a structured conversation about the problem of practice using a conversation protocol. The CFGs provided a lens into what participants considered a) puzzling problems of practice to learn from, b) the science practice of their science classroom, c) what and how they want students to think and learn, and d) institutional cultural scripts they integrated into their developing critical discourses. At each CFG, I collected teacher and student-created artifacts and recorded notes about their school context, both of which I described in previous sections.

Data analysis

In the following section I describe my analysis process for the research questions that guided this study. The research questions were as follows:

- What resources do beginning teachers recognize, generate, and use in their school contexts?

- How does beginning teachers' differing use of resources shape their particular trajectories of practice and professional learning?

Coding category 1: Resource coding

I coded multiple sources (artifacts, interviews, observations, and the resource card sort) to identify and characterize what participants use as resources to inform their practice over time (Cohen et al., 2002). I also coded how the participants discussed the resources that provided them with the most immediate and “useful” information about solving problems of practice. In other words, I coded how participants prioritized certain resources over others as more helpful as they engaged in their daily work.

Coding category 2: Participants' pedagogical reasoning

The second category of codes was to determine how beginning teachers use resources to shape and learn from practice. I looked for episodes of pedagogical reasoning (EPRs) - units of teacher talk in which they frame and solve problems of practice and describe how various resources in a context influence their decision-making. EPRs are also accompanied by some elaboration of reasons, explanations, or justifications for why the teacher made particular decisions. These episodes can be individual, single-turn utterances, such as “I’m not using that worksheet because it bores the kids.” Alternatively, these can occur over many turns of talk (Horn, 2007). When coding for pedagogical reasoning, I used data sources from all four types of interactive episodes: requested or informal planning communication, classroom observations, semi-structured interviews, and professional development sessions.

Participants' science knowledge for teaching

One intellectual resource I paid particular attention to when coding pedagogical reasoning was the participants' *science knowledge for teaching* (SKT). This resource featured

prominently in coding because some researchers, such as Ball, Thames, and Phelps (2008) in mathematics education, propose that teachers' learning of content and pedagogy is associated with their developing understanding of how and why *their particular students learn subject matter*. I coded how their science knowledge for teaching changes over time as they used various resources. When initially coding science knowledge for teaching, I used two content knowledge domains proposed by Ball et al. (2008) in their SKT framework: *knowledge of content and students* (KCS) and *specialized content knowledge* (SCK). KCS represents teachers' developing understanding of their students' ways of talking and reasoning about disciplinary ideas. SCK represents professional knowledge unique to teaching, which differs from a content specialist's understanding of subject matter. SCK describes teachers' developing understating of the difficult aspects of their subject matter to explain, the best order for topics to be taught, and how some science topics are more fundamental to overarching "big ideas" in science than other topics. These knowledge domains provide a name and framework for understanding how and why teachers' understanding of subject matter, instruction, and students is continually developed within their school context.

Coding category 3: Critical discourses and contextual cultural scripts

The third category of codes is to determine why beginning teachers used resources to shape and learn from practice. As discussed previously, a teacher's critical discourses shape their *vision of practice* (mental images of productive practice that inspire and guide decisions. They are future narratives that include a sense of what is possible in the classroom), and mediates what *problems of practice* to solve using resources (i.e., what teachers think are difficult puzzles that need a solution) and what *opportunities in practice* to learn from and take advantage of (i.e., what teachers think could be beneficial for their practice and students' learning). A teacher's

critical discourses, for example, help determine what resources teachers use when reasoning pedagogically. I also analyzed how the participants' vision of practice works to deflect or subscribe to their school's instructional expectations (see Appendix D for the participants' critical discourses and school cultural scripts).

Analyzing resource use and learning

When analyzing how teachers recognize, use, and learn from resources, I began by seeing what resources teachers draw upon on when planning, instructing, and reflecting. I also saw how the resources interacted with one another while teachers engaged in planning, instructing, and reflecting on practice. A guiding theme in looking across the data is the question of what resources teachers cited when they talked about the lessons I observed, and how teachers reported using the resources that were available to them. When analyzing field notes, transcripts, videos, and inscriptions, I looked for patterns in the codes over time. For written text (teacher and student-created artifacts, planning emails, and transcriptions of audio files), I used the codes described above to identify patterns in participants' discourse, reasoning, and instructional decisions. I coded inscriptions in the context of classroom activity with the actors' discourse and writing to make sense of how and why inscriptions are created and used over time. Finally, for videos, I reviewed the observations in real time, pausing them if necessary to write the equivalent of fieldnotes (Erickson, 1986) paying particular attention to discussions. I used the codes on the video notes, identifying overall trends. I transcribed selected discussions verbatim, and use the codes on the written text as previously described (see Alozie, Moje, & Krajcik, 2010).

Triangulating data sources

When analyzing field notes, transcripts, videos, and inscriptions, I looked for patterns in

the codes over time about the science activity in classroom spaces. For written text (teacher and student-created artifacts, planning emails, and transcriptions of audio files), I used the codes described above to identify patterns in participants' discourse, reasoning, and instructional decisions. Finally, for videos, I reviewed the observations in real time, pausing them if necessary to write the equivalent of fieldnotes (Erickson, 1986) paying particular attention to discussions. I used the codes on the video notes, identifying overall trends. I transcribed selected discussions verbatim, and use the codes on the written text as previously described (see Alozie, et al., 2010). During and after analyzing single data sources, which provided one lens into teacher learning, I triangulated the data sources. By triangulating, I mean that when analyzing the main bodies of data, I tried to find supporting or disconfirming evidence *across* data sources to enhance the credibility of the hypotheses (Merriam, 2009; Patton, 2003).

Hypotheses emergence and testing

As I analyzed and triangulated the data sources to answer the research questions, I looked for hypotheses that emerge from the coding. For all hypotheses – both initial and emergent – I sought confirming and disconfirming evidence. I also entertained alternative explanations, keeping in mind that my stance as a researcher and advocate for ambitious instruction could skew my interpretation of the data. One way I checked my own understanding of participant learning was to conduct member checks during the all semi-structured interviews. I asked participants to respond to my interpretation of the data, with the freedom to clarify, expand, or refute my interpretations during our semi-structured interviews (Merriam, 2009; Patton, 2003).

My stance as a researcher of ambitious practice

Some researchers of human learning advocate for traditional ethnographic methodologies, purposefully not layering their own definition of competent practice onto their analysis of

individual development (see Rogoff, 1995, 1997, 2003; Wolcott, 2005). I argue that studying “what is” in classrooms can place teacher education researchers in a quandary as they simultaneously advocate for ambitious teaching in contexts that often promote typical forms of instruction. For example, Thompson et al. (2013) concluded that one-third of their participants engaged in ambitious teaching practices despite working in schools with cultural scripts that promote typical instructional practices (Sykes et al., 2010). Yet Thompson and colleagues did not idly watch the other two-thirds of the beginning teachers revert to standard forms of teaching; they actively provided support to push their typical instruction towards ambitious teaching. In this study, I chose a middle ground between these two ends of researcher continuum. While I did not actively make unprompted pedagogical suggestions to the participants, I did offer ideas and planning suggestions if asked by the participants. I viewed my role as a resource for participants’ learning if they chose to use me as such. For example, I included myself in the resource card sort. I documented my role as a resource in data collection and analysis.

Findings

In this section, I organize the findings around three assertions that emerged from the data. I state each assertion below, and then situate each in the larger findings from this study:

- All participants, regardless of sophistication of practice, drew upon the same fundamental set of resources to shape and learn from their teaching. This assertion counters a hypothesis that teachers who more frequently enact ambitious practice might draw upon a fundamentally different set of resources when engaged in their work.
- While all participants used the same resources, two groups of resources acted as different primary frames for the participants’ pedagogical decision-making. One

group included resources from the university-based methods class, including “face-to-face” tools and a conceptual framework for instruction based on ambitious practice. A second group included school-based resources, such as textbooks and department expectations. The resource group selected by a participant as most beneficial for their learning seemed to be connected to their critical discourses about their role as a teacher about how students’ science ideas should be used in classroom activity. Each group of resources guided participants’ interactions with students’ ideas over time. The participants used their prioritized subset of resources to notice particular kinds of student ideas and to use those ideas to make instructional decisions.

- By using students’ ideas in concert with a group of resources when engaged in pedagogical reasoning and practice, the participants opened up opportunities for their own learning over time by becoming familiar with the breadth and depth of students’ disciplinary thinking. The participants’ learning, in turn, influenced their subsequent practice and subsequent opportunities for student participation. These cycles of learning allowed the participants to see how student thinking was influenced by an array of instructional moves, substantiating or disconfirming elements of their critical discourses.

Recognizing and using the same fundamental set of resources

All participants, regardless of sophistication of practice, drew upon the same fundamental set of resources to shape and learn from their teaching. This counters a hypothesis that teachers who more frequently enact ambitious practice might draw upon a fundamentally different set of resources when engaged in their work.

Conventional resources

The participants recognized and used three types of conventional resources: “knowledge-embedded” tools, “face-to-face” tools, and other material assets. “*Knowledge-embedded*” tools included textbooks, websites, curricula, planning tools from UW science methods class. These resources provided content and pedagogical information, recommended unit structures, and a context’s reified standards for participation in teaching activities. Participants used “*face-to-face*” tools specifically to solve problems of practice, such as scaffolding students’ use of evidence when constructing explanations for the phenomenon under investigation. By face-to-face tools, I mean that each participant used physical objects, such as poster paper and sticky notes, to inscribe students’ science ideas during class time, subsequently reviewing what students said and thought for the purpose of shaping future classroom activity. For example, Karen and her students created a “hypothesis checklist” – a poster at the front of the classroom on which Karen or a student could write an evidence-based hypothesis about a puzzling phenomenon. Once someone recorded a hypothesis on the checklist, Karen and her students devised a way to test the hypothesis. *Material assets* included lab equipment, student journals, computers and projectors. Lab equipment – the devices employed when conducting science research – acted as a representation of science (scientists use microscopes, and so do we) and provided the means to engage in classroom science work.

Social resources

The participants recognized and used three types of social resources: their peers’ and colleagues experiences and ideas, their school’s instructional expectations, ideas from their university-based science methods class, and students’ science ideas. The participants frequently gained access to social resources during planned and organized meetings of actors, such as department meetings, critical friends’ groups, or class time at school. First, the *peers’ and*

colleagues' ideas and experiences included representations of their practice (examples of student work, lesson plans, and Power Point presentations), stories from their varied practice histories, and tools they used in their school contexts. The participants used their peers' and colleagues' ideas and experiences to compare attempts at practice and see success and failures in other contexts, to obtain new tools, routines, and ideas, and to confirm their own teaching practice matched the efforts of others. For example, Joseph spoke with Maria about how to scaffold students' use of evidence from activities in an explanation. Maria described a tool she generated, called a "summary table", which helped her solve a similar problem of practice. She also informed Joseph of changes she would make to the "summary table" given her students' successes and struggles with her tool. Joseph both recognized Maria's situation as similar to his conundrum, and attempted to appropriate the solution embedded in her story of practice. He therefore created a similar tool and pedagogical routine based on Maria's story of practice.

Second, the *school's instructional expectations* provided a cultural script about "what counted" as teaching and learning that the participants encountered during department meetings, contact with administrators, discussions with colleagues. Such expectations informed the participants' pedagogical reasoning as they made instructional decisions. For example, Rebecca constantly encountered messages from the department that her role was to increase students' standardized test scores.

Third, *students' science ideas* provided the participants with students' experiences, theories, and evidence around unit topics. All participants used students' science ideas to interrogate their own understanding of subject matter and pedagogy, and to inform their pedagogical reasoning when making instructional decisions. For example, Lucy listened for students' "misconceptions" about valence electrons in a unit about chemical bonding. When she

heard students' "misconceptions", Lucy worked to "figure out how to best change the students' thinking", often through more practice problems or a Power Point lecture that included canonical information (observation debrief).

Intellectual resources

The participants recognized and used two types of intellectual resources: science knowledge for teaching and a conceptual framework for teaching. The participants recognized and used *science knowledge for teaching* (SKT) when planning, instructing, and reflecting. All the participants used their SKT to reflect on students' science ideas, to interrogate their own understanding of the content and how best to teach the science, and to reshape their unit around what they thought were students' emerging needs. The participants' SKT was not static; rather, their understanding of science and pedagogy constantly changed as the participants learned more about their students' science ideas and funds of knowledge. For example, during a unit about genetics and cancer, Karen noticed that her students simultaneously theorized about cancer on multiple levels – DNA, cells, tumors, and organ systems. Karen, however, "compartmentalized cancer into separate domains" when planning (observation debrief). Therefore, Karen decided to alter how she taught the unit given students' adeptness with various aspects of cancer biology.

The participants also selected a *conceptual framework for teaching*, which provided a narrative about, and expectations for, teaching and learning. One conceptual framework included conservative practices valued by the participants' school context. Another conceptual framework included ambitious practice promoted in the university-based methods class.

Subgroups of resources set a primary frame for practice

While all participants utilized the same resources in practice, two groups of resources emerged that acted as different primary frames for pedagogical decision-making. These frames

emerged from the data as participants prioritized certain resources over others as most beneficial to their planning, instructing, and reflecting. When prioritizing, the participants decided that certain resources provided them with the most useful information about their practice, and helped them reason pedagogically about future instructional decisions given the features of their particular school context. The participants used *primary resources* to reflect on practice and to make immediate and purposeful instructional decisions. *Secondary resources* provided information and structure for teaching activities, but participants did not use such resources as frequently to shape their learning and practice (see Figure 1 for primary and secondary resources).

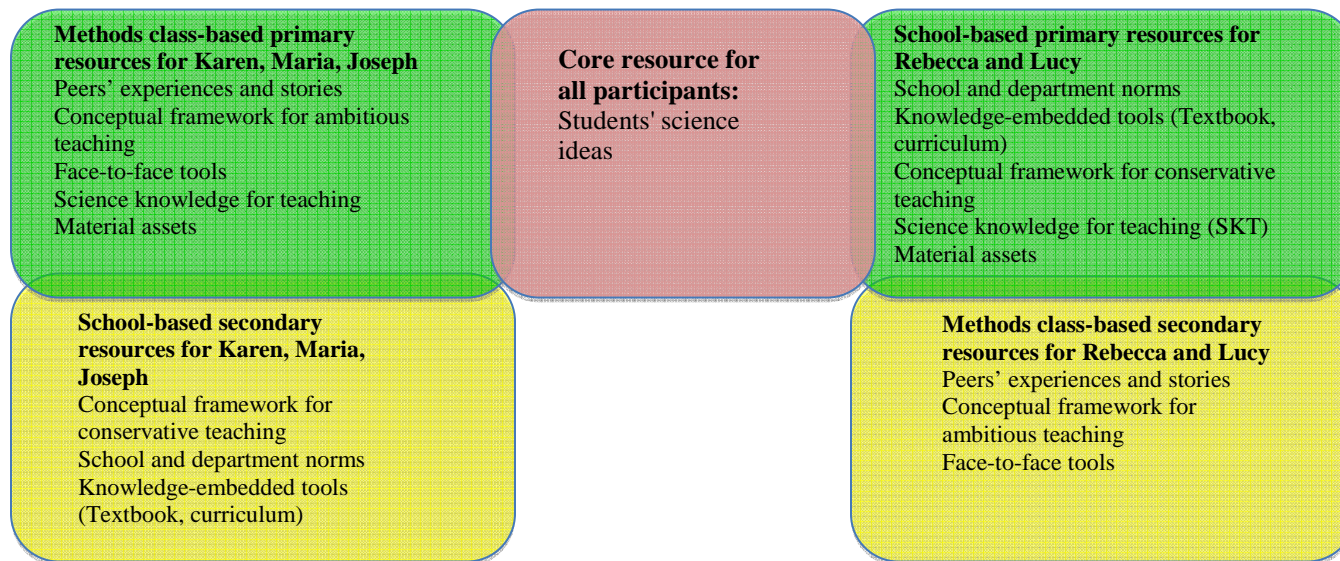
It is important to highlight that students' science ideas acted as *the core resource for all participants*. This finding counters hypotheses that teachers who readily enact ambitious practice use different resources when engaged in teaching activities than others who typically enact conservative practices. Also note that participants typically enacting conservative practices did not dismiss or ignore students' ideas; rather, the participants frequently shaped their practice around student thinking.

The resource group selected by a participant as most beneficial for their learning and practice also seemed to be connected to their critical discourses about their role as a teacher about *how* students' science ideas should be used in classroom activity. The three participants who routinely enacted ambitious practice – Maria, Joseph, and Karen – wanted to provide students with opportunities to engage in authentic science activity and to share their science ideas on the public classroom plane. They therefore *used students' ideas in concert with other primary resources to provide opportunities for students to engage in authentic science activities*. The other participants who frequently enacted instructionist practice – Rebecca and Lucy – wanted to

provide safe spaces for students to learn “correct” science ideas. They therefore *had difficulty deflecting their school’s instructional cultural script that primary resources should help students memorize information and reproduce “correct” science facts on various assessments.*

Figure 1.

Resources Prioritized by Participants. This figure shows the primary resources prioritized by each participant, the secondary resources that also informed participants' pedagogical reasoning, and core resource for all participants – students' science ideas.



Cross-case comparisons

In this section, I describe each participant's learning on a microgenetic scale (within one unit on instruction) and a macrogenetic scale (over the course of a year) as they used resources in teaching activities in their specific school context. I describe Maria and Rebecca's cases in greater detail, and use Karen, Joseph, and Lucy as supporting cases. In each participant's learning story, note four aspects of the participants' resource use and learning: 1) how participants used resources differently over time given their school context, 2) how participants' resource use provided different kinds of opportunities to learn from practice, 3) how participants' critical discourses shaped the resources they recognized and used, and 4) how the participants' learning became generative or, in other cases, aligned with the conservative expectations of their schools over time.

Maria's planning with students in mind

Before the school year began, Maria attended initial department meetings, worked with her mentor teacher and assistant principal, and went to district orientations. From these interactions, Maria learned that her school's goal was to increase students' standardized test scores by helping them learn how to use "scientific language" in class. While acknowledging the importance of her school's conventional resources such as the textbook, Maria also began to construct a specific vision of how she wanted her students to participate in science by the end of the school year. Note that Maria considered two aspects of her practice that set up opportunities for her generative learning during the year before school began. First, Maria recognized "the need to build a collaborative learning community in which students feel safe to share ideas (planning session)." Second, Maria recognized the need to constantly assess in order to use their ideas to shape practice: "I will set up my classroom so that everyday there is some kind of

opportunity for me to see where they are at. And that's ultimately what drives where I go next. Or where I don't go next (planning session)." Maria thus prepared herself to set up a classroom in which she could hear and use students' science ideas with her other primary resources to shape her practice.

Using students' ideas as resources early and often

Maria initiated her generative learning during her first unit. In this unit, Maria taught about the seasons, a required curriculum topic. Rather than use her department's activity (watching a video), Maria decided to leverage some of her Pacific Island students' lived experiences as resources for the class. She asked students to describe qualitative observations about summer and winter in both Samoa and Seattle, and students seemed eager to share. Note that Maria, in her first unit, tried to establish a classroom norm of sharing science ideas for the purpose of shaping her practice.

During my first observation, Maria used students' ideas to make an instructional decision in-the-moment, changing the lesson based on student thinking. Maria and her students began class by reviewing data from a computer simulation, which provided information about the amount of sunlight and temperature at different places on earth during the year. During this discussion, Maria decided that, based on student ideas (some students thought that the earth was "sometimes tilted" while other students thought that the earth was "always tilted" – observation notes), the class needed to revisit the computer simulation to discuss their competing theories. By revisiting the computer simulation, Maria provided herself with more opportunities to hear student thinking about their science ideas.

Maria also worked to establish her classroom as a safe space for students to share science ideas from their own lived experiences because she wanted "see their thinking so I know where

to go” – in other words, use students’ science ideas as a resource for shaping her practice (observation debrief). One discursive move Maria utilized to help students feel safe sharing ideas was to note that their ideas were valuable resources for their learning. In this example, Maria and a student discussed the seasons based on the student’s lived experiences:

Maria: Where does the temperature change as earth is tilted?

Student: I don’t know.

Maria: What about the equator? At the equator...

Student: The temperature doesn’t change much.

Maria: When you did the computer simulation and selected for a whole year’s temperatures, what did you see?

Student: Not much change in temperature.

Maria: What about looking at Seattle for a year?

Student: Yeah, the temperature changed a lot.

Maria: What’s the difference?

Student: If the earth stayed at zero degrees if it wasn’t tilted, the temperature wouldn’t change in Seattle.

Maria: Ok, so I hear you saying that if the earth wasn’t tilted, Seattle wouldn’t experience temperature change. Is that related to your life? Do changes in Seattle temperature according to the computer data make sense with what you know in real life?

Student: Yes, because if the earth wasn’t tilted, I’d only need to buy the same kinds of clothes – the temperature wouldn’t change.

Maria: So you’re starting to explain to me why the earth is tilted using both your experiences and data. That’s powerful for you and for science.”

In addition to providing Maria with access to student thinking, this interaction provided students with evidence that Maria valued their ideas and wanted to hear their thinking. Thus Maria both enacted her plan from the beginning of the school year to create a safe classroom community, and provided opportunities to hear and use students' science ideas to shape practice – the core of generative learning.

Generative learning from daily changes to practice

When I observed Maria daily for a two-week unit during the middle of the school year, she used students' science ideas in concert with primary resources to make daily changes to practice. Since the beginning of the year, Maria worked to enact her critical discourses around setting up a safe classroom space for students to share science ideas. During this unit about energy transformations in roller coasters, students readily discussed their science ideas and in turn, shaped Maria's daily instructional decisions.

To begin the unit, Maria showed students a video of a roller coaster going through a loop twice – once forward and again backward. During the video, students recorded observations of where they thought energy existed in the roller coaster and how energy transformations might occur. Maria also asked the students to create hypotheses about why the roller coaster could go through the loop twice.

After recording observations and hypotheses, Maria and her students moved to “idea space” – a physical location at the back of the room in which students shared their own science ideas as Maria inscribed them on poster paper. By utilizing “idea space”, Maria provided opportunities for students to share science ideas in a safe environment. In turn, Maria provided herself with opportunities to hear student thinking that she would not have access to if she shut down students' public theorizing.

During this time in “idea space” Maria “was listening mostly for talk about height being an indicator of energy and movement being an indicator of energy. I was also listening for talk about other types of energy that exist here (heat from friction, sound, etc.). I was also listening for any talk about how potential energy (height energy, gravity energy) turns into kinetic energy (motion energy, moving energy, speed energy). Now that I know what my students are thinking, I know what to do tomorrow (observation debrief).” In other words, Maria wanted to hear and record how students talked about relationships between energy types in order to know what pedagogical decisions to make for the next class period.

The next day, Maria enacted a task that her department mandated be part of the unit: identifying relationships between energy and the height of ramps using wooden blocks. In this episode, Maria highlighted the different roles her primary and secondary resources played in shaping her practice. Maria noted that the “external forces” [her department] drove some instructional decisions – “I have to do the lab and return the materials the next day.” However, Maria did not waiver from her critical discourses and primary resources, declaring that her department “could not decide how my students should talk about ideas and evidence in a collaborative way. I want them engaged in the kind of talk we did in methods class about getting evidence from activities (observation debrief).” Note that one of Maria’s primary resources – the conceptual framework for practice from methods class – shaped her decision to not use the school-based resources as her department thought she should.

As the wooden block activity progressed, Maria developed questions to ask students in the “spur of the moment” because “It occurred to me during 1st and 2nd periods that kids weren't able to explain the difference between "the gravity" in the low ramp vs. high ramp. I wanted to point out the directional components without overwhelming them to get at kids who need a

challenge. For kids who don't need that complex of a challenge, having them try to articulate "working *more* against gravity or *more directly* against gravity was a way to get them to think about the other forces involved. Thinking about gravity overcoming the friction of the block helps reinforce thinking about *net force* instead of just gravity (observation debrief, italics indicate Maria's emphasis on the words)." Note that Maria used students' ideas from one class to quickly interrogate her SKT, and then reasoned pedagogically that she needed to ask different kinds of questions to point out particular aspects of the block and ramp phenomenon. This example illustrated Maria's microgenic generative learning within one class period – using students' science ideas in an earlier class period to make an instructional decision, thus opening up learning opportunities that she did not have in earlier periods.

Maria learns about roller coasters from her students

The final part of Maria's unit illustrated two aspects of generative learning. First, Maria's used students' science ideas as the core resource for her daily practice. Second, Maria's primary resources shaped the opportunities she provided students to work on their ideas.

After the roller coaster video and wooden block activity, Maria decided to enact a practice from her methods class – creating an explanatory model on a poster during a whole class discussion. Maria used another primary resource, a peer's tool and her story of practice using the tool, to scaffold students' participation in the whole class model. Maria used her peer's tool after a conversation at a Critical Friends' Group in February in which both teachers discussed a similar problem of practice – helping students use evidence in an explanation. Maria's peer created a face-to-face tool called a Red light/Green light poster. Using this tool, students refuted or added strength to hypotheses and claims using evidence. Maria decided to try the tool because "I wanted an ongoing visual of what we have explained, what we have questions about...It also

‘forces’ students to come to a consensus using data and evidence and then discuss their ideas as a class (observation debrief).” Note that Maria chose not to use school-based tools to help students use evidence; rather, she selected a tool to use from a fellow methods-class peer, because they both understood how the tool fit into the conceptual framework for ambitious practice.

Using the Red light/Green light board, Maria and her students used evidence from the wooden block activity to discuss how the roller coaster traveled through the same loop twice. After a whole class discussion, Maria drew the initial roller coaster model and placed it at the front of the room. It is important to note that Maria drew the first whole class model based on her interpretation of students’ science ideas.

For the next class, Maria decided that students should try and recreate the model she drew. By allowing students to use materials to make a physical model using pipe insulation and a marble acting as the car, Maria provided students with opportunities to share science ideas while working together to test the whole class model. Subsequently, Maria heard science ideas from students who rarely spoke in class, thus providing her with more resources to shape her practice.

One critical conversation for Maria’s generative learning occurred between two students, José and Anthony, who rarely spoke in class. While attempting to recreate Maria’s roller coaster model, José and Anthony noticed that the marble kept “flying off of the tracks” and that they “can’t make it stay on (observation notes).” When they summoned Maria to their table and she observed several trials, she concluded that José and Anthony’s data problematized her model. Maria decided in-the-moment to recast her unit by leveraging the students’ evidence, and asked José and Anthony to share their results with the class. After José and Anthony shared their findings, Maria told the class “well, there goes my model. Even though you think teachers are always right, this time, your data proves otherwise (observation notes).” When I asked Maria

why she allowed José and Anthony to publically disprove her model, she replied, “correcting the class model is a good way to give credence to their [students’] ideas - it lends even me to revisions....I want to go where they want to go (observation debrief).” Note that Maria both recast her plan given José and Anthony’s evidence, and set herself up as someone who needed to learn from students’ science ideas during the remainder of the unit.

Since Maria’s model acted as the sole representation of a roller coaster thus far, the class now faced a scientific challenge. Maria asked students to generate a better model since her representation no longer held up against the evidence students compiled in class. Eventually, the students determined that the problem with Maria’s roller coaster model was that the roller coaster car started too high up on a ramp; therefore, the car had too much kinetic energy to remain on the track. The students lowered the height of the ramp, thus reducing the kinetic energy of the car, and successfully revised both the physical and conceptual model.

Generating and testing these new models required two extra days of work that took Maria off of the curriculum pace. She decided to provide students with the opportunity to construct a better model because “lots of students who rarely talk are leading groups, like José and Anthony. I want them to feel empowered to be scientists (observation debrief).” Maria paid particular attention to this talk because it gave her *access to new resources – typically silent students’ science ideas – that could inform “my planning for the next lessons* (observation debrief, italics added).”

After the unit ended, Maria reflected on her learning, noting that she began the unit thinking she was teaching what energy was and how it changes within a system, but “kids already had a bunch of science ideas about this content, such as forces, velocity, and acceleration - my focus has become teaching them to articulate science ideas both by using the language and

by putting the pieces together into an understandable explanation. I've just gotten a much better understanding of the big picture in terms of how energy and forces are related - so my ideas about how to teach this next time is much more clear. It's changed because as I've taught I've had to think about different pieces of it - so my thinking has changed as a result of me doing more research and asking more questions as well as kids asking questions to make me think about things in a different way (observation debrief).” Note that Maria’s recognition and use of students’ ideas changed how she used other resources, such as her science knowledge for teaching, to shape and learn from practice.

Maria’s final unit: The result of generative learning with resources

By the end of the school year, Maria’s work of enacting her vision of a collaborative scientific community resulted in an ecology unit that would likely not have been possible at the beginning of the year. At this point in the school year, students “felt comfortable sharing ideas about complex phenomena (observation debrief).” Note that as Maria provided herself with opportunities to hear students’ science ideas, she also helped students feel comfortable sharing science ideas. By constantly shaping and reshaping her class using students’ science ideas and her primary resources, Maria provided herself with opportunities to learn from practice and create units in which students engaged in authentic science work.

In this unit, Maria planned for students to work on local ecological puzzles, so she selected the relationship between cougar and rabbit populations in the local region. During my observation, students generated and revised a model of a food web, worked in small groups to complete another tool (a “summary table, which helped organize evidence gathered in an activity), and engaged in a whole class discussion around theories about the cougar/rabbit relationship. Maria noted “I now see and hear students’ ideas that I had hoped I would get when

planning at the beginning of the school year (observation debrief).” Maria thus enacted her vision of practice as she used her primary resources and students’ science ideas to shape practice over the school year.

Karen and Joseph’s generative learning

Like Maria, Karen and Joseph set up opportunities for generative learning when planning for the school year. They both recognized the need to build classroom communities in which students felt safe to share science ideas, and to constantly assess student thinking in order to use their ideas to shape practice.

Karen’s planning with students in mind

Like Maria, Karen navigated the tensions of her context through the framework of her primary resources, taking a stance that the conceptual framework for instruction from methods class provided opportunities for students to learn science. Karen faced a unique context because she co-taught a class with a language arts teacher called “Biology-Literature.” Since there were two teachers in the classroom, the administrators doubled the amount of students – Karen’s class had fifty-five tenth grade students – a “daunting challenge” for Karen because she wanted to “use methods practices to hear student thinking (planning session notes).” Karen’s co-teacher, who had no science background, recommended that she follow the science department norms because there was “no way to merge ideas from methods class” with the school’s expectation of increased standardized test scores (planning session notes).”

However, Karen, like Maria decided to push school-based resources into a secondary role. For example, Karen recognized her department’s expectation that she use certain resources like textbook and curriculum. Karen decided to use such resources to “highlight science topics that might be important and to provide suggestions about how to organize information into

manageable unit segments”, but not to shape her thinking about “how students should share out ideas in public (planning session).” Note that, like Maria, Karen considered how to provide students with opportunities to share science ideas while deflecting her school’s press to use resources for more conservative forms of teaching.

Using students’ ideas as resources early and often

Karen knew that enacting ambitious instruction would be a challenge for her students because they “are afraid of taking intellectual risks and of being ‘wrong’ (Critical Friends’ Group reflection).” However, Karen, like Maria, provided students with multiple opportunities to share their science ideas. For example, in the lesson I observed, Karen created a face-to-face tool using sticky notes for students to revise their ideas using evidence. During this activity, students worked in small groups as Karen reminded them to share and use each other’s science ideas. In the following example, Karen and two students discuss why sharing science ideas is important in the class:

Student 1: Do you want the right answer or not?

Karen: Science is a changing process, and scientists are always changing their ideas. Just like you are today.

Student 1: So it’s ok if I my first idea wasn’t great, but I know how to make it better?

Karen: That’s exactly what I want you to think all year. We are all about revising ideas.

Student 2: Can I use [Student 1’s] idea to revise my idea?

Karen: Does [Student 1’s] idea help you understand the science?

Student 2: Yep – he thought of something I didn’t.

Karen: Then of course you should use the idea! Just be sure to give credit to [Student 1] for helping you expand your thinking.

In this episode, Karen, like Maria, worked to build a classroom community in which students felt comfortable sharing their science ideas. This interaction provided students with evidence that Karen valued their ideas and wanted to hear their thinking. Thus Karen both enacted her planning from the beginning of the school year for a safe classroom community, and provided opportunities to hear and use students' science ideas to shape practice – the core of generative learning.

Generative learning from daily changes to practice

Like Maria, Karen used students' science ideas in concert with primary resources to make daily changes to practice. In her next unit Karen asked students to theorize about how ricin, a toxin, could prevent cancer. Throughout the unit, Karen provided students with opportunities to share ideas thus gaining access to their changing thinking over time. As unit progressed, Karen changed the original emphasis of the unit from cell structure and function to cell division in relation to cancer based on students' ideas. Note that Karen, like Maria, decided to recast her unit based on student thinking and using the conceptual framework for teaching from the methods class.

Karen's final unit: The result of generative learning with resources

By the end of the school year, Karen's work of enacting her vision of a collaborative scientific community resulted in an ecology unit that would likely not have been possible at the beginning of the year. Note that as Karen herself with opportunities to hear students' science ideas, she also helped students feel comfortable sharing science ideas. By constantly shaping and reshaping her class using students' science ideas and her primary resources, Karen provided herself with opportunities to learn from practice and create units in which students engaged in authentic science work.

For her final unit, Karen decided to focus on English ivy, an invasive species in her students' communities. Karen's students "drove" the science work – collecting plant samples, making GIS maps, generating seven hypotheses about why ivy was so successful, running experiments to test the hypotheses, refuting or supporting the hypotheses with evidence, and revising initial explanatory models. Karen was "pleased that students got to move on from answering simple 'yes' or 'no' questions to actually thinking like scientists (final interview)." Note that, like Maria, Karen's ecology unit emerged from her generative learning using students' science ideas as the core resource.

Joseph's planning with students in mind

Like Maria and Karen, Joseph considered how to provide students with opportunities to share science ideas while deflecting his school's press to use resources for more conservative forms of teaching. Joseph's context was unique because he was helping to start a new project-based learning school and was the only science teacher in the building. However, he still faced the district instructional expectations of increasing standardized test scores. Yet Joseph, like Maria and Karen, pushed back on his school expectations, planning to create a "learning community in which students simultaneously talk about and do science, with everyone in the class learning from everyone" (planning session). Note that Joseph planned to provide students with opportunities to share science ideas to shape the science work of the classroom, bringing in the conceptual framework for ambitious practice into his classroom.

Using students' ideas as resources early and often

Joseph, like Maria and Karen, provided students with multiple opportunities to share their science ideas. However, during my initial observation, Joseph enacted a unit designed by a research group piloting a 'global warming' curriculum (observation debrief). In the previous

unit, Joseph enacted practices from methods class, guiding students' learning about a puzzling phenomenon, and reported "students loved theorizing together (observation debrief)." The global warming unit, however, was an administrative mandate – the principal was "friends with the curriculum group and they 'strongly encouraged' [Joseph used "air quotes"] me to follow this curriculum with fidelity (observation debrief)."

The lesson I observed became a critical learning moment for Joseph because he noticed that using school-based resources as a primary framework for instruction limited students' opportunities to learn science. The goal of the unit was to have students "focus on the experimental design aspects of science while looking at big problems like global warming" (observation debrief). However, Joseph's students felt "constrained" by the curriculum because they had "less voice" than the previous unit (observation debrief). The task of the day was to conduct a peer review of experimental methods to look at factors of climate change on plant growth – specifically, "Wisconsin fast grow plants" [Note: These plants grow faster than "normal" plants and are typically sold to schools and labs by biological supply companies]. However, as the students worked in small groups and during whole class discussion, students became "increasingly agitated" (observation debrief). Finally, Joseph asked the students why they did not want to participate and students' answers "surprised" him (observation debrief). Students requested to do "real science again" (observation notes), and Joseph asked students to explain:

Student 1: I thought we were going to do big projects. When we did the English Sole in the Puget Sound [the previous unit], that was good. This project with growing seeds is not great.

Student 2: I like developing explanations for one big thing.

Student 3: Yeah, that was way better, the local problem we worked on. Who cares about plants from Wisconsin?

Student 4: Hands-on is good, yes, but hands-on with stuff we have outside. These seeds [“Wisconsin fast grow” seeds] aren’t related to us.

This conversation marked an important learning moment for Joseph because it “solidified, for me, that students’ ideas and my instruction around Big Ideas should not be given a back seat to some curriculum (observation debrief).” Note that Joseph’s stance about primary resources became solidified – he marked the boundary between primary resources (students’ science ideas and core practices) and secondary resources (curriculum and administrative mandates).

Generative learning from daily changes to practice

After the global warming unit, Joseph, like Maria and Karen, used students’ science ideas in concert with primary resources to make daily changes to practice. On the first day of a unit about homeostasis, Joseph and his students predicted that a person’s body temperature would increase when exercising. However, during the activity to test this hypothesis, each student’s temperature decreased. After hearing his students theorize about this seemingly contradictory set of data from their original hypotheses, Joseph made this conundrum the focus of the unit. He also noted that he “purposefully did not look up the ‘correct’ answer because I wanted to theorize authentically with students” (observation debrief). Note that Joseph did not “know” the answer as to why temperature decreased. Instead he decided to learn about the science with his students. Like Maria and Karen, Joseph’s students ultimately shaped his pedagogical decisions as he revisited and recast the homeostasis unit.

Joseph’s final unit: The result of generative learning with resources

By the end of the school year, Joseph's work of enacting his vision of a collaborative scientific community resulted in a neuroscience unit that would likely not have been possible at the beginning of the year. Like Maria and Karen, Joseph provided himself with opportunities to hear students' science ideas and to subsequently learn from practice and create units in which students engaged in authentic science work.

Joseph's final unit leveraged students' interest in learning about how the brain controls cognition. Joseph selected a puzzling phenomenon in which a scientist waved a "magic wand" over people's heads, and subsequently, the individuals could no longer count coherently from 1-30. By this point in the year, students were prepared for authentic science work – like Maria and Karen's students, they understood Joseph's participatory expectations. During my observation, students generated and revised a model of how the brain works, and engaged in a whole class discussion around theories about puzzling phenomenon. Note that, like Maria and Karen, Joseph's neuroscience unit emerged from his generative learning using students' science ideas as the core resource.

Rebecca's planning with students in mind

Like Maria, Karen, and Joseph, Rebecca used primary and secondary resources in concert with students' science ideas to learn from and shape practice. However, her learning became more aligned with the school's conservative expectations over the course of the school year.

Two aspects of Rebecca's case emerged during observations that bear mentioning because they influenced how she used resources as a frame to shape and learn from practice. First, Rebecca's department and school preached an increase in test scores, and to achieve this goal, they asked teachers to help students recall "correct information" faster (observation debrief). Second, Rebecca interpreted the contextual press for fast and correct answers as a

mandate to publically praise students' "correct" answers during whole class discussions. This aligned with her desire to "make a community in which students feel comfortable participating verbally in class (planning session)." Note that Rebecca's planned classroom environment differed from Maria's, Karen's, and Joseph's community vision – she did not focus on students' scientific reasoning; rather, Rebecca wanted to create a space in which students participate as long as they recited "correct" answers.

Using students' ideas as resources early and often

I observed Rebecca navigate the tensions of how resources should be used to shape and learn from practice from the beginning of the school year. In October, Rebecca and her department planned a unit about why cells shrink in salt water, a puzzling question that appeared in the textbook. Rebecca tried to "incorporate both methods class ideas (a puzzling phenomenon) and school expectations (using the textbook to pick the actual question)" (observation debrief). Note that Rebecca planned to use both the methods class conceptual framework for practice as well as her school's conservative expectations in a unit.

During my observation of her unit about osmosis, Rebecca provided students with opportunities to share science ideas; however, she placed great emphasis on students answering questions "correctly (observation notes)." In this class, students watched a video of a plant cell shrinking in water, and then worked in small groups to review facts stated in the film. Rebecca walked around to each table, and stayed until a student produced the correct answer. When a student recited the answer, Rebecca told them they were correct and then left the table. However, if a student had difficulty, she focused their thinking to "correct answers." For example:

Rebecca: What do you mean here? [looking at student paper]

Student: It's hypertonic.

Rebecca: So if you have four free water molecules inside a cell, talk in terms of inside versus outside.

Student: The water leaves the cell.

Rebecca: But before. What happens? What are we adding to the outside of the cell?

Student: Salt water.

Rebecca: So now show me that there is more salt water outside of the cell. There is less free water initially, but there is lots of free water inside the cell [leaves] (observation notes).

Note how Rebecca worked to “fill in gaps” in student thinking when they responded to her questions with “sentence fragments” during small group conversations (observation debrief). During the class period, Rebecca’s emphasis on “correct” answers limited her opportunities to hear students’ scientific reasoning.

After Rebecca circled around the room and heard from each group, she announced, “Ok, we can move on because everyone sounds like they understand the facts (observation notes).” Note that students’ ideas shaped Rebecca’s instruction – she made an instructional decisions to “move on” based students’ ideas and other primary resources (the curriculum and department norms).

Daily learning shaped by conservative instructional expectations

When I observed Rebecca’s genetics unit, she continued to use students’ science ideas in concert with her primary resources to shape her practice. Rebecca’s instructional decisions, however, resulted in opportunities for students to only share “correct” ideas, and during this unit, students began to speak less in class if they did not know the “right” answer.

On the first day of the unit, Rebecca asked her students to “theorize about why some twins look similar and some look different (observation notes).” The students discussed their ideas with a partner, a practice Rebecca implemented at the beginning of the school year because “I found that they [students] are more willing to share out ideas with the whole class after they have talked it over with a partner. I also get a chance to overhear what students are thinking- especially the ones I know will not want to speak up in front of the large class (observation debrief).” Note that Rebecca provided herself opportunities to hear student thinking, and that she attempted to increase student participation in order to hear more ideas.

Next, Rebecca used a face-to-face tool for the first, and only time, during the school year. After talking in small groups, students inscribed their initial ideas on sticky notes and placed the notes on a poster. Rebecca enacted this routine based on methods class ideas and her department’s expectation to get students “participating” in class. After class, Rebecca used students’ inscribed ideas to assess the “correctness” of their thinking. In reflection, she noted “I saw that a lot of students who typically struggle with most material seemed to really get it today! I’m hopeful that that continues (observation debrief).” Rebecca decided that her students could move on to the next curriculum topic based on her analysis of their thinking; note again that Rebecca made consequential instructional decisions based on students’ ideas.

In the next class, Rebecca continued to navigate the use her school-based resources and students’ science ideas to shape practice. Rebecca delivered a 20-minute Power Point presentation that culminated in the definitions of genes, DNA, and alleles. After this lecture, students completed an activity – the inventory of traits – that asked students to answer questions such as “Do I have a widow’s peak, attached earlobes” and other physical traits (observation notes). This was a confirmatory activity according to Rebecca – “I wanted to see if they

understood the terms (observation debrief).” During her reflection, Rebecca noted that her students needed more practice with linking “traits” to meiosis, so she decided to spend one more day “reviewing” traits (observation debrief). Again, note that Rebecca used students’ ideas – their “correct” or “incorrect” answers to questions – to determine her actions for the next class.

After a day more of reviewing traits and alleles, Rebecca knew that her curriculum and department wanted her to move on to Punnett squares – an example of how her primary resources shaped her actions. She felt pressure to get through the content, and lectured for 50 minutes using a Power Point presentation prepared by her department chair, choosing multimedia as the content delivery tool because “the Power Point provided a fast way to go through the steps of making a Punnett square and allowed students to take notes about this process so they will be able to make Punnett squares themselves. It also gave them [students] the chance to practice making Punnett squares (observation debrief).” At the end of class, Rebecca saved enough time for example problems with fictional characters – Harry Potter and Sponge Bob. She chose those two characters because students had heard of them, and therefore, the characters are “relevant” to students’ lives: “I picked Harry Potter traits because I was pretty excited about them, and I thought that students could relate to those better than other random traits I chose (observation debrief).” Note that Rebecca incorporated ideas from the methods class instructional framework (using students’ lived experiences), yet how she used interpreted the practice of leveraging students’ lives was shaped by her school’s conservative instructional expectations.

Rebecca continued with Punnett squares for two days because students had difficulty setting up the problems (placing alleles along the outside of the “boxes” to cross). On the third day of Punnett square practice, a moment emerged for Rebecca to deviate from her typical

practice by using a student's idea to reshape her lesson and unit. While all of the students' questions up to this point in the unit concerned clarification of instructions, repeating facts, and inquires about the impending summative assessment (i.e., "will alleles be on the test?"), Nick, a student, asked the first substantive question of the unit about Punnett squares. Rebecca explained to students that scientists use Punnett squares to calculate the likelihood of one child having particular allele combinations from their parents. Nick, however, thought otherwise:

Nick: Punnett squares have four little squares, so that means four kids.

Rebecca: Go on.

Nick: So what about if there are five kids? Where does the fifth kid go?

Rebecca: Great question Nick. We'll get to it next week.

In this class, Rebecca had an opportunity to unpack Nick's idea and to help him, and the class, better understand Punnett squares – to use his idea to shape practice based on students' disciplinary thinking, the core of generative learning. However, she acknowledged the question and then dismissed it to "next week", a nebulous term that Rebecca used when she did not immediately answer a question in class.

By the end of the unit, the students no longer spoke unless called on by Rebecca. During the final lesson, Rebecca enacted another department mandate – a lesson designed by a curriculum company about epigenetics. The students watched a Nova[®] video about epigenetics in which a journalist interviewed scientists about their work, and the scientists answered with strings of complicated jargon. Students attempted to complete fill-in-blank questions on a worksheet, and when class ended, they left rapidly. Rebecca acknowledged the difficulty of the topic and was grateful for the video: "I thought the NOVA[®] video provided an understandable and interesting explanation of epigenetics through the concept of twins, which students had just

read an article about” (observation debrief). Note that Rebecca seemed satisfied with her lesson, and the unit, as she used resources to shape her practice that aligned with her school’s conservative instructional expectations.

Rebecca’s final unit: The result of learning shaped by conservative instructional expectations

By the end of the school year, Rebecca used students’ science ideas and other primary resources to plan a unit in which students rarely, if ever, had opportunities to engage in science practice. Rebecca planned her final unit with Maria because both were the same cougar/rabbit food web unit simultaneously. While Maria relied on students’ ideas to continually shape the unit, Rebecca’s students no longer uttered any sentence except “correct” answers to questions. During my observation, Rebecca began a “concept check”, placing a chart with vocabulary terms that students needed to copy down in their notebooks along with the a canonical definition. During this activity, students remained silent unless called on by Rebecca.

When reflecting on the year, Rebecca spoke about her students’ inability to “do” science. She wondered why students seemed “bored” during her class, reasoning that next year “I need to make the Power Points and lectures more engaging (final interview).” She concluded, ““the next time I teach this unit [about ecology], I will be sure to emphasize the fact that even maladaptive traits remain in a population after natural selection has taken place. This will hopefully combat the student idea that evolution happens neatly or simply or with a particular goal in mind” (CFG notes). Note that at the end of the school year, Rebecca began to think that students’ ideas were not only “incorrect”, but that they must be “combated.” While Rebecca’s used the same set of resources as Maria, Joseph, and Karen, how she used the resources, and how her school context told her resources should be used, limited opportunities for generative learning.

Lucy's planning with students in mind

Like Rebecca, Lucy used primary and secondary resources in concert with students' science ideas, and initially, her practice aligned with her school's conservative instructional expectations. However, Lucy is unique because in the middle of the school year, she decided to try out more ambitious forms of teaching. However, *Lucy did not fully consider how she would have to use resources differently to try out and learn from ambitious practice.* Lucy's attempts at ambitious practice resulted in confusion for her and the students as she tried use resources differently than she had previously done all year.

At the beginning of the school year, Lucy planned much like Rebecca. She placed high priority on school-based resources, such as her curriculum, textbook, and department, which she credited to her "lack of content knowledge" (planning session). As a biology major now teaching ninth grade physical science (physics and chemistry), Lucy thought that she did not know enough about those sciences to enact ambitious practice – she did not know of any puzzling phenomena, she did not understand *why* phenomena happened as they did, and she feared not knowing the answers to students' questions (planning session).

Her school department had a wealth of experience, activities, and lectures already planned – Lucy was the first new science teacher hired in five years. Since the department was cohesive in sharing ideas, tips, and strategies, they achieved high test scores. Lucy was expected to "continue this trend (planning session)." Like Rebecca, Lucy also wanted to establish a classroom "community" in which "students felt safe to talk about science" (planning session). She felt that she needed to hear students' ideas in order to help them "fill in the gaps of their thinking (planning session)." Note that Lucy placed students' science ideas as a core resource for

her practice. She wanted to establish a community in which students felt safe to participate and so that she could help them learn science by “fixing” their ideas.

Using students’ ideas as resources early and often

During her first unit, Lucy used students’ science ideas in concert with her primary resources to shape practice. Lucy purposefully asked students many questions in order to “gauge their understanding” of the topic - valence electrons (observation debrief). Like Rebecca, Lucy wanted to gather information about students’ understanding before making the decision to move on to the next curriculum topic. In this lesson, Lucy felt “rushed to get through information because we have to move on”, so she elicited student thinking and then “filled in” correct answers when students did not state such responses publically (observation notes). For example, during a whole class discussion, Lucy elicited a student’s idea and then completed a their answer:

Lucy: Student 1, how could Beryllium become a neutral atom?

Student 1: It needs the same stuff.

Lucy: Why?

Student 1: The positive and negative charge cancel out.

Lucy: Right. So Beryllium has a plus two charge and needs a negative two to cancel out and be neutral. So yes, it has 2 valence electrons, and needs two more.

In this example, which Lucy repeated many times in the lesson, Lucy quickly assessed student thinking, and provided the “correct” answer based on what she heard. Thus Lucy’s practice reflected the pull of her core resource, students’ science ideas, and her primary school-based resources (e.g., the curriculum).

Daily learning shaped by conservative instructional expectations

During my daily observations, Lucy expressed interest in changing her practice because she was “inspired” by the February Critical Friends’ Group and seeing her peers providing students with opportunities to “do science” (observation debrief). However, Lucy did not fully consider how she would have to use resources differently to try out and learn from ambitious practice. For example, in her unit about forces, Lucy tried to use the conceptual framework for instruction from methods class, selecting a puzzling phenomenon (a gymnast’s vault) for students to explain. However, Lucy had not yet attempted this practice. When she planned the explanation for students to construct, she faced tensions between having students “fully explain the gymnast and completing the learning objectives that my department wanted me to teach (observation debrief).” Lucy reconciled this tension by including every topic about forces from her textbook (including 40 science terms) in the causal explanation. Note that Lucy, while attempting to use resources differently, ultimately reverted to her school’s instructional expectations.

Lucy began the unit by showing a video of a gymnast vaulting at the Olympic trials, and students recorded observations of where they thought forces acted on the gymnast. Then students worked in small groups to create initial models – their first time all year using a face-to-face tool. Students were confused at first, asking questions such as “do you want the correct answer or not (observation notes)?” Lucy offered conflicting answers to such inquiries, sometimes answering “No, I want to see your thinking”, while other instances telling students “I want to make sure you do understand what’s covered on the test (observation notes).” Note that Lucy tried to use the suite of methods-based and school-based resources in concert with student thinking

One line of thinking that emerged from student conversations concerned gravity’s effect on the rotation and landing of the gymnast, a topic that Lucy “did not think students would talk

about (observation debrief).” While she felt conflicted about how to use students’ gravity ideas, Lucy felt “lucky because students brought up gravity at a time when we have to do the egg drop lab” (observation debrief). The egg drop lab was a department tradition, typically used by physics teachers when studying force and motion. Lucy had access to the materials and received tips from her colleagues about how to enact the lab. However, Lucy again faced tensions about how to use the egg drop lab materials from an ambitious practice framework. Given the logistical challenges of the three-day lab, Lucy reverted to more conservative forms of practice in order to “get the materials back to the teachers on time” (observation debrief). Thus, Lucy again decided to prioritize school-based resources as a driving factor in how she used students’ science ideas. While students enjoyed creating landing pads to minimize the egg’s force of impact when dropped from 20 meters, Lucy and her students spent three days on this activity without connecting egg drop ideas to the original gymnast phenomenon.

After several more department-mandated activities (yanking a tablecloth out from under dishes and crashing toy cars together), Lucy noticed that neither she, nor her students, made connections between the events and the original gymnast phenomenon. Lucy did not consider how to use the school-based resources with the methods-based resources; rather, she “assumed students would make the connections” (observation debrief). Note that Lucy continued to enact department activities while still expressing a desire to try out more ambitious forms of practice.

As the unit entered its last day, Lucy decided to revisit the gymnast, asking students to revise their original small group models. Again, students “confused because I [Lucy] did not really tell them how to revise the models and they kept wanting to put the right answers on the paper” (observation debrief). Note that students’ “confusion” stemmed from Lucy’s dual expectations for student participation in the community – during most of the unit, Lucy expected

students to produce correct answers. During the modeling days, Lucy wanted students to create explanatory representations of the gymnast. However, Lucy continued to make such instructional decisions because she thought she helped students “better participate in the class community” (observation debrief).

Lucy’s final unit: The result of learning shaped by competing instructional expectations

For her final unit, Lucy’s curriculum directed her to teach about sound. In this unit, Lucy continued to find a “balance between school norms and methods ideas” (observation debrief). While Lucy debated internally about how to use resources to shape her instruction teach, her actions continued to reflect her school’s conservative expectations.

For this unit, Lucy again chose a puzzling phenomenon – why tuning forks make water splash. When I observed her class, Lucy attempted to use another face-to-face tool, a summary table, which she saw a peer bring to a Critical Friends’ Group. Lucy’s students, however, were again confused because they wondered if Lucy was still searching for “the right answers” (student comment, observation notes). Much like the gymnast unit, Lucy offered conflicting responses to student questions, sometimes requesting that they “provide more factual information”, and other times telling students to “really theorize about the topic” (observation notes). At the end of the lesson, Lucy summarized what students “should have learned” from the day’s activity. Note that Lucy allowed students to discuss their science ideas, but by the end of class, decided to “fix” their “misconceptions”, illuminating the pull of her department’s instructional expectations for how to use students’ science ideas.

When reflecting on the year, Lucy noted the influence of her methods class peers in Critical Friends’ Groups to try and reprioritize *how* she used various resources to learn from and shape practice. She noted that “I wanted my students to share ideas better, but I don’t think I

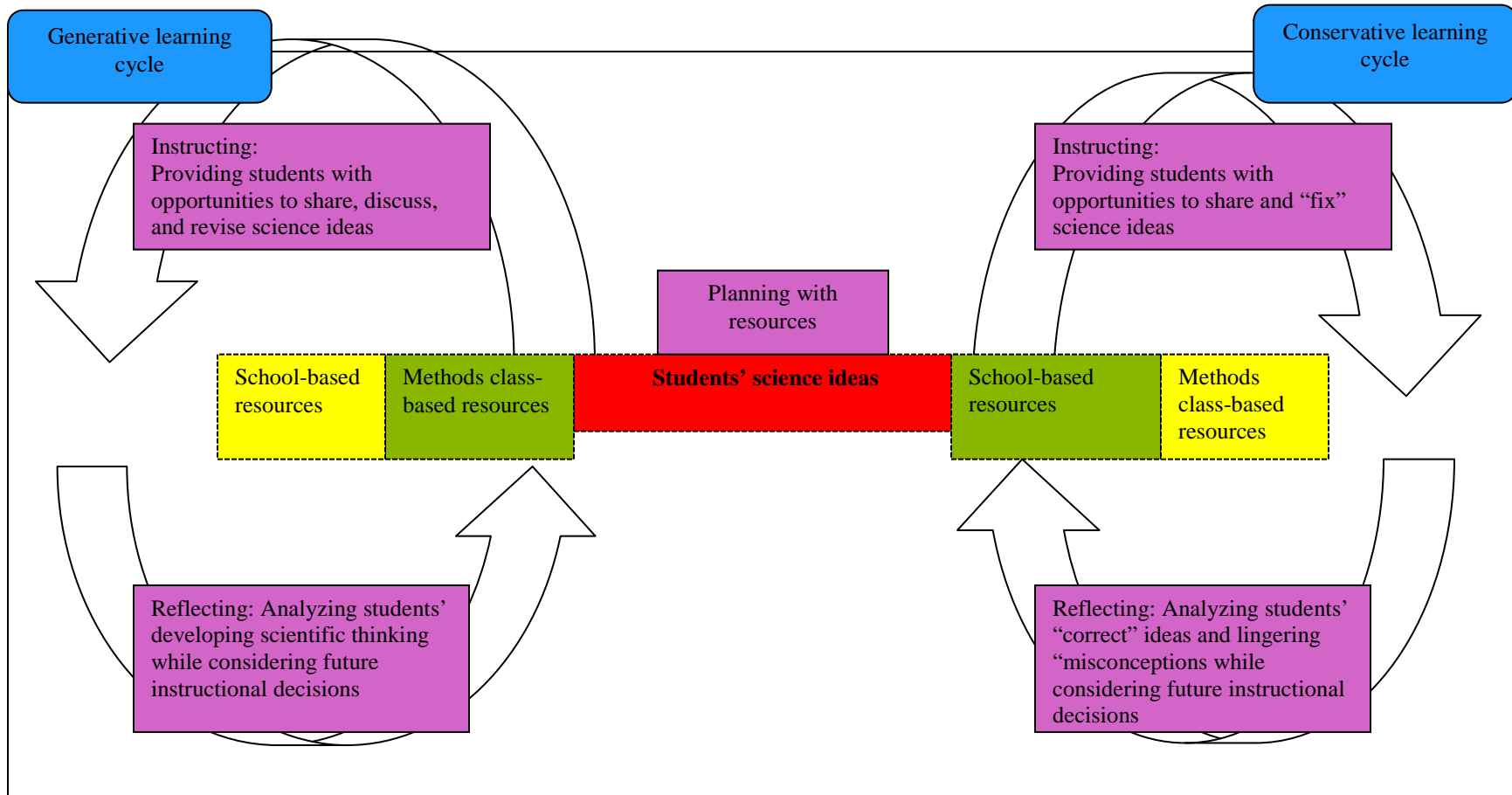
gave them enough chances to share out” (final interview). Note Lucy recognized that she needed to provide herself with different kinds of opportunities to hear students’ ideas, which she observed through her peers’ practice stories at Critical Friends’ Groups. However, she expressed frustration that her department did not support her efforts at ambitious practice because “it takes too much time” (final interview). Ultimately Lucy, like Rebecca used resources to limit her opportunities for generative learning.

Learning cycles

How the participants used students’ ideas in concert with other primary and secondary resources in their school context shaped their learning over time. By using students’ ideas in concert with a subset of resources when engaged in pedagogical reasoning and practice, the participants opened up opportunities for their own learning by becoming familiar with the breadth and depth of students’ disciplinary thinking. These cycles of learning – planning, instructing, and reflecting through the lens of student thinking throughout the school year – allowed the participants to see how student thinking was influenced by an array of instructional moves, substantiating or disconfirming elements of their critical discourses. As the participants’ prioritized resources and used them to learn from and shape practice, they initiated and continued cycles of learning as they saw the results of their professional work on a daily basis (see Figure 2).

Figure 2.

Participants' learning Cycles



These cycles occur over a few days – over the course of the year, what the three participants learned in a generative cycle was much different than what those on conservative cycles learned. Each learning cycle involved using students' science ideas as the core resource for shaping practice. Each teacher used students ideas with other primary resources – in green – with secondary resources – in yellow – exerting less influence on reasoning and practice.

Participants in generative cycles presented themselves with opportunities to learn from practice that did not become available to teachers conservative cycles because of how resources were used differently over time. Maria, Karen, and Joseph used their primary resources to plan opportunities to publicize student thinking and engage them in legitimate science work – in other words, they used resources to plan for, enact, and learn from ambitious practice. When this happened in class, the participants pressed and probed student thinking to unearth their ideas. During reflection teachers interrogated their own understanding of subject matter and pedagogy based on students’ ideas. They revised their plans, recasting their unit to be more relevant to students’ lives and interests, sometimes scrapping entirely what they intended to do. The more opportunities the participants provided students to share their science ideas, the better instructional decisions the participants could make to meet students’ intellectual and pedagogical needs.

Maria, Karen, and Joseph also stand apart from Rebecca and Lucy because of how they used secondary resources as exemplars of decisions *not* to enact as a teacher. Karen, for example, spent planning time at the beginning of the school year “getting rid of activities that have no purpose”, yet were seen by her department as valuable in previous years (Karen, initial interview). She also noted “It’s [the textbook] so bad. It makes no sense. I’ve tried. I’ve looked and I’ve read through it because a lot of times what I’ll do is I’ll use a reading from either...from a textbook I’ll adapt it or I’ll type up parts of it or I’ll photocopy parts and I haven’t used anything. I’ve tried to use stuff from it. It’s so bad” (planning session). Maria noted that while her school and department provided structure to what they should teach, the required curriculum had too many “throwaway days” that focused on preparation for standardized testing (Maria, observation debrief). Therefore, she chose to use the school’s curriculum as a frame *what* she

should teach, but not *how* she should enact instructional practices. Joseph was more blunt: “If I look at a textbook and see that’s how they think I should teach, I know I need to do something very different” (observation debrief). The primary resources, then, provided support for the Maria, Joseph, and Karen *not readily available from the school’s resources* to enact their ambitious vision of practice.

Participants on conservative learning cycles – Rebecca and Lucy – already felt constrained by curriculum and expected pace of instruction – they planned to “cover” a certain amount of information in a day and then to move on to the next required information. Rebecca and Lucy also funneled student thinking to “correct answers.” They compared students’ ideas with canonical ideas to see where students have misconceptions. They juggled the balance of “reteaching” and keeping the pace of the curriculum. If students had too many misconceptions, they spent part of the next class fixing their ideas. Over time enacting routines focused on getting students to produce correct answers reduces opportunities to hear students’ science ideas over time because such routines become more entrenched.

Note that Rebecca and Lucy both described their schools’ and departments’ established history of success with student learning. As new teachers, Rebecca and Lucy wanted to limit tensions between expectations from methods class about how to use resources and their schools’ constant press for improving student test scores (observation debriefs). Rebecca and Lucy saw their secondary resources – peers’ experiences and stories, practice-based ideas from secondary science methods, and tools – as providing an “ideal goal for instruction” at some future point in their career, but not feasible given current instructional expectations at school.

Discussion

How and why participants used resources to shape and learn from practice differently over time involves interconnected elements of their pedagogical reasoning, critical discourses, and context. First, I discuss how teachers in generative learning cycles recognized “points of departure” from the conservative forms of practice promoted by their school – moments during planning, instructing, and reflecting in which they made consequential instructional decisions about students’ participation in authentic science practice. Over time these decisions provided different learning opportunities for the students and participants. Second, I discuss *why* the participants made their particular instructional decisions using resources. Such an explanation involves their pedagogical reasoning and the mediation of their critical discourses with their school’s cultural script.

“Points of departure”

All of the participants in this study used the same suite of resources to shape and learn from practice. However, the participants prioritized different groups of resources, and by doing so, provided a frame for how to interact with students’ science ideas. By using a particular group of resources, the participants’ learning cycles became generative, the core of ambitious practice, or aligned with conservative forms of practice emphasized by their school. A question remains about why this is the case. One element of my explanation involves “points of departure”, moments during planning, instructing, and reflecting in which teachers enacting ambitious practice recognize and make consequential instructional decisions to scaffold students’ participation in disciplinary work that most teachers, enacting more conservative forms of instruction, might not make (Cobb, 2011).

In this study, the participants' recognition of "points of departure", and their subsequent actions, share two common features. First, Maria, Karen, and Joseph – the teachers engaged in generative learning cycles – used students' science ideas, and other primary resources, differently than Rebecca and Lucy, who frequently enacted conservative forms of practice. Maria, Karen, and Joseph recognized that using students' science ideas in concert with *their* primary resources afforded them opportunities to learn from practice that other conventional and social resources (textbook, curriculum, their department's instructional expectations) could not provide. For example, Maria's recast her roller coaster unit based on José and Anthony's ideas, and not because of textbook information or curricular pressure to "cover" topics. Rebecca and Lucy, while stating their interest in ambitious practice, did not reconcile their school's conservative expectations with the goals of ambitious teaching. They viewed students' science ideas as "misconceptions", and used *their* primary resources promoted by their school to "fix" errant thinking.

Participants' differing use of students' science ideas as resources aligns with Larkin's (2012) claim that teachers have difficulty in knowing what to do with students' ideas given the cacophony of discourses about how to leverage student thinking in science classrooms. Larkin found that teachers who treated students' ideas as resources for their learning, and who used ideas about instruction that aligned with ambitious practice, were more likely to use the resources together to shape instruction around students' needs as science learners. In such classrooms, students also used each other's ideas as resources for their learning. Conversely, Larkin found that teachers who viewed students' ideas as "misconceptions" used students' ideas as resources to know what to "fix" through better information delivery.

A second aspect of recognizing “points of departure” is that while all participants stated the importance of students’ science ideas as a resource to shape and learn from practice, *how they acted on* such recognition depended on their pedagogical reasoning. As Cochran-Smith and Lytle (1999) note, “If learning to think like a teacher is central to teacher knowledge, so is being able to act effectively on these insights” (p. 273). While Rebecca and Lucy “nominally” recognized students’ science ideas as resources, a foundational piece of ambitious practice, their subsequent actions and semi-structured interviews suggested that school context’s press for conservative instruction weighed heavily in their pedagogical reasoning.

As Horn (2007, 2010) noted, decisions teachers make changes the kinds of opportunities available for them to learn from practice. In this study, the participants’ varied reasoning with resources, particularly students’ science ideas, led to differing learning opportunities over time. As the year progressed, Maria, Karen, and Joseph provided students with more chances to engage in authentic disciplinary work because the participants noticed that such ambitious instruction opened up opportunities to hear students’ disciplinary reasoning. Rebecca and Lucy, however, *limited their opportunities to learn from students during their first unit of instruction* because they felt pressure from their school to enact conservative forms of teaching. Relative to Maria, Karen, and Joseph, as the year progressed in Rebecca and Lucy’s classrooms, students had fewer and fewer opportunities to engage in authentic disciplinary work. This perpetuation of conservative practice constantly constrained students’ participation to the point that by the end of the year, students rarely spoke and if they did, uttered brief “right” or “wrong” answers.

Maria, Karen, and Joseph provided themselves access to more sophisticated student thinking as they enacted ambitious practice. Rebecca and Lucy, however, limited their learning opportunities by privileging “correct answers” over time. Maria’s recognition of her ill-

conceived roller coaster model and subsequent charge to students to create a better model resulted in a greater number of students sharing ideas, such as José and Anthony. There were moments in Rebecca's class, such as Nick's question about Punnett squares, for her to use student ideas as a resource differently than assessing the correctness of it; however, she did not. This finding is supported by Coffey et al. (2011) who note that teachers can create opportunities to adapt instruction that they did not previously have when they gain access to students' ideas.

Critical discourses

Why three participants recognized "points of departure" involved the mediation of their critical discourses with their school's press for conservative practice. Each participant's learning was driven, in part, by students' science ideas. However, *why* participants wanted to hear students' science ideas differed. Teachers in generative learning cycles adapted instruction to better engage students in authentic science work. These instructional decisions emerged as Maria, Karen, and Joseph acted on their critical discourses around scaffolding students' participation in science practice, including their disciplinary reasoning, rather than view their ideas as "misconceptions" to "repair" (Franke et al., 2001). As Maria, Karen, and Joseph saw the results of their ambitious instruction framed around their critical discourses, they were able to both provide more opportunities to hear students' ideas, and deflect school pressures to teach using conservative practices.

Rebecca and Lucy also wanted to help students learn science, but their critical discourses were more focused on creating and maintaining safe classroom environments and helping students become better organized, and not on scaffolding students' participation in science practice. Their use of students' ideas as resources did not conflict with either their critical

discourses or their school's expectations. Rebecca's school, for example, encouraged her to increase student participation, which she felt was a successful aspect of her practice.

Conclusion

This study was an attempt to better understand how to better support beginning teacher learning through resources as they moved from a university-based program promoting ambitious practice to a school context that pressed for conservative forms of teaching. Specifically, I wanted to better understand how beginning teachers recognized and used the same set of resources, cited as important for their learning and practice, across contexts. In my study, the participants' differing use of the same resources provided them with varied opportunities to learn from and shape practice. I want to be clear that I do not ascribe the participants' use of resources solely to their pedagogical reasoning absent of context, or to individual "characteristics" such as beliefs, orientations, or dispositions. Each teacher made instructional decisions to enhance student learning as they constantly mediated messages about conservative forms of practice from their school context with the expectations for ambitious practice from their methods class community.

I end with three concluding ideas that I draw from my work with these participants. First, those supporting beginning teacher learning need to work across contexts, including schools during beginners' first years of instruction, to support ambitious practice with resources. One reason to support novices across contexts is that very different messages about how similar resources should be used exist in each setting (Gainsburg, 2012). Given the lack of coherence across contexts in this study, some participants felt supported to use resources to plan for and learn from ambitious practice while others did not. I argue that *if teacher educators want to*

provide resources to beginning teachers to support their learning of ambitious practice, the field needs to help them understand how to use the resources across contexts (Ensor, 2001).

A second concluding idea is about helping beginners understand how professionals enacting ambitious practice think about and “do” their work. As Kennedy (1999) notes, "How to develop what a teacher thinks is the 'stuff' of learning and the nature of teaching is one of the greatest dilemmas of teacher education" (p. 88). Left unanswered is a question about developing particular critical discourses related to ambitious practice – if teacher educators want beginning teachers to use resources in particular ways because doing so provides opportunities for generative learning and supporting ambitious practice, how can the field better prepare teachers for this thinking and action? Of equal importance is the issue of deflecting school pressure to maintain conservative forms of practice. How can teacher educators better prepare beginning teachers to uphold the professional standards of their school, learn from the valuable experiences of their colleagues in their school, and still push for ambitious instruction?

A final concluding idea is that I now think about my own learning as a teacher educator – my generative learning. How does my own understanding of teaching change as my methods students learn from practice? How do I make changes to methods classes, and a teacher preparation program, based on what I learn from my methods students? What kinds of resource support do they need to enact ambitious practice, and how I can adapt my own class to better support the next cohort of beginning teachers? Such questions help put the onus on teacher educators, rather than novice practitioners, for supporting the work of ambitious practice across contexts.

SECTION 2

Examining secondary science classrooms as epistemic communities fostering science-as-practice

Debates about the purpose of science teaching and learning in American K-12 schools stretch back over 100 years (Rudolph, 2002, 2005). Generally, the field of science education agrees that students should learn both conceptual information and methods of science (Abell, 2007; NRC, 2011). Recent literature expands expectations for students to learn *science-as-practice*, meaning that students, in addition to learning concepts and methods, should become legitimate participants in the social, epistemic, and material aspects of science (Duschl, 2008; Lehrer & Schauble, 2006).

Such learning goals, however, do not match students' experiences as science learners in most classrooms, particularly with regard to the roles they and their ideas play in the trajectory of instruction (NRC, 2007, 2011; Windschitl, Thompson, & Braaten, 2008). I argue that reframing learning expectations around participation in actual science practice requires that students take on a new role as *epistemic agents* – individuals or groups who take, or are granted, responsibility for knowledge production through their participation in science practice (Ahlstroms, 2010; Damsa, Kirschner, Andriessen, Erkens, & Sins, 2010; List & Pettit 2006; Pickering, 1995; Rupert 2005; Scardamalia, 2002; Tollefsen 2002, 2004).

Redefining the role of students as epistemic agents is challenging because most science instruction positions the teacher as the sole instructional and knowledge authority – the only epistemic agent in a classroom. As documented in large-scale observational studies of American classrooms, conservative science teaching limits opportunities for students to become epistemic agents by focusing on activity rather than sense making, rarely taking students' prior knowledge

into account during lessons, seldom pressing for evidence-based explanations, and treating students' ideas as incongruent with canonical science. In many classrooms, students' science ideas play no substantive role at all in instruction (Alexander et al., 2000; Banilower et al., 2006; Barton & Tan, 2009; Horizon Research International, 2003; Maskiewicz & Winters, 2012; Roth & Garnier, 2007; Weiss, et al., 2001; NRC, 2011).

I argue that the purpose of instruction is *not* for a teacher to “cover curriculum” or “fix” students' “misconceptions.” Instead teachers can help students' revise their science ideas over time and provide opportunities for them to participate in authentic science practice using all available resources. In this study, therefore, I examined a framework for science teaching and learning – referred to as *ambitious practice* – that differs from conservative science instruction. Teachers enacting ambitious instruction support students' learning across ethnic, racial, class, and gender categories while scaffolding their legitimate participation in science practices. In other words, teachers enacting ambitious practice take a stance that *anyone* can engage in authentic science work and view position students as epistemic agents in a science classroom context as part of their professional responsibility (Minstrell, 1982; Warren et al., 2001; Warren & Rosebery, 1995; Windschitl, Thompson, Braaten, & Stroupe, 2012).

Problem framing

Literature about ambitious practice makes a compelling case that teachers enacting such instruction can redefine and scaffold students' participation as epistemic agents in classroom spaces. However, two issues arise when trying to understand how this process unfolds. First, there are few studies in science education that examine ambitious practice as a framework for supporting students' learning science-as-practice. The second issue is that science as a discipline in the “real world” – unlike classroom spaces – rarely provides opportunities for those without

epistemic agency to gain access to the conceptual, epistemic, social, and material features of the practice. In other words, scientists who have, or take, the power to make and verify knowledge claims rarely grant such authority to others (Addelson, 1983; Longino, 1990; Pickering, 1995). Yet such a redistribution of power, and therefore epistemic agency, is embedded in ambitious science teaching and students' participation in science-as-practice.

Given the tensions and power struggles that can arise between teachers, students, and a school's historic conservative norms for instruction around "what counts" as science teaching and learning, I use literature from both science, technology, and society (STS) and the History and Philosophy of Science (HPS) to better understand the complexity of epistemic classroom activity over time. I use STS and HPS literature because such researchers often focus on issues of power and epistemic agency that are rarely explored in the field of science education.

Using STS and HPS literature, I frame classrooms as an *epistemic community* – a physical and conceptual space in which actors negotiate particular epistemologies – theories of what knowledge is, the standards of evidence for making knowledge claims, the questions that are legitimate to ask, and the limits of knowledge (Harding, 1991). An epistemic community includes the culture of science practice, the physical/spatial components of a context, the interactions between actors around science, and the materials used to engage in science investigations in order to understand what counts as knowledge and why (Longino, 1990).

In this study, I examined three aspects of an epistemic community that signal how teachers and students negotiate their roles in classroom science activity, and illuminate the science practice that emerges over time when students are positioned as epistemic agents (or not). One aspect was "*who knows*" – whether science practice was framed as a private enterprise engaged in by individuals, or if science was public practice continually constructed and

negotiated by a larger community. A second aspect was *cognitive authority* – the power granted to, or taken by, certain individuals to shape what was known and the work that was done (Addelson, 1983). A third aspect was the *geography of science ideas* – where science ideas originated, and how they traveled over time and through space. I selected these three aspects because they are connected through themes of power (who has authority and who does not) and the treatment of knowledge (as static “truth” or malleable theories and ideas).

I argue that the framework for instruction that shapes teachers’ practice – ambitious instruction or more conservative forms of teaching – influence classroom epistemic communities and students’ subsequent opportunities to act as epistemic agents. Therefore, framing classroom spaces as epistemic communities provides a novel lens into how and why students learn science-as-practice – the aim of ambitious instruction. If one purpose of ambitious instruction is to redefine students as epistemic agents, the field needs a better understanding of *how* using particular instructional routines and discursive moves support a different kind of science in classrooms. By utilizing lenses from STS and HPS literature that researchers apply to study how science is made and done in variety of settings, I hope to apply lessons and ideas to better understand what classroom science is and what it could be.

Research questions

Using the three features of epistemic communities as lenses and a situative theoretical framework, I conducted a multi-case study of five beginning teachers during their first year of teaching. Though teachers and students negotiated epistemic communities in all classrooms, I investigated how the science activity (conceptual, epistemic, social, and material aspects of the work) changed as teachers’ and students’ roles as participants evolved. Specifically, I asked:

- How is science framed as a “public” or “private” practice? Over time, how and why does the public or private framing of science influence actors’ (teachers, students) participation in the epistemic work in classroom spaces?
- How do teachers and students negotiate “what counts” as a science idea in classroom spaces? How is value assigned to science ideas and by whom?
- How do teachers and students work on science ideas over time given the kind of epistemic community they negotiate?

Background and conceptual framework

In this section, I describe how ambitious teaching could reframe science work in classrooms by positioning students as epistemic agents who negotiate “what counts” as science with their teacher. I begin by describing how Lehrer and Schauble (2006) framed science teaching and learning historically – science-as-logic, science-as-theory change, and science-as-practice, to which I add science-as-accumulated-knowledge. I next discuss how ambitious practice positions students to learn “science-as-practice” and give examples of such work in the CheChe Konnen project and Jim Minstrell’s classroom-based research. Finally, I frame my study around themes from STS and HPS literature on epistemic communities to explore epistemic agency in the epistemic communities of classroom spaces.

Relating “typical” frames of science learning to “typical” teaching

Science education literature contains diverse opinions about how science should be learned in classrooms (Chinn & Malhotra, 2002; Maskiewicz & Winters, 2012; NRC, 2011). In this section, I summarize how Lehrer and Schauble (2006) framed science teaching and learning historically – science-as-logic, science-as-theory change, and science-as-practice, to which I add science-as-accumulated-knowledge.

Classrooms framed around *science-as-logic* emphasize the role of scientific reasoning that can apply across disciplines, such as formal logic, heuristics, and thinking strategies. In this framing of science, evidence and disciplinary reasoning are independent from the context of theory – what scientists know and how they think are not dependent on any theoretical framework, but emerge from universal process of scientific reasoning. Research in science education pressing for science-as-logic in classrooms advocates for students to acquire strategies for coordinating theory and evidence, to identify and reason about experimental design, and to distinguish patterns of evidence that do and do not support a definitive conclusion (Chen & Klahr, 1999; Fay & Klahr, 1996).

Classrooms framed around *science-as-theory-change* embody Kuhn's (1962) theory of “scientific revolutions”, viewing students' learning as conceptual change (Carey, 1985a; Samarapungavan, 1992). A student's development of scientific reasoning is like Kuhn's theory of the development of scientific knowledge. For example, some scholars suggest that students' disciplinary knowledge evolves in ways that typically involve the gradual accretion of new facts, or, occasionally, the replacement of one idea by another (Carey, 1985b).

Classrooms framed around *science-as-accumulated-knowledge* invoke the ideals of natural philosophy in the 1700 and 1800s. During the Enlightenment, scientists collected, characterized, and categorized information about the natural world. By accumulating information, many people believed that “truths” about the natural world emerged as the sheer quantity of data was gathered and organized (Gould, 2002; Livingstone, 2003). In this framing of science learning, students memorize facts from canonical textbooks, whose authors pre-organized the information for public consumption.

I argue that most conservative science instruction framed around science-as-logic, science-as-theory-change, and science-as-accumulated-knowledge promote a vision of science in classrooms that does not align with actual science practice in the world. In these classrooms, students come to view science as linear process of “domain free” problem solving, and that their science ideas contain “misconceptions” that must be “corrected” through the passive accumulation of facts (Lehrer & Schauble 2006).

Such conditions provide a context for most current science teaching, the primary activity of which is a teacher’s delivery of the “correct” canonical information to students (Papert, 1993; Sawyer, 2008). The outcome of instruction is for students to reproduce certain scientific work privileged by the teacher or other instructional authority (Cuevas, Lee, Hart, & Deaktor, 2005; Driver, Newton, & Osborne, 2000; Reveles, Cordova, & Kelly, 2004). In these epistemically conservative classrooms, the implicit assumption is that the ways in which students make sense of the world do not align with canonical science norms, and can subsequently impede their science learning (see Ball & Cohen, 1999; Barton & Tan, 2009; Costa, 1995; Maskiewicz & Winters; Warren & Rosebery, 1995). Therefore, teachers often implicitly or explicitly limit the role of student thinking in classroom science practice.

Conservative science instruction limits students’ learning opportunities in three areas. First, many students rarely participate in authentic forms of scientific practice, though they are presented with wisps of science work in the form of process skills. For example, Weiss, Pasley, Smith, Banilower, and Heck (2003) used a nationally representative sample of 31 middle schools in the United States to categorize dimensions of instruction such as engaging students, creating learning environments, and helping students make sense of science ideas. They found that teachers rarely provided students with opportunities to learn science practice, instead treating

science as a collection of known facts and procedures. Abrahams and Reiss (2012) report similar findings in United Kingdom schools.

The second way that conservative forms of instruction limit students' science learning opportunities is that few teachers in American classrooms help students link science processes to conceptual ideas. For example, Pasley (2002) found that teachers rarely helped students make connections between the data they had collected in classroom investigations and how such information fit into the larger ideas of a unit. In a later study, Roth, et al. (2006) analyzed TIMSS (Third International Mathematics and Science Survey) videos and found that almost one-third of U.S. lessons promoted students' engagement in activities without making connections to science ideas.

The third way that conservative forms of instruction limit students' opportunities for science learning is that teachers explicitly or implicitly position students as blank slates waiting to absorb information, rather than as intellectuals capable of sophisticated scientific reasoning. For example, Weiss et al. (2003) found that teachers frequently asked students low-level "recall" questions and expected students to quickly reply with the "correct" answer. In a different study, Bowes and Banilower (2004) analyzed lessons from classrooms and found that fewer than half of the lessons had high-level questioning and sense-making talk as a prominent feature of instruction.

Ambitious teaching and science-as-practice

Unlike conservative forms of instruction, ambitious practice redefines "what counts" as skilled practice by helping students revise their own scientific thinking over time. By prioritizing students' disciplinary reasoning in a classroom space, teachers enacting ambitious instruction aim to position students as legitimate participants in science. I argue positioning students as

legitimate participants in science redefines their roles as *epistemic agents* – individuals or groups who take, or are granted, responsibility for knowledge production and disciplinary work (Ahlstroms, 2010; Damsa, Kirschner, Andriessen, Erkens, & Sins, 2010; List & Pettit 2006; Pickering, 1995; Rupert 2005; Scardamalia, 2002; Tollefsen 2002; 2004). As students become legitimate participants in the science practice of their classroom epistemic community – taking and using their epistemic agency –they move away from science-as-logic, science-as-theory-change, and science-as-accumulated-knowledge, and to learning *science-as-practice*.

The science-as-practice framing emerged from Lehrer and Schauble (2006), Duschl (2008), STS, and HPS literature that feature studies of how and why scientists learn and engage in their practice. Such studies describe four dimensions of disciplinary work that newcomers to science learn in a context:

- A conceptual dimension: how theories, principles, laws, ideas are used by actors to reason with and about,
- A social dimension: how actors agree on norms and routines for handling, developing, critiquing and using ideas,
- An epistemic dimension: The philosophical basis by which actors decide what they know and why they are convinced they know it,
- A material dimension: How actors create, adapt, and use tools, technologies, inscriptions and other resources to support the intellectual work of the practice (Pickering, 1995).

These four dimensions of scientific work suggest that scientific knowledge and reasoning are components of a larger network of activity that includes specialized discourse, historical norms for participation, and is influenced by social, political, and cultural aspects of a context

(Bazerman, 1988; Gooding, 1989; Hankinson-Nelson, 1990; Knorr-Cetina, 1999; Latour, 1999 Longino, 1990).

While studies of classrooms framed around science-as-practice are rare in science education literature, two examples stand out. First, Minstrell (1982) conducted a series of self-studies in which he examined how student thinking became more sophisticated as he provided them with opportunities to publically test and revise their ideas. Second, the Chèche Konnen Project framed science classroom communities as places where students' intellectual, cultural, and linguistic resources shape the class' scientific inquiry into local questions and phenomena (Warren & Rosebery, 1995). Their findings suggest that:

- As teachers and students gain a sense of self as someone who can do science, they are more likely to try actual science in classrooms (Warren & Rosebery, 1995);
- Teachers who see students everyday argumentation and explanation discourses as scientific reasoning “admit” this kind of talk in classrooms as valid science talk, and try to structure instruction around students' everyday talk (Ballenger, 1997);
- Teachers learn to orchestrate scientific sense-making in the classroom by thinking through scientific practice and linking how to know in science to teaching and learning (Warren & Rosebery, 1995);
- Science teachers' pedagogical development is associated with their identity development as scientists (Rosebery & Puttick, 1998; Warren & Rosebery, 1995);
- As teachers develop a scientist identity, they can better facilitate scientific practice and reasoning in their classrooms (Rosebery & Puttick, 1998);
- When students' everyday ideas and experiences are positioned as central to instruction, they engage scientific reasoning and practice (Warren et al., 2001).

While Minstrell's study and the CheChe Konnen project tell the story of science-as-practice, they do not describe the teacher's underlying pedagogical moves in helping to redefine students' roles as epistemic agents. In other words, Minstrell's study and the CheChe Konnen illustrate the epistemic communities that became possible when students took on the role of epistemic agents. However, these studies show the epistemic communities as established structures. In this study, one of my aims is to show how and why teachers enacting ambitious practice help establish and maintain communities in which students act as epistemic agents.

STS and HPS lenses into classroom science practice

Studying how teachers and students participate in classroom science activity requires lenses from STS and HPS literature because such research focuses on how and why science practice develops in epistemic communities. An epistemic community is a physical and conceptual space in which people advance particular epistemology - theories "what counts" as knowledge about the natural world and the processes of generating knowledge (Haraway, 1988, 1991; Harding, 1991; 1993; Knorr-Cetina, 1999; Latour, 1987; Livingstone, 2003; Ochs, Jacoby, & Gonzales, 1996; Owens, 1985). Studying epistemic communities can focus on both physical aspects (e.g., the tangible artifacts, the layout of the room, and the ways in which the objects in a space shape actors' interactions) and conceptual aspects (e.g., how and why actors discuss ideas and explanations for natural phenomena) (Foucault, 1984; Harding, 1991, 1993; Haraway, 1988; Harkness, 2007; Knorr-Cetina, 1999; Latour, 1987, 1999; Livingstone, 2003; Ochs et al., 1996; Shapin, 1988; Smith and Agar, 1998). STS and HPS literature also notes that science practice is negotiated between actors rather than existing as an undisturbed and unaffected by the values and interests of its context. By negotiated, I mean that *while individuals learn what counts as science in a context, they can, in turn, influence science practice over time based on their experiences*

and expectations for disciplinary work (Addelson, 1983; Hankinson-Nelson, 1990; Longiono, 1990).

While STS and HPS lenses are useful tools for studying science practice in the “real” world, such studies rarely include science classrooms in K-12 schools as spaces for authentic science activity. Since ambitious practice and conservative forms of instruction promote different visions of science, understanding how science work is done in physical and conceptual spaces could help explain why science activity differs across classrooms. In this study, I use three features of epistemic communities from STS and HPS literature to analyze science classrooms: cognitive authority, the geography of science ideas, and “who knows.” All three of these aspects relate to teaching practice because they provide unique lenses into instructional assumptions teachers and students make about power and knowledge in classrooms – who has the authority to make and work on knowledge, what happens to science ideas over time, and whether science is framed as a “public” enterprise engaged in by individuals or is a “public” practice negotiated by a larger community.

Cognitive authority

While science is generally thought of as independent of people’s biases, some STS and HPS scholars argue that *who* is theorizing matters for what is known (Hankinson Nelson, 1990). As a society, certain people have, or are granted, *cognitive authority* – their understanding of factual matters and the nature of the world becomes “expert” knowledge (Addelson, 1983). Granting cognitive authority to some individuals implies a division of cognitive labor exists in which those with such authority get to “certify” and communicate knowledge, and those without authority are assigned the tasks and work that those with power deem necessary. These divisions in cognitive labor result in a hierarchy in which those without cognitive authority are

placed in *less powerful* positions. Addelson (1983) suggests that such divisions in power *have a bearing on how and what knowledge develops within science communities and how that knowledge is communicated to and received by the society at large*. In classrooms, cognitive authority is also distributed between teachers and students. In conservative science classrooms, teachers could maintain their status as cognitive authority over students. In ambitious classrooms, however, the division of cognitive labor could be different, since students' science ideas are central to the science activity.

Geography of science ideas

A second aspect of epistemic communities to consider is the *geography of science ideas* – how and why ideas emerge, travel, and have a particular fate that is determined by individuals and groups in a context (Livingstone, 2003). While analyzing the origin and movement of ideas is rare in education research (see Saxe, Gearhart, Shaughnessy, Earnest, Cremer, Sitabkhan, Platas, & Young, 2009; Windschitl, 2001 for examples of studies examining the movement of ideas), such analyses are common in STS and HPS literature. In a famous example Latour (1987) discussed how powerful groups of scientists and politicians construct “centers of calculation”, in which they create instruments and instructions, outline experimental and data collection methods, and decide what questions researchers associated with the center will pursue. Even as explorers or lab technicians physically leave the center to work in a peripheral location, the authorities in the center dictate the science practices they engage in through the pre-established methods, instruments, and ideas (Haraway, 1988, 1991; Latour, 1987). Any data collected and science ideas constructed on the periphery cannot become canonical knowledge until the authorities at the center of calculation process, interpret, and proclaim it true (Foucault, 1984; Latour, 1987).

To trace the geography of science ideas, researchers examine the questions that are deemed pertinent to answer, how data travels back to the those with cognitive authority, and where ideas and data are interpreted, verified and permitted for use in explanations (see Foucault, 1984; Hannaway, 1986; Harding, 1991; Rudolph 2002, 2005). In conservative classrooms, teachers could act as the center of calculation, positioning themselves as the subject matter authority, presiding over the interpretation of data while deciding pertinent questions for students to answer, and establishing the best answer to each question. In “ambitious” classrooms, however, how science ideas emerge and travel could differ from conservative classrooms because of the central role that students play in shaping the classroom science activity.

Who knows

The third aspect of epistemic communities I consider is *who knows* – whether an individual or community is considered to be the unit of “knowing.” Some researchers frame science as an individual enterprise in which lone scientists discover truths about the world (Hankinson-Nelson, 1990; Longino, 1990). This view of science positions individuals and their actions as independent of a contextual influence (Grene, 1985; Hankinson-Nelson, 1990; Longino, 1990). Other researchers, however, argue that individuals' ideas cannot, by themselves, have value until they are worked on by and with others. From this perspective, what individuals come to know and how they come to know it depends on their community's standards for practice. This public negotiation is more than vetting ideas and peer-review to seek the truth; science knowledge and practice shape, and are shaped by, public interactions of actors, tools, resources, and historical norms in a context (Longino, 1990). In “traditional” classrooms, teachers could position students as individual knowers, keeping the work of science private. In such classrooms, students' ideas remain hidden from other students. In “ambitious” classrooms,

however, the science work is likely public, since students' ideas shape the classroom activity. In such classrooms, students learn that their ideas have value as resources for the whole class, and that science knowledge emerges from work on the public plane.

Theoretical framework

I use situative theory to address the complexity of examining epistemic classroom communities. Situative theory posits that individuals learn through their participation in activity and interactions with actors, tools, and norms for participation in a context (Cobb, 2000; Fairbanks et al., 2010; Greeno, 2006; Peressini, Borko, Romagnano, Knuth, & Willis, 2004; Putnam & Borko, 2000; Sykes et al., 2010). For this study, a situative perspective frames my main unit of analysis – the activity in science classrooms. I examine the epistemic community, science practice, and changing epistemic roles that teachers and students negotiate over time.

Methods

Participants and context

In this multi-case study, I investigated five first-year teachers' learning during the 2011-2012 school year. Each participant holds a bachelor's degree in a science field and was a full-time secondary science teacher in the Pacific Northwest (See Table 2 for descriptions of the participants). All participants completed a master's degree in teaching from a large public university in the northwest United States, and during their time at the university, were students in the same secondary science methods class.

I first interacted with the participants as the teaching assistant for their secondary science teaching methods class. My duties included planning with the participants, observing their instruction during student teaching, and reflecting with them about their practice. Such interactions with the participants helped build rapport and trust (Merriam, 2009; Patton, 2003).

For this study, I selected participants based on two criteria: their practice history during methods class and student teaching, and their school context's instructional cultural scripts (the historic norms and messages about what counts as teaching and learning – see Sykes et al., 2010). I purposefully selected participants who demonstrated a range of practice histories during their secondary science methods class and student teaching – three of whom readily attempting ambitious practice, and two of whom typically enacted more typical forms of practice. I characterized the participants' initial practice histories based on artifacts (methods class assignments, and any student teaching-related documents such as lesson plans, assessments, and tools and scaffolds created by participants and their students), semi-structured interviews with participants about their methods class and internship experiences that occurred during another research project, classroom observations of participants' instruction, and observation debriefs.

I also selected participants based on their first year teaching contexts. I searched for schools whose cultural scripts focused on typical forms of teaching, which often included pressure to improve students' achievement on standardized tests. The ultimate purpose of both selection criteria was to help develop a theory of science-as-practice in classroom spaces, and not to generalize unproblematically to similar “populations” of teachers, students, and classrooms.

Table 2.

Description of Participants

Pseudonym and Education	First Year Teaching Assignment	Reasons for Selection in Study
Maria (BS in biology)	8 th grade general science in urban middle school	<ul style="list-style-type: none"> • History of planning for, enacting, and reflecting about ambitious practice during student teaching • Teaching some content (physics) outside of college major • First year teaching assignment different than student teaching assignment (high school biology)
Joseph (BS in chemistry)	Biology and algebra teacher at new project-based learning suburban high school	<ul style="list-style-type: none"> • History of planning for, enacting, and reflecting about ambitious practice during student teaching • Teaching content (biology) outside of college major • First year teaching assignment different than student teaching assignment (high school chemistry)
Karen (BS, MS, PhC. in biology)	Biology at urban high school	<ul style="list-style-type: none"> • History of planning for, enacting, and reflecting about ambitious practice during student teaching • Teaching content in college major (biology) • First year teaching assignment different than student teaching assignment (high school chemistry and physics)

Rebecca (BS in biology)	Biology at urban high school	<ul style="list-style-type: none"> • History of planning for, enacting, and reflecting about conservative instruction during student teaching • First year teaching assignment same as student teaching assignment (high school biology)
Lucy (BS in biology)	9 th grade physical science at suburban high school	<ul style="list-style-type: none"> • History of planning for, enacting, and reflecting about conservative instruction during student teaching • Teaching content (physics and chemistry) outside of college major • First year teaching assignment different than student teaching assignment (high school biology)

Participants' university-based science methods class

The participants' classroom epistemic communities cannot be understood without some background into their university-based science methods course. One goal of the secondary science methods class in promoting ambitious instruction was to frame-shift how the participants thought about organizing instruction, and to socialize them into new visions of "good teaching." This socialization included scaffolding the participants' attempts at creating a classroom space in which students could learn science-as-practice.

I also helped organize the class around four practices considered to be central to ambitious teaching: constructing the "Big Idea", eliciting students' ideas to adapt instruction, helping students make sense of material activity, and pressing students for evidence-based explanations. These four practices served as both an organizing pedagogical framework and were designed to scaffold students' participation in science-as-practice. Throughout the methods course, the participants had opportunities to approximate the four practices using a suite of planning tools and through microteaching – attempting one practice with peers and a methods instructor (Grossman et al., 2009a). The purpose of approximating the practices was for the participants to try out the practices in a safe and collegial environment with peers and instructors and to receive immediate and principled feedback about their work. I will now describe the four practices.

To construct a Big Idea, teachers confront the limits of their own understanding of the science topic, and then investigate their topic, connecting new information to state and national standards. Second, teachers situate a science topic among other ideas to determine how foundational the original topic is. Third, they determine a relevant, observable, and puzzling phenomenon for the students to explain, and construct a causal explanation for the observable

phenomenon involving unseen processes or characters. Finally, teachers predict what student success looks like as the unit progressed. For example, a teacher could decide for a unit about sound to focus on energy, force, and motion as fundamental ideas. They could then select a puzzling phenomenon, perhaps asking why windows shake when a car playing loud music drives by. The teacher then constructs a causal explanation, involving molecules hitting each other. Finally, the teacher anticipates what students might think about sound and what kinds of experiences students may have had with this phenomenon.

When eliciting students' ideas, teachers plan a rich task that can reveal a broad range of student thinking about the target big idea, elicit observations from students about the phenomenon of interest to them, encourage the students to offer initial causal hypotheses about the phenomenon, assist students in synthesizing what they think they know and what they want/need to know, and after class, analyzing students' contributions to shape instruction.

When teachers help students make sense of material activity, they design conversations with students that allow them to connect various kinds of activity with the big idea. This practice helps students understand how activities relate to the observable phenomenon they have been puzzling over, assist students in using the observations or data collected during the activity with the big idea, support the development of students' academic language as a resource for communicating concepts and making sense of scientific ideas within the classroom community.

The final practice, pressing students for evidence-based explanations, requires that the teacher help students co-construct evidence-based explanatory models for the puzzling phenomenon illustrating the big idea. These models depict students' reasoning, linking their observations and information from a variety of sources students had experiences with to unobservable events, structures, or processes. Teachers re-orient students to the possible

explanatory models and hypotheses that could have been proposed up to this point, coordinate students' tentative explanations with available evidence, prompt students to talk about the strength of the evidence and the reasoning that links evidence with explanations, write a final explanation, and have students apply the new explanatory model in contexts beyond those previously discussed.

After methods class ended, the participants were placed in schools for three months of student teaching experience during the 2010-2011 school year. All the participants in this study were student teachers in different high schools in the Pacific Northwest. During student teaching, the participants moved from a secondary to primary instructor role in their classroom, planning, teaching, and reflecting on lessons with their assigned mentor teacher and other influential actors – their methods class peers, instructors, and university-sponsored “site coaches.” In addition, the participants were required to use the ambitious planning tools from methods class, and had access to the methods class website, which provided sample lessons, units, and reflection materials. *Data sources and collection*

During the 2011-2012 school year I collected and analyzed multiple forms of data from four different types of episodes: requested or informal planning communication, classroom observations, semi-structured interviews, and professional development sessions. In this section, I provide a description of the features of each episode.

Data sources

Requested or informal planning communication

The first category of data sources I used for this study involved requested or informal planning communication that was initiated by the participants. When engaged in planning communication with participants, I paid attention to how they framed problems of practice

around science activity. For example, in August, 2011, two participants requested to meet with me to discuss their upcoming plans for science teaching. During these planning sessions, a participant and I used their school resources (textbook and curriculum) as well as methods class resources (ambitious planning tools) to plan for the upcoming year. We first discussed a framework for the school year, considering the fundamental science ideas students should know by the end of the year. We then broke the fundamental ideas into units, attempting to create yearlong story of science ideas for students. I audio recorded and transcribed each conversation. As a researcher, I recognized my potential influence on the participants' practice. However, as an advocate of ambitious practice and a teacher educator, I chose to act as a resource for the participants if they requested my assistance (see section about my stance as a researcher of ambitious practice for more information).

While some planned conversations occurred at the beginning of the 2011-2012 school year, the most frequent form of participant-initiated planning communication was through email. Participants often sent emails, requesting that I help them prepare or review their unit planning, assessments, or activities. For email requests, I replied with questions and comments, and I then saved the original email from the participant and my own reply.

During planning communications, participants frequently discussed science teaching and learning in relation to their school's cultural scripts about teaching and learning (Sykes et al., 2010). Participants discussed a multitude of school-related topics, such as department requirements, results from planning sessions with colleagues, successes and struggles with students, upcoming standardized assessments, and student learning. I scripted notes or audio-recorded such details and saved them in the participants' folders, keeping track of their

perceptions about what the school valued as teaching, science activity, and students' roles in classroom work.

Classroom observations

The second set of data sources I used for this dissertation was classroom observations. I observed each participant teach during three timeframes throughout the 2011-2012 school year: October, 2011, January – April 2012, and May/June, 2012. In October 2011 and mid-May – June, 2012, I observed one lesson. The purpose of the October and May/June lessons was to get a snapshot of the participants' classroom science activity at the beginning and end of the school year, and to see evidence of both the development of classroom science activity over the school year. In the time period of January 2012 – April 2012, I observed each participant teach one entire unit, meaning that I was in the same class each day. The purpose of the unit-long observations was to observe the development of science activity in a short time, and to see evidence of how activity was negotiated daily between teachers and students.

Each participant taught a unit of different length. Listed below are the length of each participant's unit that I observed daily and the number of students in their class:

Maria: 11 days (each class period was 70 minutes with 28 students)

Joseph: 9 days (each class period was 75 minutes with 24 students)

Karen: 4 days (each class period was 90 minutes with 55 students)

Rebecca: 12 days (each class period was 55 minutes with 33 students)

Lucy: 15 days (each class period was 55 minutes with 32 students).

Video record classroom observations

One purpose of classroom observations was to capture as much discursive interaction between all the actors as possible. To capture discursive interactions, I video recorded all

classroom observations using a hand held camera. The primary subject on camera was the teacher and their interactions with students during class time – “between the bells.” I turned the camera on when the class bell rang, and turned the camera off when the dismissal bell sounded.

Observation notes

During each classroom observation, I wrote down questions and notes as the class unfolded, highlighting instructional moves and aspects of classroom practice to ask the participant about during our daily debrief. For example, I recorded and asked about moves that I knew were planned and moves that appear spontaneous, such as elevating a students’ question in a small group to the public plane of whole class discussions. I also recorded any learning objectives, warm-ups, and closing statements written on the board.

Daily debriefs

I informally debriefed with teachers after each lesson. During these 10-15 minute conversations, I scripted notes as the participant described the successes and failure of the lesson to me. In addition, I asked them about particular pedagogical moves they planned (for example, why they use a Power Point lecture) and moves that are unplanned or spontaneous (for example, why they skipped over an episode listed on the daily agenda). Since this lesson replay occurred immediately after class ends, the participant remembered specific moves and their pedagogical reasoning, which informed their instructional decision (see Horn, 2007, 2010). When engaged in daily debriefs with participants, I paid attention to their pedagogical reasoning, critical discourses, and how they framed problems of practice around science activity.

Teacher and student-created artifacts

I collected teacher and students-created documents related to planning, instruction, and science activity for each unit I observed, and all work associated with the classroom context, including:

- lesson plans
- assessments
- instructions for activities/tasks
- the participant's analysis of student work
- tools (created, modified, or adapted by participants to solve problems of practice)
- various forms of communication, such as email

Data from such artifacts, when triangulated, can be useful for making sense of teachers' practice in their particular context (Penuel & Gallagher, 2009; Borko, Stecher, Martinez, Kuffner, Barnes, Arnold, Spencer, Creighton, and Gilbert, 2006).

Photographs of tools and scaffolds in the classroom

After classroom observations, I also took photographs of five categories of objects that teachers and students created: graphical inscriptions produced by teachers and students, subject matter representations, scaffolding, directions, norms for participation. I photographed these objects each day I was there to document how they changed during the long unit. I also wanted a record of how the participants' used their pedagogical reasoning and critical discourses to provide opportunities for students to share ideas using physical representations of their thinking.

Semi-structured interviews

The third set data sources I utilized for this dissertation were semi-structured interviews. A semi-structured approach allowed me to adapt the protocol to probe participants' comments, ideas, and theories about practice while still focused on the overall goal of a one-hour interview

(Merriam, 2009; Patton, 2003). These interviews provided the participants an opportunity to describe their understandings about teaching and learning (Dilley, 2000). Interviews were recorded using two digital recorders and were sent to a professional transcriptionist. I conducted three types of semi-structured interviews during this study: A unit interview with a resource card sort, a reflection on the first year teaching, and a personal epistemology of science interview.

Semi-structured interview one: Unit interview including resource card sort

During the January – April 2012 daily unit observations, I conducted three fifteen-minute semi-structured interviews, which include a resource card sort. I asked each participant to answer questions about their unit planning, content understanding, pedagogical reasoning, and classroom activity just before their unit begins, in the middle of their unit, and at the end of their unit (See Appendix A for questions). Included in this semi-structured interview was a resource card sort, which asked participants to discuss what resources informed their pedagogical reasoning processes during planning, instruction, and reflection (Lampert et al., 2011). I asked the participants: “For this unit, you have several resources to draw on as you plan and teach lessons—such as your department, curriculum, ideas from university-based science methods class, the tools from methods perhaps some others I did not name. How would you rank the influence of these on your planning, teaching and reflecting? Did this change over time? Why?” I also asked the participants how they used resources when planning, teaching, and reflecting. I video recorded participants as they sorted cards with those potential resources as well as blank cards that they could have added resources on to. This task provided a lens into a) what participants’ thought were resources to use when planning, teaching, and reflecting, b) how and why participants view certain contextual factors and ideas as resources but not others, and c) how and why participants used resources to learn from and shape practice.

Semi-structured interview two: Reflection on first year teaching

The second semi-structured interview occurred during June 2012, the week after school ends in the participants' school districts. I asked the participants to reflect on their planning and instruction, to describe the details of teaching science in their school context, and their experiences of working with various actors. These questions allowed me to characterize the participants' perceived contextual affordances and constraints on their practice as they made sense of teaching in their school context (see Appendix B for the questions). I audio-recorded all interviews and sent them to a professional transcriptionist.

Semi-structured interview three: Personal epistemology of science

The third semi-structured interview asked the participants about their personal scientific epistemology, which includes their understanding of what science knowledge is, the processes scientists engage in to collect data, and why scientists believe their evidence and theories are "correct. While few researchers ask teachers' about their personal epistemologies of science, studies in science education of students' epistemologies (e.g., Sandoval, 2005; Smith, Maclin, Houghton, & Hennessey, 2000) and STS and HPS literature claim that an individual's personal epistemology of science influences both how they learn science and how they shape the actual science practice in spaces where they hold cognitive authority (Harkness, 2007; Hannaway, 1986; Knorr-Cetina, 1999; Owens, 1985; Rudolph, 2002; Shapin, 1988). The questions in the third semi-structured interview (see Appendix C for the questions) allowed me to a) make sense of the circumstances under which the participants revisit and reassess their understanding of subject matter and pedagogy, b) better understand the role of participants' conceptual understanding of science and epistemology on their pedagogical reasoning and practice throughout the year, and c) describe possible associations between teachers' personal

epistemology of science, how they set up science practice, and how the science practice shapes teachers' understanding of science. I conducted this interview once, at the end of the school year.

Professional development sessions: Critical friends' groups

The fourth set data sources I utilized for this dissertation came from the participants' participation in three professional development sessions – called “critical friends groups” (CFGs) – throughout the 2011-2012 school year: one in October 2011, one in February 2012, and one in May 2012. Each CFG lasted for one hour, and occurred at the university where the participants were students in their teacher preparation program. The purpose of the CFGs was for the participants to share puzzles of practice that were focused on student thinking and learning. To illustrate the problem of practice, participants shared samples of student work and their analysis of student thinking with a small group (4-5 people) of their teaching peers and a university researcher (myself, the methods instructor, or another secondary science research assistant). At each CFG, I purposefully placed 2-3 participants in the same group, with my faculty adviser or myself as the facilitator. The group then engaged in a structured conversation about the problem of practice using a conversation protocol. The CFGs provided a lens into what participants considered a) puzzling problems of practice to learn from, b) the science practice of their science classroom, and c) what and how they want students to think and learn. At each CFG, I collected teacher and student-created artifacts and recorded notes about their school context, both of which I described in previous sections.

Data analysis

In the following section I describe my analysis process for the research questions that guided this study. The research questions were as follows:

- How is science framed as a “public” or “private” practice? Over time, how and why does the public or private framing of science influence actors’ (teachers, students) participation in the epistemic work in classroom spaces? (Coding Category 1)
- How do teachers and students negotiate “what counts” as a science idea in classroom spaces? How is value assigned to science ideas and by whom? (Coding Category 2)
- How do teachers and students work on science ideas over time given the kind of epistemic community they negotiate? (Coding Category 3)

I coded data sources using a system informed by the literatures on ambitious teaching, and typical instructional practices, science-as-practice, as well as using emergent codes. My coding scheme, described below, was an attempt to foreground the primary objects of analysis while also tracing the relationships between these interactions and the larger sociocultural context that shape teachers’ interactions and individual teacher development. Across all of these codes I looked for shifts in teacher learning and the classroom epistemic community over time and looked for events, relationships, and interactions surrounding those shifts.

Coding category 1: “Who knows”

The first category of codes to analyze epistemic communities in classroom spaces is identifying the unit of “knowing” – the individual actors or the classroom community. My coding focused on who ascribes the title of “knower” and to whom such a distinction is given. I looked at interactions between actors on the public plane, and in particular, during whole class and small group conversations. During such interactions, I marked how various actors describe the work as private (ideas remain isolated or left alone by other actors; individuals work on problems) or public (actors work on others’ ideas; community works on problems).

When analyzing the epistemic classroom community, I looked at how students and teachers interacted together around science activity. In doing so, I got a different perspective on the science work in the classroom than if I gave students pre- and post assessments to measure their knowledge of science practice. For example, participating in science-as-practice might include students' developing skill in making arguments for their claims, recognizing a confusion between a theory and evidence from an activity, and making a new connection among ideas (Engle & Conant, 2002), all of which are difficult to measure using standardized assessments.

Coding category 2: Cognitive authority

The second factor I considered when analyzing epistemic communities in classroom spaces is the role of actors in exercising cognitive authority – the special authority given to (or taken by) certain actors to decide who get to engage in particular kinds of theorizing, decide “what counts” as the epistemic aspects of such reasoning, determine what ideas should be worked on and how, and assign value (see cognitive significance section) to ideas (Addelson, 1983). In physical and conceptual spaces, not all actors are trusted as reliable idea sources, nor are all science ideas treated equally (Livingstone, 2003). Individuals that exercise cognitive authority are those that the community positions as having expertise over factual matters and the nature of the world. Such authority can be conferred (bestowed on particular individuals by other actors) or negotiated (all actors decide, together, who has the authority to assign value to ideas over time). As noted by STS and HPS literature, those with cognitive authority use their life experiences and values as filters for deciding “what counts” as science in their space, and thus who is theorizing has a bearing on the actual science content and epistemology (Hankinson-Nelson, 1990).

Coding category 3: The geography of science ideas

The third category of codes to analyze epistemic communities in classroom spaces is the geographies of science ideas. While analyzing the treatment of science ideas as representative of science practice is rare in science education and just beginning in mathematics education (i.e., Saxe et al., 2009). Such spaces serve a socializing function, introducing novices to what those in authority consider proper practice and permitting certain kind of interactions between people and ideas (Livingstone, 2003). To analyze the geography of ideas, I created “idea maps” in order to track their introduction (where ideas come from – teachers, students, canonical texts) and treatment (how ideas change over time).

An important aspect of the introduction and treatment of ideas is understanding how ideas are initiated and are “kept in play” on the public plane; in other words, how and why ideas travel through time and space (Mercer, 2008). For example, science ideas could be inscribed (recorded for particular purposes) and transported across space and time (for example, a teacher recording students’ ideas on a poster, placing the poster on a classroom wall, and using the poster as a reference over the course of a unit). The work of inscribing science ideas could also serve as a reminder of the specific conceptual and epistemic values of a space, shaping the future treatment of ideas (Pickering, 1995).

Understanding how individual’s cognitive authority relates the geographies of science ideas in physical and conceptual classroom spaces involves unpacking how and why certain ideas are assigned value, while other ideas are treated as unimportant (Hempel, 1965). This difference in an idea’s status – its cognitive significance – refers to the epistemological and conceptual value an idea offers to a scientific community. This value designation by actors with cognitive authority shapes both the present science work that is permitted – what current ideas and questions should the community address, and future work – what ideas and questions should

a community pursue next (Hankinson-Nelson, 1990). I marked which actors grant cognitive significance to ideas, what values they assign, and how such designations change over time.

Triangulating data sources

When analyzing field notes, transcripts, videos, and inscriptions, I looked for patterns in the codes over time about the science activity in classroom spaces. For written text (teacher and student-created artifacts, planning emails, and transcriptions of audio files), I used the codes described above to identify patterns in participants' discourse, reasoning, and instructional decisions. I coded inscriptions in the context of classroom activity with the actors' discourse and writing to make sense of how and why inscriptions were created and used over time. Finally, for videos, I reviewed the observations in real time, pausing them if necessary to write the equivalent of field notes (Erickson, 1986) paying particular attention to discussions. I used the codes on the video notes, identifying overall trends. I transcribed selected discussions verbatim, and use the codes on the written text as previously described (see Alozie, Moje, & Krajcik, 2010). During and after analyzing single data sources, which provided one lens into science classroom activity, I triangulated the data sources. By triangulating, I mean that when analyzing the main bodies of data, I tried to find supporting or disconfirming evidence across data sources to enhance the credibility of the hypotheses (Merriam, 2009; Patton, 2003).

Hypotheses emergence and testing

As I analyzed and triangulated the data sources to answer the research questions, I looked for hypotheses that emerge from the coding. For all hypotheses – both initial and emergent – I sought confirming and disconfirming evidence. I also entertained alternative explanations, keeping in mind that my stance as a researcher and advocate for ambitious instruction could skew my interpretation of the data. One way I checked my own understanding of participant

learning was to conduct member checks during the all semi-structured interviews. I asked participants to respond to my interpretation of the data, with the freedom to clarify, expand, or refute my interpretations during our semi-structured interviews (Merriam, 2009; Patton, 2003).

My stance as a researcher of ambitious practice

Some researchers of human learning advocate for traditional ethnographic methodologies, purposefully not layering their own definition of competent practice onto their analysis of individual development (see Rogoff, 1995, 1997, 2003; Wolcott, 2005). I argue that studying “what is” in classrooms can place teacher education researchers in a quandary as they simultaneously advocate for ambitious teaching in contexts that often promote typical forms of instruction. For example, Thompson et al. (2013) concluded that one-third of their participants engaged in ambitious teaching practices despite working in schools with cultural scripts that promote typical instructional practices (Sykes et al., 2010). Yet Thompson and colleagues did not idly watch the other two-thirds of the beginning teachers revert to standard forms of teaching; they actively provided support to push their typical instruction towards ambitious teaching. In this study, I chose a middle ground between these two ends of researcher continuum. While I did not actively make unprompted pedagogical suggestions to the participants, I did offer ideas and planning suggestions if asked by the participants. I viewed my role as a resource for shaping classroom activity if they chose to use me as such, and I documented my role as a resource in data collection and analysis.

Findings

In this section, I organize the findings around four assertions that emerged from the data. I state each assertion below, and then situate each in the larger findings from this study. For each

assertion, I also indicate which epistemic community lens (“who knows”, cognitive authority, and the geography of science ideas) I used when analyzing the data to warrant the claim.

- The negotiation between teachers and students about “what counted” as science ideas influenced a) the percentage of students sharing ideas on the public plane of the classroom community, and b) the number of science ideas initiated and kept in play on the public plane. To make this assertion, I used the epistemic community lenses of “who knows”, cognitive authority, and the geography of science ideas.
- Participants’ *personal epistemologies of science* – i.e., the individual teacher’s understanding of what science knowledge is, the processes scientists engage in to collect data, and why scientists believe their evidence and theories are “correct” – shaped how the teachers positioned students as epistemic agents or, alternatively as information recipients in the classroom epistemic community. To make this assertion, I used the epistemic community lenses of “who knows”, and cognitive authority.
- The teacher played a key role in publically and purposefully assigning value to ideas over time. Using their *instructional authority*, participants positioned some ideas as important by making discursive moves, signaling students to either work on the ideas as epistemic agents or, alternatively, to judge the information as “right” or “wrong.” To make this assertion, I used the epistemic community lenses of “who knows” and cognitive authority.
- Over time, the participants’ and students’ treatment of science ideas framed the science activity in their classroom as “public” or “private” work. The public or private framing of science then influenced how teachers and students participated in the epistemic work in classroom spaces over time. To make this assertion, I used the epistemic community lenses of “who knows”, cognitive authority, and the geography of science ideas.

Students' participation in class around their science ideas

This section provides a description of the differences in classroom epistemic communities with regards to the percentage of students participating and the number of science ideas “in play” publically emerged between teachers regularly enacting ambitious practice (Maria, Joseph, & Karen) and those frequently engaged in conservative forms of science teaching (Rebecca & Lucy). First, I describe how the classroom epistemic communities differed with regards to student participation around science ideas. In the following sections, I unpack why differences emerged across classroom settings.

Across all participants' classrooms, science ideas became known as any utterances about conceptual, epistemic, social, and material aspects of science that emerged from canonical texts (book, curriculum), students, or teachers. These included, for example, facts, theories, hypotheses, fragmented and partial understandings, and stories from personal experiences. Teachers and students became aware of each other's science ideas during interactions in the public plane of whole class or small group conversations (Note that science ideas were not the same as instructional prompts or questions, e.g., “Please write five sentences for your homework”; “Where do I write my name on this assignment?”).

Though all participants and students generally agreed that science ideas emerged from canonical texts (book, curriculum), from students, or from teachers, how science ideas were treated, and by whom, differed between classrooms in which teachers enacted ambitious practice and those that frequently engaged in conservative forms of teaching.

In Maria's, Joseph's, and Karen's classrooms, teachers and students negotiated that *any* idea regarding the conceptual, epistemic, social, or material aspects of science could be considered a science idea. In addition, science ideas were not static; rather, they were malleable,

tentative, and could be worked on over time by anyone in the classroom. In Rebecca and Lucy's classrooms, however, teachers and students appeared to agree that science ideas would only pertain to conceptual features of science and, in addition, be regularly framed as "right" or "wrong" by the teacher.

In this section, I describe how the understanding negotiated between teachers and students about "what counted" as science ideas made a difference in a) the proportion of students sharing ideas on the public plane of the classroom epistemic community, and b) the number of science ideas in play during lessons. First, the percentage of students sharing ideas in Maria's, Karen's, and Joseph's classrooms was consistently higher than the number of students participating in Rebecca's and Lucy's classrooms (see Figure 3. Please note that Karen had a class with 55 students, which skews the picture of participation).

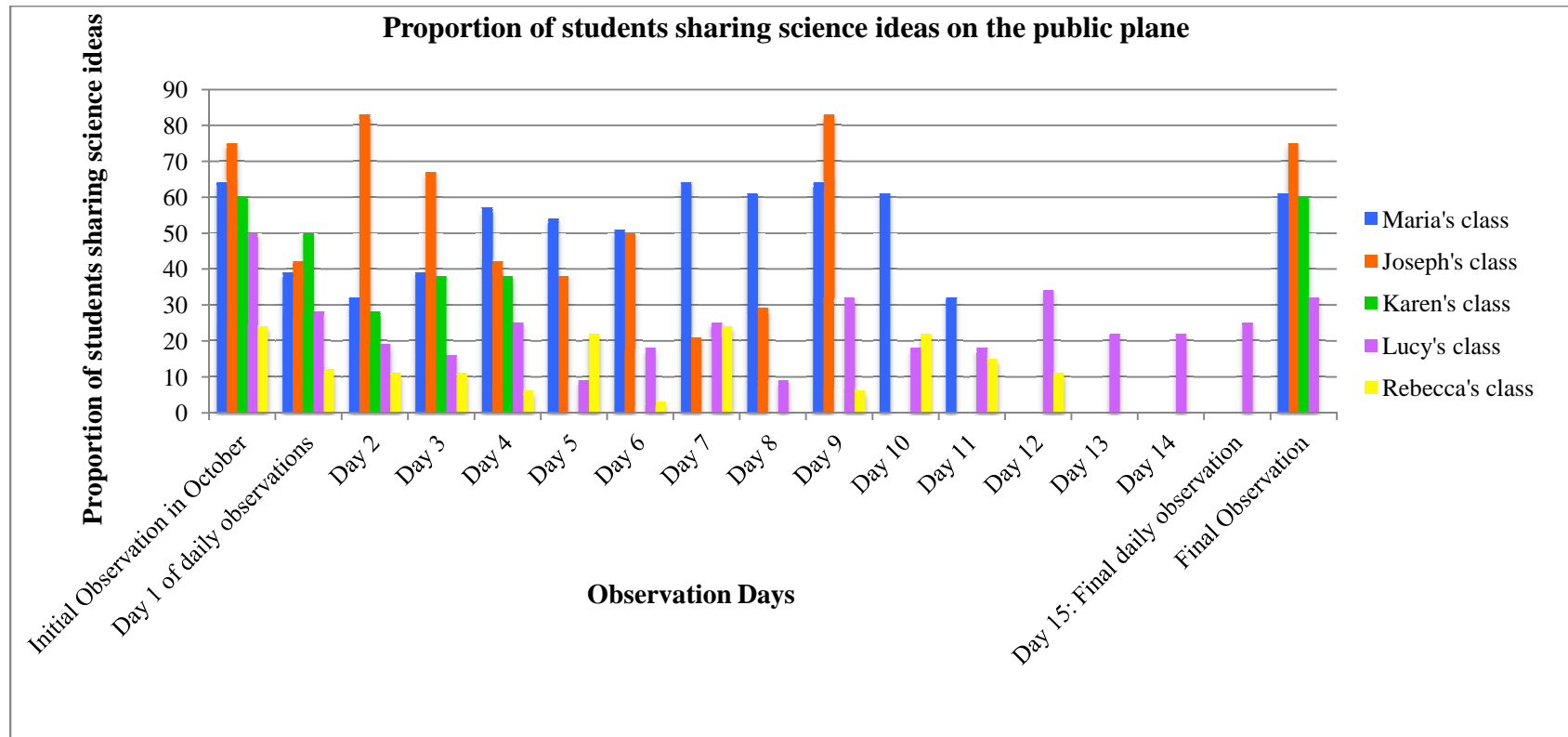
In Maria, Joseph, and Karen's classrooms, a greater proportion of students participated as science ideas became frequently shared on the public plane by the teacher and students. In Rebecca and Lucy's classes, fewer students participated publically. In fact, there was only one instance in Lucy's class (my first observation in a unit about valence electrons) that more than fifty percent of students participated by sharing a science idea publically. In another example, during my final observation of Rebecca's classroom, *zero* students participated by sharing science ideas publically. This class was not a testing period; rather, Rebecca occupied the talk time herself by lecturing and required that students work silently on a writing assignment. In Maria, Joseph, and Karen's classes, however, *having less than fifty percent of students sharing science on any day ideas was uncommon.*

The second finding that emerged from data about the understanding negotiated between teachers and students about "what counted" as science ideas concerns the number of science

ideas in play during lessons. The sheer quantity of science ideas shared publically *by students* was higher in classrooms where science ideas were treated as “in play” and worked on over time (see Figure 4). For example, during Maria’s ninth day in a unit about roller coasters, her students shared over 60 sciences ideas publically during one class period.

Figure 3.

Proportion of Students Sharing Science Ideas on the Public Plane.



This graph shows the proportion of students who shared ideas on the public plane of the classroom at the beginning of the year, during one whole unit, and at the end of the year. As a reminder, the length of the long unit differed for each participant, as did the number of students in their class.

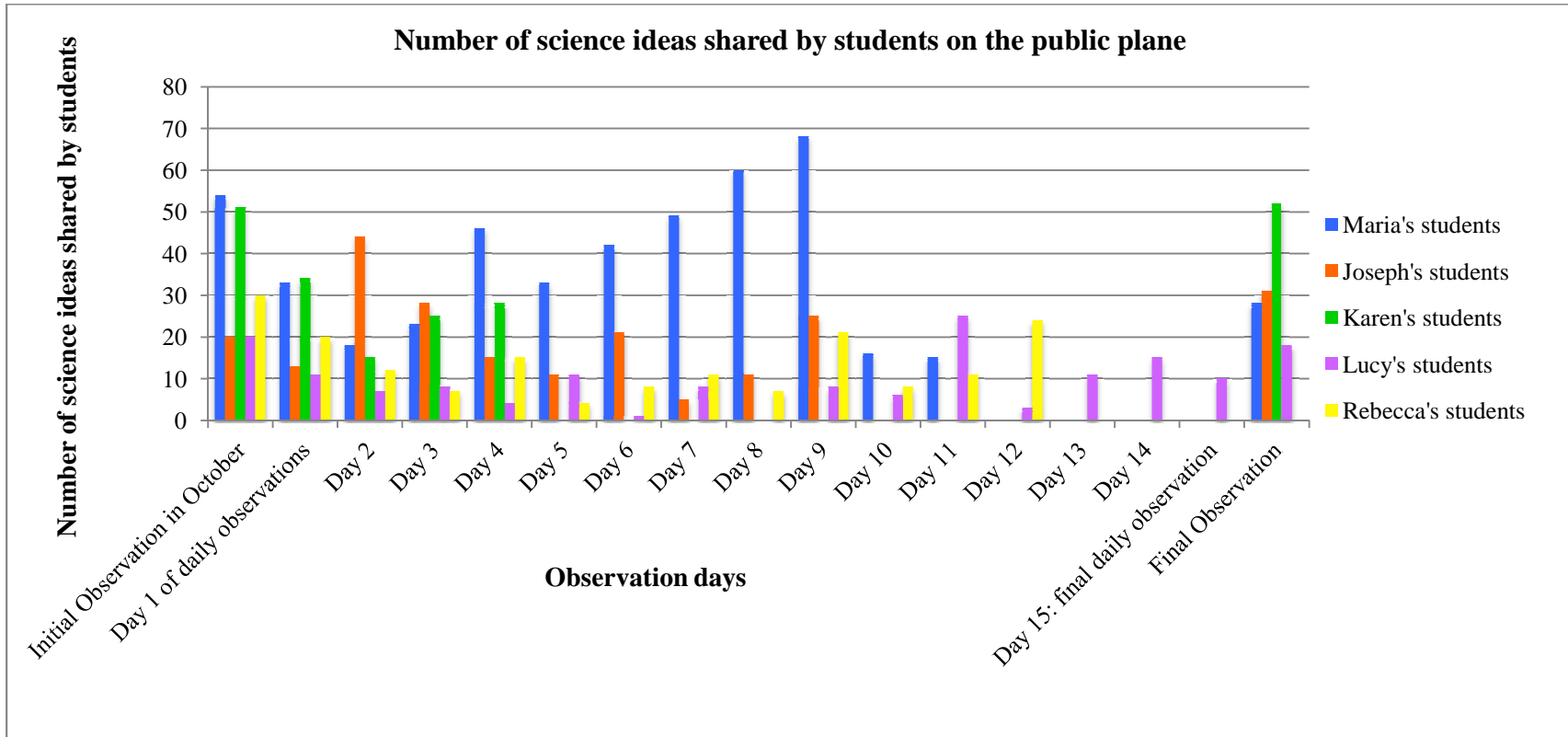
Listed below are the length of each participant’s unit that I observed daily and the number of students in their class:

- Maria: 11 days (each class period was 70 minutes with 28 students)

- Joseph: 9 days (each class period was 75 minutes with 24 students)
- Karen: 4 days (each class period was 90 minutes with 55 students)
- Rebecca: 12 days (each class period was 55 minutes with 33 students)
- Lucy: 15 days (each class period was 55 minutes with 32 students)

Figure 4.

Number of Science Ideas Shared by Students.



This graph shows the number of science ideas shared by students on the public plane of the classroom at the beginning of the year, during one whole unit, and at the end of the year. As a reminder, the length of the long unit differed for each participant, as did the number of students in their class. Listed below are the length of each participant's unit that I observed daily and the number of students in their class:

Maria: 11 days (each class period was 70 minutes with 28 students)

Joseph: 9 days (each class period was 75 minutes with 24 students)

Karen: 4 days (each class period was 90 minutes with 55 students)

Rebecca: 12 days (each class period was 55 minutes with 33 students)

Lucy: 15 days (each class period was 55 minutes with 32 students)

As the graphs illustrate, distinct differences emerged in classroom epistemic communities with regards to the percentage of students participating and the number of science ideas “in play” emerged between teachers regularly enacting ambitious practice (Maria, Joseph, & Karen) and those frequently engaged in conservative forms of science teaching (Rebecca & Lucy). In the following sections, I unpack why differences emerged across classroom settings and how the participants provided different science experiences for students that, over time, resulted in more than a proliferation of ideas. These experiences fostered distinctly different kinds of epistemic communities where teachers and students took on varied roles as epistemic agents, knowledge authorities, or recipients of information.

Teachers’ personal epistemologies of science shaped students’ science experiences

Using data from daily classroom observations, observation debriefs, planning sessions, and semi-structured interviews, it appears that the participants’ *personal epistemology of science* shaped opportunities for students to participate in science activity in their classroom. A teacher’s personal epistemology of science includes their understanding of what science knowledge is, the processes scientists engage in to collect data, and why scientists believe their evidence and theories are “correct.” In addition, as the adult in the classroom, the participants had power to shape both students’ roles in the epistemic community and the daily classroom routines around science activity using their *instructional authority*. Therefore, what the participants thought science is, combined with how they thought students’ science experiences should be shaped, had substantial influences on the development of the classroom epistemic community, and subsequently, students’ opportunities to participate in science as epistemic agents (or not).

In the following sections, I describe each participant's personal epistemology of science and how their developing theory of science shaped their pedagogical vision. While all participants shared some common ideas about science (for example, scientists interact socially to argue about knowledge claims), each teacher's personal epistemology featured unique aspects based on their own experiences as learners of the discipline. All quotes from participants come from the personal epistemology of science semi-structured interview.

Karen: the "messy" work of empirical and experimental science

Karen, a doctoral candidate in ecology before changing careers, spoke often about the work of science as *empirical and experimental*, trying to explain the world "around us." As a doctoral student, Karen was privy to multiple aspects of science practice: "I liked the kind of work that I got to do and I liked designing experiments and going out and the whole process from start to finish. And I just loved reading articles and papers about people doing cool research and picking them apart." Karen viewed this work of sharing evidence publically and working on theories as foundational for science and her own science teaching: "You use data to lead to theories, which have broad explanatory power and a wide body of supporting evidence. Then you interpret the results and then communicate that to a larger audience." These processes were important to Karen because she thought that scientists were people who make informed decisions and hypotheses through controlled experimentation – canonical science knowledge emerges *after* experiments are run, theories are vetted, and ideas argued about.

Karen wanted her teaching to be the opposite of her own experiences in secondary and higher education, which consisted mostly of memorizing vocabulary and taking notes. Instead, Karen wanted students to "participate as scientists in a knowledge-making community." Creating such a community required Karen to confer some of her cognitive authority to students, stating,

“I learn with and from my students, even if that means “I don’t ‘figure out’ solutions and science ahead of time.” This suggests that Karen viewed her role as a facilitator, noting “I try to guide students’ reasoning and actions: “I just try to give them scaffolding and space to do that. You just have to build a community where it’s okay to take risks and it’s okay to talk and it’s okay to be ‘wrong’.” Note the community-building – Karen viewed her role not as the knowledge authority, but rather as the person who is responsible for helping students participate in authentic disciplinary work.

Maria: “Tinkering” with materials and ideas

Like Karen, Maria also had a background in research biology as an undergraduate. These experiences provided her with insight into science practice, which she viewed as a process of *informed tinkering* – making evidence-based, in-the-moment decisions about, and revisions to, theories, hypotheses, equipment, and other aspects of science work while simultaneously making claims about the natural world. Unlike Karen, Maria viewed material manipulation a key feature of science practice.

Maria also noted that scientists make knowledge by “just tossing ideas around and saying things that might be crazy - but make another person think, “Wait, that sounds crazy but this part actually isn’t.” In this way, Maria, unlike Karen, viewed science as a social enterprise in which scientists build off of each other’s ideas: “In fact, it is through scientists’ willingness to examine other ideas that science happens at all. I mean, so many of these things we have strong evidence for only until someone finds strong evidence for something else. Keeping things open and investigate-able is, I think, the true nature of science.”

Maria, like Karen, did not have fond memories of science in secondary school. She did not “remember much about middle school science except that my teachers were strong-willed

male teachers who lectured a lot.” Also like Karen, Maria’s research experiences changed her image of science – she began to think of science not as information in books, but as a way to explain, “how the natural world is constructed.”

In her science classroom, Maria wanted students to be open to hearing and using each other’s ideas “on the fly” to “revise their ideas and models.” To do so, Maria wanted to build a safe and collaborative community. She explicitly mentioned community, wanting students to understand that “science is a community that they have something to give to. That it is, yes, a collection of ideas - but not a collection of facts. It is revisable, depends on a diverse input, and will never be a truly complete field until there is true representation of our world in it.” Maria’s definition of equity in science – that there is “true representation” if everyone participates – underlies how she thought science should be taught in schools. Included in a “true representation” of science was Maria providing opportunities for students to take up epistemic agency. Like Karen, Maria was prepared to learn “with my students about science, not just tell them the truth.” Maria’s stance included her acknowledgement of “uncertainty” in daily practice: “I know that my students may have an idea that comes out of nowhere or doesn’t seem connected to our topic. My job is to work with that idea and that student because for them, their idea connects somehow. Nothing is irrelevant.”

For Maria, this meant her role, like Karen, was to facilitate and “fade away” into the background as the year goes on. Maria planned to have students work on science ideas as objects of interrogation and revision by “sharing ideas, explaining their observations, suggesting changes with explanations, trying to explain why something happened the way it did, asking others for their ideas, challenging ideas, changing their own ideas, collecting data for a purpose, compiling a product by synthesizing pieces of ideas, opening up and finding something that excites them.”

To do so, Maria wanted to teach students how to use each other's science ideas as resources for advancing their understanding of science practice.

Joseph: "Turning down the volume of white guys in coats"

Joseph, like Karen and Maria, had experiences doing science research, and discussed science practice as a process by which people can "look at the world around us, ask questions and then to know how to figure out the answers to those questions." Joseph's research experiences as a chemist also shaped his understanding that science is an "ever-changing amorphous beast in which we don't have all the answers"; like Maria and Karen, Joseph thought that science was "uncertain," and this influenced how he thought science should be taught. Unlike Karen and Maria, Joseph's personal epistemology also placed great value on the human body as a sensory object (using one's sense of smell, sight, touch as evidence) and research tool, wanting student to use evidence from "what they feel, smell, and hear during experiments."

To teach science, Joseph, like Maria and Karen, wanted to build a safe and collaborative community in which "we [teacher and students] talk about our science ideas, data, and questions. We use our space to share ideas, not shut them down." Joseph, like Karen and Maria, planned to have students work on their science ideas as objects of interrogation and revision by placing value on every student's idea, not just the "big guy in the white coat and the fancy glasses with the buck teeth, who's rich, white, and old, yeah he's got a lot of letters after his name but he doesn't know everything."

Joseph noted that other science teachers lecture and provide "fact delivery", but "that's not what grown-up science looks like." In other words, Joseph wanted to use his understanding of authentic science to shape the science that could happen in his classroom. This meant he had to "not to flat ignore the guy in the big white coat with the big fluffy mustache who's white, rich,

and dead, but to turn down his volume, because kids' ideas are really important." Therefore, Joseph viewed his role as a "coach" of students' reasoning and action as scientists. Such a role for Joseph meant, like Maria and Karen, conferring some of his cognitive authority to students and preparing himself for the uncertainty of students' reasoning and actions: "learning with them [students] even if it means I do not figure out solutions to the science problems ahead of time."

Rebecca: Organization and information

Like Karen and Maria, Rebecca had a background in biology. Unlike the first three participants, however, Rebecca did not conduct science research in college or graduate school. During her undergraduate years, Rebecca liked her biology professors because they made science "interesting." She enjoyed the laboratory components of her coursework, citing, for example the thrill of animal dissections, which taught her "about the function of organs and why they [animals] needed such organs to survive." Rebecca's interest in dissections illuminated her understanding of science practice as a "very organized and a straightforward way to learn about the world" – scientists described the natural world as it existed and classified that information so that other people can learn the "truth."

Like Karen, Rebecca thought that scientists built upon the work of others – "Scientists are more 'important' [uses fingers as quotation marks] or smarter than non-scientists about science issues, and can come up with something that they're interested in looking at further by examining the work of others, they try to use the scientific community to figure out what is known about a certain topic and then work on filling in gaps of what they don't know." However, Rebecca's personal epistemology of science differs from Karen's personal epistemology in two important ways. First, for Rebecca, a scientist has to know what facts currently exist before they can solve problems – one must be aware of what established science thinks are gaps to fill in the

knowledge canon. Second, Rebecca emphasized the hierarchy of power in science practice – those who have been positioned by science as “authorities” get to decide what the gaps are and require new practitioners to “fill in” those gaps.

Like Karen and Maria, Rebecca recounted her own secondary science learning experiences as “worthless.” She recalled “almost nothing from high school biology and chemistry. I remember it being memorization and it being learning the facts and you're good. That was basically all.” For Rebecca, science teaching meant making science “relevant and interesting” for students because she did not want them to think of science as memorizing random pieces of information and not understanding why they are learning what they are learning.

To make students excited about science learning, Rebecca wanted to create a community that helped students participate in class. She noted,

“A science class community should be a place where kids participate. Ever since the beginning of this school year I was trying to get oral participation up. That was especially difficult because typically you have the kids that always want to answer the questions and then some that just will never. And then that class is very highly populated with ELL and SPED students that it's difficult for them anyway to be able to [contribute].”

To achieve the kind of science community in which students would frequently participate, Rebecca viewed her role as an organizer. She noted, “I'm an organizational freak and in trying to make some sort of comprehensive explanation if I didn't give them [students] some sort of way to organize themselves in trying to like put everything together that we'd learned in a unit it would have been impossible. Like they just probably would have lost a bunch of the things. Or

just maybe it wouldn't be in a coherent order." Note that unlike Maria, Joseph, and Karen, Rebecca seems averse to uncertainty in science practice and her instruction.

Rebecca also struggled to make sense of her as the knowledge authority in a classroom. Rebecca knew that "the idea of authority is really big with kids. They believe 'Oh, you [Rebecca] are a science authority. I will trust exactly what you say.' And not—I'm trying to get them away from seeing me sometimes as that because that's how my—most of my education was. It's like, 'Well the teacher knows everything'." However, Rebecca thought part of her professional responsibility was to "hit the required standards" and help students "tell a full explanation of a phenomenon using required curriculum topics", both of which illustrate her willingness to follow rigid department norms for teaching and learning.

Lucy: Evidence-based winners and losers

Like Rebecca, Lucy was a science major with little research experience. Lucy became interested in science in college because of her professors, specifically in anthropology, which "led me to human evolution and that kind of led me more into biology." Lucy noted that biological anthropology is "rife with emotion and pressure to get the human story straight." Therefore, Lucy thought that scientists must distance themselves from their feelings and "what they want the story to be." This view that scientists break away from emotion led to Lucy's characterization of science as a practice of "winners and losers", the "winners" being those whose theories "have the most evidence to support them and that are reproducible." A key feature of Lucy's personal epistemology in her description of science the foundational role "evidence" plays in separating "truth" from "fiction." Note that in these three quotes, Lucy's distinguishes between "winners" or "losers" based on evidence influenced what she thought science teaching and learning should be.

Like all the participants, Lucy did not enjoy her science experiences in secondary school. She noted she learned science by “studying and memorizing stuff and I studied and memorized science not as much as other classes.” She also noted that she often had “no idea what the facts mean at all. Therefore, Lucy wanted to “build a safe and collaborative community in which students worked together on some common experience they can get evidence about.” Part of building community was helping students see that their good ideas are supported by evidence – “A good science community is a place where students learn that the distinction between ideas that a kid or any person has, and science ideas, is being able to support them [science ideas] with evidence.”

To achieve this community, Lucy thought her role was to be a “questioner, getting students to take a step back and think about what their results mean, or maybe why they got the results that they did” (personal epistemology interview). Note how Lucy’s consideration of student thinking sounds like how Maria, Karen, and Joseph position students’ science ideas. However, Lucy struggled, like Rebecca, with the balance between letting students “do science that they [students] want to” and ensuring that students leave her class with correct canonical information. Lucy admitted being “scared that students would share out misconceptions in class”, and her job was to fix the false ideas – “I guess you run into more opportunities for kids to teach each other things incorrectly, but...so then I guess you kind of have to intervene there and put up a red flag” (personal epistemology interview). Therefore, Lucy wanted to create opportunities for students to think about science, but which she controlled and regulated through “fixing” misconceptions, like Rebecca, reducing uncertainty in her daily classroom activity.

Note that *all* participants discussed the importance of building a community in which students shared science ideas. However, two themes stand out from interviews with participants

that illustrate qualitative differences between participants routinely enacting ambitious practice (Maria, Joseph, & Karen) and those engaged in conservative forms of science instruction (Rebecca & Lucy). First, Karen, Maria, and Joseph emphasized the importance of viewing both students *and* scientists' science ideas as objects of interrogation and revision on the public plane in their classroom spaces. For example, Maria discussed how she required students to test the validity of canonical knowledge when they engaged in various activities. Rebecca and Lucy, however, thought of science ideas as static and placed a higher value on scientists' "correct" ideas rather than on students' "misconceptions." For example, Rebecca described her role as one who "fixes" student thinking using canonical knowledge as a tool for "conceptual change" (personal epistemology of science interview). Second, Karen, Maria, and Joseph recognized and accepted that, inherent in their enactment of ambitious instruction, was *a risk of uncertainty about what students might say and do*. In acknowledging this risk, Karen, Maria, and Joseph viewed their role as "facilitators of a classroom community" (Karen, personal epistemology of science interview). Rebecca and Lucy, however, discussed the need to help students become "better organized" and focus their "misconceptions" to canonical science ideas (personal epistemology of science interview).

Teacher's role in assigning value to ideas

Given each participant's personal epistemology of science, I now describe how the teachers publically and purposefully assigned value to science ideas over time using their *instructional authority* to position some ideas as important while shutting other ideas down. To assign value to science ideas (i.e., give some science ideas more *cognitive significance* than other ideas), the participants made discursive moves to encourage or discourage student participation.

In Table 3 below, I describe the different kinds of discursive moves that I categorized during data analysis.

In Maria, Joseph, and Karen's classrooms, science ideas were rarely positioned as "right" or "wrong"; instead, they were treated as resources for the community's science work. Maria, Karen, and Joseph all assigned value to ideas that promoted productive puzzlement or reasoning and simultaneously signaled that such contributions were welcome on the public plane. Rebecca and Lucy, however, assigned a "truth value" to ideas, which precluded interrogation of the idea itself by the epistemic community. In other words, Rebecca and Lucy made it clear to students that science ideas could only be treated as "right" or "wrong" answers and questions (i.e., students could ask "wrong" questions) that they either accepted or dismissed as irrelevant to their classroom community.

Table 3.

Participants' Discursive Moves to Assign Value to Science Ideas

Discursive Move Category	Examples from Ambitious Classrooms	Examples from Conservative Classrooms
<p>Epistemic Press on Students' Science Ideas: A public statement about the knowledge status of a science idea</p>	<p>Teachers asked each other for evidence or ideas to support or refute prior statements: Maria: "How do you know that?" Karen: "What is your evidence?" Joseph: "Unpack that claim some more."</p>	<p>Teachers asked students about the "correctness" of ideas: Lucy: "What is wrong with what you just said?" Rebecca: "How can we fix [a student's] wrong answer?"</p>
<p>Question: A public question about an idea or a question designed to prompt idea sharing or emergence</p>	<p><i>Clarify</i> (Asking students to unpack their thinking) – Karen: "What do you mean? Please tell me more about your idea." <i>Soliciting information</i> (genuine desire to understand situation better): Joseph: "Rose, you just told the class about your experience in going in a sauna after a cold swim. Could you please go a bit further – what did you notice about your shivering that seemed to connect with homeostasis?" <i>Participation</i> (encouraging sharing ideas on public plane) Joseph: "I want to know all of your ideas. If you are not comfortable sharing right now out loud, write down your hypothesis on a piece of paper and turn it in. I need to see everyone's thoughts."</p>	<p><i>Clarify</i> (Used to "diagnose" misconceptions): Lucy: "What do you mean? Do you really mean something else?" <i>Soliciting information:</i> Rebecca: "How many of you have ever seen twins?" <i>Asking students to participate:</i> Rebecca: "Can you please to pay attention so we can finish this practice problem?" <i>Rhetorical</i> (a question posed typically at the end</p>

	<p><i>Metacognitive</i> (why are you doing this?) Maria: “How does what you said just now relate to our model/activity/current idea thread (when student says something tangential, she does not dismiss it). Also: I want you to be aware of how your thinking is changing over time.”</p>	<p>of discussion that is never again addressed): Rebecca: “How could a fertilized egg split to have twins? We’re now left with that question until another day.”</p>
<p>Signal: A public statement indicating how students and the teacher should participate in the classroom community.</p>	<p><i>Participation</i> (general expectations for how to participate in class): Maria: “If you are finished, help others. We are all responsible for each other’s learning.” Karen: “When one person is sharing, everyone else is silent. We respect, listen, and consider all ideas in this class.”</p> <p><i>Quality of idea</i> (value – it’s cognitive significance): Karen: “Do not worry about being correct – just worry about ‘did I use evidence from my life or a class activity when I said what I said?’” Joseph: “Your idea is very strong because you used your peers’ hypotheses and tried to tie them together.”</p> <p><i>Ascribing ownership of ideas</i> (Using students’ ideas as resources during class time): Maria: “Michael has this hypothesis, so we will call it ‘Michael’s hypothesis’ and I will write it on the board so we can test it.”</p>	<p><i>Participation in classroom and/or science community</i> (general expectations for how to participate in class): Rebecca: “It is silent time to work on your own ideas; be sure to tell me when you are finished so I can check your work.”</p> <p><i>Quality of idea</i> (value – it’s cognitive significance) Lucy: “That is correct.” Rebecca: “Nope, try again.”</p> <p><i>Ascribing ownership of ideas</i> (Using students’ ideas as resources during class time): Rebecca: “Did everyone see how Jonas said that? That’s the way your explanation should sound.”</p>

Ascribing agency (Teacher telling students they can think and act like a scientist). Joseph: “We are testing your ideas, not mine.” Maria: “this is your time to reason and make claims, you can do it.” Karen: “The local government scientists need your help – you know things they do not.”

Ascribing agency: Rebecca: “Let’s now look at the textbook’s answers to fix our mistakes.”
Lucy: “That was great talking in small groups.
Take out paper to copy down the right answer from these Power Point notes.”

Publicize Private Ideas:

Teachers publically and purposefully telling students ideas or actions that students typically do not have access to

Revoicing (Teachers or students publically restate a science idea): Joseph: “Here’s what I heard you say [repeats student’s science idea]. What do other people think?”

Summarizing (Teachers or students repeat several science ideas in relation to a science activity): Maria: “Let’s take a second and see where we are because we have three ideas in play right now. Robert claims that when potential energy goes down, kinetic energy goes up. Shuana agrees, but she is wondering about the role of friction in this possible relationship. Tran is hypothesizing that if we move the starting point of the roller coaster higher the kinetic energy will increase and will decrease friction’s force.”

Revoicing (Teacher repeats student’s science idea to gauge the “correctness” of the idea): Lucy: “I think I heard you saying that the more acceleration something has, the more force it has?” Student: “Yes.” Lucy: “That’s true.”

Summarizing (Teacher “stiches” together students’ science ideas to construct correct answer): Rebecca: “I’m going to take all of the ideas I’ve heard and put them together for the correct answer.”

	<p><i>Reasoning</i> (pedagogical and scientific – Teacher explains why they engage in certain actions or answered a question in a particular way):</p> <p>Maria: “We are doing this summary table because we need to organize our activities and see what evidence we have, and because we need to make claims using evidence – we cannot just say this is this just because. The summary table helps us link evidence to parts of our explanatory model.”</p>	
<p>Instructions: How to begin and complete a task, routine, or discussion. Often include participatory norms.</p>	<p>Maria: “You have five minutes to finish writing your hypothesis and then discuss it with your partner. Remember to use evidence when talking to each other, and ask each other questions if you don’t understand your partner’s hypothesis.”</p>	<p>Rebecca: “You have five minutes to complete the writing assignment. Be sure to make your paragraph five sentences long. You are required to turn this in at the end of class.”</p>
<p>Tagging on: Teacher or student injects facts or information to a conversation.</p>	<p>Student: “The average body temperature is 97 degrees.” Joseph: “Actually it’s 98.6 degrees. But your statement begs two questions. First, what does ‘average body temperature mean’? Two, why is it 98.6 degrees and not 97 degrees?”</p>	<p>Student: “Carbon has four valence electrons.” Lucy: “Because it already has two electrons in the inner shell.”</p>
<p>Push or Pull Ideas: Dismissing (pushing) or extracting (pulling) students’ science ideas</p>	<p><i>Pulling ideas:</i> Maria: “I see that no one wants to share their ideas. That’s alright. I will use my ‘name bucket’ [a bucket with each student’s name on a piece of paper] and draw someone to speak. After they talk, I will draw again, and the next person has to add onto the first person’s idea.”</p>	<p><i>Pulling ideas:</i> Rebecca: “Where is DNA?” Student: “In a cell.” Rebecca: “Where?” Student: “Inside.” Rebecca: “Where?” Student: “In the nucleus.” Rebecca: “Good.”</p>

<p>during discussion</p>		<p><i>Pushing ideas:</i> Student: “Why do some parents have triplets?” Rebecca: “That doesn’t have to do with our conversation about twins right now.”</p> <p>Student: “What about valence electrons of middle elements?” Lucy: “We might get to those next week.”</p>
<p>“Move on” Moments:</p> <p>Teacher cuts off conversation or idea sharing for the purpose of advancing through an agenda/schedule/curriculum</p>	<p><i>Providing space for “tangential” talk</i> (Teacher lets student ask question or share their idea and provides them with a way to keep idea in play):</p> <p>Student: “I heard that astronauts say going up in a rocket is like a roller coaster. Is that true?” Maria: “That is an interesting idea. We don’t have time to talk about it right now, but if you write it down and put it in our class ‘parking lot’ [a poster used for students to write down any question or idea they have about science], I or another student will answer it before the unit is over.”</p>	<p><i>Refocusing “tangential” talk</i> (Teacher lets students talk about ideas related to topic, but then refocuses student thinking): Lucy [after hearing students’ science ideas]: “I want to reign you back in.”</p> <p><i>Cutting off ideas</i> (Teacher abruptly stops student from discussing their idea more in public):</p> <p>Student: “How do scientists know that alleles are alleles” Rebecca: “That’s enough of that. We need to move on.”</p>

Note that sometimes all participants used similar discursive moves, such as “clarify.” However, some participants used certain discursive moves while other participants did not. If a discursive move does not appear in a cell of the table, that means I did not observe that particular move in the participants’ classrooms. For example, Rebecca and Lucy both asked “rhetorical” questions to students, but Maria, Joseph, and Karen did not.

Science as “public” or “private” practice

The discursive moves made by teachers to place certain value on science ideas, particularly students’ science ideas, represented efforts to make the science work “public” or “private” in the classroom epistemic communities. Maria, Joseph, and Karen negotiated science as a “public” practice with students in their classroom epistemic communities. As a public practice, teachers and students together engaged in the conceptual, epistemic, social, and material aspects of science work over time, and as a result, advanced their collective understanding of science in their localized classroom context. Rebecca and Lucy negotiated science as a “private” practice with students in their classroom epistemic communities. Rebecca and Lucy frequently positioned students as solitary individuals responsible for completing tasks alone and silently. As a result, students had limited opportunities for collaborative learning in their classroom context.

To negotiate an epistemic community in which the classroom community is the “knower”, Maria, Joseph, Karen and their students positioned each other as responsible for everyone’s learning and for the science work. This negotiation began at the beginning of the year when Maria, Joseph, and Karen helped create a safe classroom space for sharing ideas. For example, Joseph told his class, “We need to be able to talk about science ideas, data, and questions. We need this kind of space to share ideas” (observation notes). If during a whole class discussion the noise level was too loud, Maria reminded the class, “your peer is speaking, please give them the respect they deserve. The more ideas that are heard, the more you’ll learn” (observation notes). Maria and Joseph linked a safe space for sharing ideas, learning, and science together, and in doing so, advanced their view of science that the community is the unit that creates knowledge. Like Maria and Joseph, Karen framed class as a “learning community”, stating “We have so

much knowledge in room, we want to share knowledge and hold each other accountable. You're not just talking to me, you're talking to each other" (observation notes).

Maria, Joseph, and Karen also worked to connect students and their ideas together. For example, Joseph told three students during a small group discussion, "I like this group's idea because it's different – a different train of thought. I'd like for you to share that during whole class talk" (observation notes). Joseph wanted this idea elevated because he knew that the classroom community needed to hear it in order to advance the whole class' understanding. In another move, Joseph sent student "ambassadors" around during small group discussions. As students talked in small groups, this outside representative infused new ideas not currently available in the conversation. Maria also encouraged students to talk to each other about ideas or questions that she could have answered. For example, when looking at students work in small groups, she said, "Oh Jean, you should talk to Tyler. He's thinking in similar ways to you" (observation notes). Maria enacted these discursive moves to "help students see that they could use each other's ideas to learn" (observation debrief). These statement and actions support Maria, Joseph, and Karen's statements during their personal epistemology interviews about wanting to create a community in their classroom in which students carried out science work.

Maria, Joseph, and Karen also purposefully chose to not "know" the complete explanation of the complex phenomenon they organized when planning their unit because they wanted to authentically learn with students. Joseph explained why he chose not to know when a student asked if he knew the "real answer" to the puzzling phenomenon: "A lot of times, teachers have you [students] pretend to be scientists as opposed to actually being scientists. Instead, I want to be a scientist with you as we figure this out together" (observation notes). In this

statement, Joseph told students that he expects them to participate as scientists in the classroom and that he wants to work together to solve the puzzling phenomenon.

Unlike Maria, Joseph, and Karen, Rebecca and Lucy negotiated science as a “private” practice with students in their classroom epistemic communities. One means to privatize science was for teachers to make purposeful statements about the individual nature of science and learning. For example, Rebecca frequently told students *not to work together*: “work on your science assignment alone because you [students] are responsible for your own learning” (observation notes). This resulted in students not having opportunities to collaborate together to work on science ideas unlike Maria, Joseph, and Karen’s students. Rebecca also placed students in competition with each other for individual success handing out prizes, for example, to students who scored the highest on quizzes. As students worked individually on assignments, she would often say out loud “Wow, [student name] is almost done. See if you all can catch up with him” (observation notes).

Subsequently, students learned that successful participation in Rebecca and Lucy’s classrooms meant becoming adept at “playing school.” Students often guessed what Rebecca or Lucy wanted them to say by following the teachers’ explicit and tacit cues about the importance of information memorization and recall. Students spent considerable time completing assignments silently and individually, while being reminded by Lucy, for example, that their main task was to “finish before the bell rings” (observation notes). By holding students, not the class, responsible for the intellectual work, Rebecca and Lucy isolated students and reduced the number of students willing to publically share science ideas over time.

The role of “space” in science practice

In addition to discursive moves made by the teacher, all of the participants used physical classroom space to shape the treatment of science ideas on the public plane. In this section, I describe two features of the physical classroom space that influenced the classroom community: the layout of the classroom and inscribing science ideas.

Each participant's classroom shared features found in most classrooms, such as tables, desks, a dry erase board, an overhead projector, and other common objects. How the participants used the space and objects in their classroom influenced the kind of epistemic community negotiated between teachers and students. Maria, for example, created an "idea space" in her classroom. In "idea space", students physically carried a chair to the back of the room, sat close together, and discussed theories, partial understandings of concepts, and observations from activities. Maria scaffolded these discussions while inscribing students' science ideas on a poster, which she then hung on a wall. Maria and her students negotiated that "idea space" was not a place for "right" answers; rather, students "know when they're back there that it doesn't matter if they are 'right', I'm [Maria] going to write it down. That there's no wrong answer" (observation debrief). Maria and her students set up "idea space" for a specific kind of interaction – a safe environment for sharing science ideas "in progress" – that became a place where students felt comfortable engaging in conversations they might not feel comfortable with at their "regular" desks. Karen and Joseph also partitioned part of their room off as a "safe" space for students to share science ideas. One student told Karen, "My favorite part of the unit is when we go to the place to share ideas without worrying if they are correct" (observation notes). Joseph's students also rearranged the chairs during idea-sharing time, moving their seats out away from tables and into a circle.

Rebecca also divided her classroom into two distinct spaces. At the front of the room, students' desks faced the overhead projector screen, and each day, they copied notes about canonical science that Rebecca put on public display using a Power Point presentation. Even Rebecca deferred to canonical science texts by removing herself from the front of the room and sitting on the left-hand side during lectures to make sure students could “clearly see the science they need to learn” (observation debrief). At the back of the room stood lab tables and equipment, a space for enacting methods of science experimentation. In this space, students engaged in confirmatory activities in which they mimicked data-gathering processes of scientists and obtained results that Rebecca told them they should get by the end of class. Interestingly, Rebecca's two spaces never overlapped – students rarely discussed science experiments and procedures in the note-taking space, and did not mention science concepts in the laboratory space. Lucy also positioned the back area of her room as “lab space” and the front part of the room as “concept space” (observation debrief). Like Rebecca, Lucy's students understood that conceptual talk was not permitted in “lab space”, and that Lucy shut down experimental discussions in “concept space.”

Tools for inscribing and transporting science ideas

In addition to the positioning of students and objects, tools held an important function in the shaping of the classroom epistemic community. In the physical classroom space, all participants used tools as a means to inscribe and transport science ideas over space and time. Some tools seemed more universal than others. For example, each participant required that students use *science journals* as a place to record science ideas during specific part of class, such as “warm-ups” and “exit tickets.” Each participant also used *temporary places*, such as the

chalkboard, overhead projector, or “smart board” to record science ideas and to transport the ideas to the next class period.

Participants also generated, adapted, and used *face-to-face tools* to record students’ science ideas. By face-to-face tools, I mean that each participant used physical objects, such as poster paper and sticky notes, to inscribe students’ science ideas during class time, subsequently reviewing what students said and thought for the purpose of shaping future classroom activity. Listed below are the types of face-to-face tools used by participants with a brief description of each tool. I indicate the participant who used each tool, and provide a brief description of how they used the tool:

- *Summary table* (Maria & Rebecca): A chart that listed the activities Maria and her students engaged in during a unit, and provided space for linking evidence from the activity to an explanation for some puzzling phenomenon under investigation. Rebecca, however, used a summary table as a list of facts students should memorize, and provided space for students to write out the information they learned from experiments.
- *“Insta-table”* (Joseph): A variation of the summary table in which students selected a hypothesis they were testing and evaluated the strength of the hypothesis given evidence from activities.
- *Hypothesis list* (Karen): A poster on public display showing students’ initial and evolving hypotheses about a puzzling science phenomenon under investigation in the classroom.
- *Red light/Green light* (Maria & Karen): A poster on public display that students use to judge the strength of hypotheses using evidence from activities. “Red light” refers to

the act of using evidence to refute a hypothesis, where as “green light” is when a hypothesis is bolstered with evidence. This tool first appeared at a Critical Friends’ Group and was generated by a university-based methods class peer of Maria and Karen’s. Both Maria and Karen recognized how they could use this tool in their own classroom.

- *Everyday/Science language “converter”* (Maria): A poster on public display by “idea space” on which students’ everyday language is paired with language scientists might use. For example, one card read “That girl is flyin’ down the hill on her skateboard.” The card next to it read, “The girl is accelerating down the hill.”
- *Whole class model* (Maria, Joseph, & Lucy): Maria and Joseph used this tool a poster on public display on which an initial explanatory model is drawn and written, and that changes over time as teachers and students revise the model. Lucy tried this tool during her final unit, but did not provide scaffold for students to add science ideas and revise the model using evidence from classroom activities. Instead, students added information, which Lucy judged as “correct” or “incorrect” and, if “incorrect”, erased it from the model (observation notes).
- *Sticky notes* (Maria, Karen, Joseph, & Rebecca): Maria, Karen, and Joseph used these notes to revise a whole class model. Students used sticky notes to revise part of an idea, add a new idea, remove an idea, and ask questions about part of the model. Rebecca used sticky notes once, on the first day of her genetics unit as way for students to write down “initial information” about the topic. After students placed their sticky notes on the dry erase board, Rebecca recorded the information and threw away the sticky notes.

- *Small group models* (Maria, Joseph, & Karen): Same as the whole class model except students work on these during small group conversations.

As the use of face-to-face tools indicated, *why* teachers and students inscribed science ideas was different given the epistemic community – simply inscribing ideas did not mean that all science ideas held equal value across contexts. Maria, Joseph, and Karen designed multiple tools that allowed science ideas to be used as resources for the classroom community’s learning, to help reify disciplinary reasoning, and to show students how their science ideas changed over time. Rebecca and Lucy also wanted students to see how their science ideas changed, but generally inscribed students’ science ideas to demonstrate how current “misconceptions” could be “fixed” given “correct” information

Students’ epistemic roles and tracing science ideas over time.

Given that the participants shaped the classroom epistemic community, over time, students’ roles in the negotiation of classroom epistemic communities reflected the participants’ personal epistemologies of science, their treatment of science ideas, and the framing of science as a public or private practice.

Maria, Joseph, and Karen publically and purposefully exerted instructional authority to position students’ as drivers of science practice. Students in these classrooms engaged in science-as-practice, creating and revising explanatory models, planning and conducting peer reviewed experiments, and challenging science ideas of each other and the teacher (see Table 4 for examples). Students in Rebecca and Lucy’s classrooms had few opportunities to discuss science ideas together since the participants framed science as a private practice. When students did have permission to talk on the public plane about science ideas, they typically stated answers they thought were “correct”, and asked questions to clarify instructions given by the teacher.

Table 4.

Examples of Students' Discursive Moves Illustrating Epistemic Agency

Discursive Move Made by	Example from Classroom Observations
Students	
Making Claims (Students asserted science ideas in relation to phenomenon under study)	<p><i>About knowledge/data:</i> “I think that the roller coaster energy decreases because it gets slower at the bottom of the loop (Maria’s class). “I think that our data shows that our body is trying to counteract the increase in our temperature by cooling down the rest of our body” (Joseph’s class).</p> <p><i>Agree/disagree with others:</i> “I agree with Michael’s hypothesis because in our roller coaster model, the marble needed to increase speed to get through the loop” (Maria’s class). “I disagree with Sean because I do not think that our brain can control how fast electric impulses travel across neurons” (Joseph’s class).</p> <p><i>Invoking evidence:</i> “Our data shows that the speed of the roller coaster decreases constantly as it goes up a ramp” (Maria’s class).</p> <p><i>Explanation talk:</i> “Maybe our homeostatic responses are related – there could be a relationship between the increase in heart rate, breathing rate, and temperature” (Joseph’s class)</p>
Integrated Science Ideas with Other Ideas	<p><i>Personal experience:</i> “Once when I went downhill in my car, my dad didn’t put on the brakes. We went so fast – faster and faster as we went further down the hill” (Maria’s class)</p>

<p>(Students made sense of their science ideas with other science ideas brought up on the public plane)</p>	<p><i>Invoking other student and teacher ideas:</i> “I want to add onto James’ idea about temperature. He said that the brain controls how fast temperature increases. Perhaps also the brain controls <i>whether or not</i> temperature increases at all” (Joseph’s class)</p> <p><i>Challenge science ideas:</i> “I am not sure about that claim. Can you please talk about the activity that made you say that?” (Karen’s class)</p> <p><i>Predict:</i> “When we exercise faster, our temperature will increase because we are burning energy faster” (Joseph’s class)</p> <p><i>Propose tests/experiments:</i> “To test the hypothesis about heart rate, let’s do jumping jacks for one minute and then immediately take our temperature – we can do it several times and see if our temperature increases when heart rate increases” (Joseph’s class)</p>
<p>Question (Students asked other students and the teacher about science ideas)</p>	<p><i>Clarify:</i> “Are you saying that cells divide faster if they are cancerous?” (Karen’s class)</p> <p><i>Press on science ideas:</i> “Can you explain more about what you mean by ‘heat energy’?” (Maria’s class)</p>
<p>Introduced New Science Ideas to Pubic Plane (Students elevated their own science ideas to the public</p>	<p>“Our roller coaster model is missing gravity – we haven’t talked about that yet” (Maria’s class)</p>

plane they felt were missing from the community's discussion)	
Assign Cognitive	"I like your idea – you back it up with evidence" (Maria's class)
Significance (Students gave other student's science ideas value)	"Your idea will help our model become more explanatory" (Joseph's class)

Note that these categories emerged from observations of Maria, Joseph, and Karen's classrooms. I did not observe any students in Rebecca or Lucy's classrooms using these discursive moves.

Students' discursive moves illustrated their changing epistemic roles in the classroom community. In every classroom community, participants and students negotiated particular ways of knowing and doing science over time. However, not every actor had the same power to make such decisions. This power – *cognitive authority* – was granted to, or taken by, certain people to shape what is known and the work that is done, in other words, to act as an epistemic agent. Maria, Joseph, and Karen purposefully and publically redistributed cognitive authority to their students, resulting in opportunities for students to redefining their role as epistemic agents. By continually shifting power to students, teachers reframed “what counts” as student learning; rather than have students reproducing canonical facts found in textbooks, teachers support students' participation in the actual work of science.

For example, Joseph noted that his students seemed more engaged when they worked on problems that had meaning in their lives: “*Kids want to do science, not someone else's science....* Students want me to guide them in answering questions, not just tell them they changed the correct variable. They don't want a prescribed path. They want to do science the way they see scientists doing it” (observation debrief, italics added). Joseph often worked with students to choose problems to work on, allowing them to plan and enact experiments to answer their questions and test hypotheses. During one unit about homeostasis (whether students could “fake a fever” to miss school), an unexpected result emerged. Students' body temperatures dropped rather than increased during exercise. Joseph did not know the “correct answer” and publically told his students that he did not know, and that they would find out together – redistributing the cognitive authority to students.

Maria, like Joseph, purposefully and publically redistributed cognitive authority to students by stopping class discussions to elevate one student's idea onto the public plane. For example, one student, Fernando, proposed in a unit about the seasons that the earth was closer to the sun in the summer than in the winter. Rather than tell the class whether Fernando was "correct", Maria and her students wrote his hypothesis on a poster and over time, revisited it after completing activities. Eventually, the students' public peer review of Fernando's hypothesis based on evidence from activities resulted in Fernando acknowledging that the data did not support his idea. When he stated this publically, Maria told the class that "we just worked on Fernando's idea together" (observation notes).

Like Joseph and Maria, Karen also worked to redistribute cognitive authority to students over time. During my initial observation, Karen's class did a unit about genetics and why some mutations result in genetic disorders. Karen constantly told students "I won't be up here [talking] for long....you will practice working with your own ideas" (observation notes). Instead of leading students to the correct answer, Karen assessed what the student was thinking, and then encouraged them to revise science ideas. For example, in a brief exchange with students, Karen stated:

Karen [to a student]: See, Sabrina is using evidence.

Student: can I add to Sabrina's idea?

Karen: Of course (observation debrief).

Karen continued to position students as capable of working on science ideas and directing the science practice. For example, Karen, when visiting a small group discussion, reminded students that they are intellectuals capable of engaging in science practice:

Karen: [to group]: Tell me why Marfan's syndrome occurs. And tell me how

it's similar to your disorder. Paul [a student], what's yours?

Paul: Similar because it's deletion.

Karen: Where does it happen?

Paul: In your DNA.

Karen: But where?

Paul: In amino acids?

Karen: Talk as a group. Paul said that Marfan's and hemophilia are deletion.

Where do they occur?

Student 2: Mutations occur in DNA. It's at a certain number.

Karen: Oh, right. You guys found a map of a chromosome on the internet. Why do mutations matter?

Student 2: Because it changes DNA of future cells.

Karen: Ok.

Student 2: Changes nucleotide, which cause change in gene, which causes change in protein.

Karen: Ok, but what about...

Student 3 [interrupts]: RNA.

Karen: Ok. Great idea.

Student 3: It has to turn into RNA to get codons to get amino acid.

Karen: I think you're saying that it's complicated. Where in the process do mutations occur?

Student 2: For sure.

Paul: Hmm...we didn't think that all the way through.

Student 3: Can we work on it now?

Karen: Of course.

Note at the end of this episode that students do not arrive at final answer, and Karen allowed them to continue theorizing as a group.

Throughout the year, students came to recognize Karen's expectations. Remnants of typical science classroom experiences remained for students though, when, for example a student asked if instead of doing model-based inquiry, they could just "watch a video and take notes." When Karen said "of course not", the student retorted, "but it's easier that way." Karen's response was simple: "but your ideas, not your ability to copy my notes, are what are important in this class" (observation notes) – she thus ascribed epistemic agency to students.

While Maria, Joseph, and Karen purposefully and publically redistributed cognitive authority to their students, Rebecca and Lucy maintained the power to shape science practice while positioning students as passive receivers of information whose role was to reproduce science ideas from their teacher or the textbook. One feature of conversations on the public plane in Rebecca and Lucy's classrooms was the constant funneling of students' ideas to "correct" canonical facts. Over time, the expectation for "what counted" as science resembled a purposeful step-by-step question and answer process in which the teacher "led" students to the truth – what I refer to here as *breadcrumb epistemology*. Like the Grimm Brothers fairy tale in which the protagonists find their way home by following a trail of carefully laid breadcrumbs, Rebecca and Lucy set out a path of questions for students designed to lead them to "truths" about the world. Students did not deviate from the set path of questions because if they did, they would get "lost", deviating from the task or in keeping pace with the curriculum standards. To "make it home" successfully, students needed to merely answer a series of questions from the teacher, and then

had to repeat back their statements in the set order Rebecca or Lucy hoped to hear. For example, Lucy entered a small group discussion to check on students' progress in completing a problem about valence electrons:

Lucy: What are the electrons doing?

Student: Moving around.

Lucy: If I'm in one place versus moving, how much space do I take up?

Student: More if you are moving.

Lucy: So electrons take up space because they move. Why can't we cram them together?

Student: Not enough space.

Lucy: Ok, that's part of it. What about the charge? What is the charge here?

Student: Negative.

Lucy: What about two positives and two negatives – what about the charges there?

Student: They cancel out.

Lucy: So put it together...

Student: There is too much space taken up because the charges cancel out and the electrons are too close together.

Lucy: Good. Write that down.

Note two features of Lucy's questioning that illustrate her simultaneous expectations that students to participate in science and learn the standards. First, Lucy was not simply asking "fill-in-the-blank" questions. She expected students to make sense of complicated science ideas. Second, Lucy pressed the student to repeat a predetermined answer. Rather than asking a question designed to press on the student's answer about space and electrons, Lucy steered the student back to the "path" by asking another leading question.

In another example of breadcrumb epistemology about cells and homeostasis from Rebecca, she enacted a similar pattern of asking questions and “covering” standards:

Rebecca: What is hypertonic?

Student: Low concentration.

Rebecca: Of what?

Student: Whatever.

Rebecca: Hypertonic is more solutes outside the cell than inside. When we added salt water, we made it hypertonic. What do you need to add to the outside of your drawing?

Student: Water molecules.

Rebecca: More or less?

Student: More.

Rebecca: Ok, but still show the salt in your drawing. What happens to the water?

Student: Don't know.

Rebecca: When you add salt here, there is less room for the water. More salt equals less water. So put that together.

Student: If there is a low concentration of water outside the cell and more salt there, the water will go outside.

Rebecca: Good. Write that down.

Tacitly or explicitly, Rebecca and Lucy worked to maintain cognitive authority in their classroom's epistemic community through the establishment of breadcrumb epistemology as the norm for science practice.

The retention of cognitive authority by Rebecca and Lucy limited students' opportunities to engage in science-as-practice. For example, Rebecca frequently told students that their main

role during class was to complete the required assignments, and not to worry about their conceptual understanding. She frequently told students “it’s ok if it is not right yet – we’ll correct it tomorrow if we need to.” During Rebecca’s final unit, students did not offer up one science idea other than to “correctly” answer a question posed by the teacher.

Like Rebecca, Lucy reinforced her role as the cognitive authority by making the primary activity in her class copying notes from the overhead projector. Making note-taking the central focus of instruction set up tensions between students asking science questions and Lucy’s insistence that they class “stay on task” (observation notes). For example, a student asked about the number of valence electrons in the outer shell of an atom Lucy was using as an example problem:

Student: Why can the outer shell hold only three valence electrons. Why not four?

Lucy: Did you count to see how many extra electrons there are?

Student: Yes, but my question is more about why three can fit, but not four.

Lucy: Well, that’s complicated. Let’s stay on task for now.

Lucy also positioned the textbook as a primary source for “correct answers.” In the unit about valence electrons, she told students that “reading the chapter will teach us about bonding” (observation notes). Students completed problem after problem of examples, and at the end of class, Lucy enacted an exit ritual to reinforce her power. She made students line up in a single file line and as they passed by her, they stated one correct fact about valence electrons. Thus Lucy established herself as the clear authority, acting as the physical and metaphorical gatekeeper – students could not leave until she heard them utter a correct statement.

Three unit examples

As the findings illustrate, the participants and their students negotiated epistemic communities during the school year through complex interactions around *placing value on science ideas, defining epistemic roles of teachers and students, and positioning science as a public or private practice*. In this section, I present stories of three units – Maria’s roller coaster unit, Karen’s English ivy unit, and Rebecca’s genetics unit – to illustrate how the negotiation of a classroom epistemic community differed across contexts. For each unit story, I describe how the participant and their students shaped the science activity together.

I present Maria and Karen’s unit stories because they illustrate an interesting phenomenon I observed – even among participants enacting ambitious practice – differences emerged between the epistemic communities. Since Maria, Joseph, and Karen all developed different personal epistemologies of science and visions of how science teaching and learning should occur in the classroom, “shades of gray” between these participants surfaced as they worked with their particular students in their school context to shape opportunities to learn science-as-practice:

Maria, Joseph, and their students constructed localized knowledge within their classroom epistemic community. The knowledge developed in the community was not “new” or “grand theory” knowledge such as scientists would recognize, but is knowledge that developed and applied to problems generated by the classroom community within the school context.

For Karen, her classroom became a *hybrid space* in which she and her students worked on problems from their neighborhood, blurring the boundary between the classroom epistemic space and the local community. The class generated data, made claims, and worked on ideas that added new information that scientists recognized as advancing a theory about a phenomenon in the students’ community.

Maria's roller coaster unit

In this section, I describe Maria's roller coaster unit. Note that how Maria and her students work on science ideas shaped, over time, the outcome of the unit in a way that Maria could not have predicted when planning. Also take note of how Maria learned *with* and *from* her students.

In the roller coaster unit, Maria presented students with a video of a puzzling scenario of how a roller coaster could go through the same loop twice on a track – once forward, and once backward after traveling up a small hill. Though Maria tried to shape the unit around students' interests and lived experiences, she acknowledged that “this puzzling phenomenon is not really new – scientists know how roller coasters work.” However, working on roller coasters was unique for Maria and her students in their localized classroom context. In the initial part of the unit, Maria and her students engaged in activities that provide evidence about potential and kinetic energy. These discussions led to a conversation in which Maria drew a whole class model that began to explain how high up the roller coaster cart needed to begin in order to go through the loop.

Continuing to negotiate an epistemic community, Maria agreed to students' requests that they recreate and test the model she drew to explain the roller coaster's energy. To build and test the model, students used long pieces of foam, created a loop, and dropped a marble down the foam from the height indicated on Maria's drawing. Despite numerous attempts students could not create a physical model that matched Maria's drawing – the marble continually dropped off of the track before the loop. Rather than become frustrated, *some students gathered evidence that overwhelmingly demonstrated that Maria's model did not represent the roller coaster*

phenomenon from the video. During this class period, Maria noted her students' evidence, asking students about their research:

Maria: You mean you can't get the marble to go through the loop at all?

Student 1: Nope, it can't get enough energy.

Maria: What do you mean?

Student 2: We mean that the marble doesn't start high enough in your model to get enough energy to go through the loop.

Student 3: Not enough potential energy to turn into kinetic energy.

Maria: What do you think needs to change about my model?

Student 1: I wonder what would happen if we started the marble higher up on the track.

Student 3: Could we try that?

Maria: Sure, tell me what happens.

In this example – Maria's first discussion with students about her model – Maria decided in-the-moment to let students revise *her* model because "they [students] did such great work pointing the flaws, I thought they should get the chance to make it better" (observation debrief). Maria thus granted students cognitive authority to act as epistemic agents and revise her explanatory model. She told the students that she did not know the "correct" answer since students disproved her model. However, Maria also informed students that the job of the classroom community would be to build a better model using ideas about potential and kinetic energy. The rest of the unit involved multiple rounds of Maria and her students using evidence from their various attempts at modeling, and face-to-face tools such as small group models and the Red light/Green light poster, to create a better whole class model that more accurately represented the roller coaster phenomenon.

At the end of the unit, Maria told students how much *she learned from them*: “When I say we revise our ideas in this class, I don’t just mean you [students]. I mean me too. You showed me that my model was wrong, and I wouldn’t have known that without your help and hard work” (observation notes). Maria thus thanked students publically for helping her learn, and showed students their role as epistemic agents shaped the classroom epistemic community.

Karen’s English ivy unit

In this section, I describe Karen’s roller coaster unit. Note that how Karen and her students work on science ideas shaped, over time, the outcome of the unit in a way that Karen could not have predicted when planning. Also take note of how Karen learned *with* and *from* her students when they ventured out into the students’ community rather than remained in their classroom setting.

In this unit Karen wanted students to study invasive species and how their presence altered ecosystems. Karen, when walking around her students’ community, discovered that the English ivy covering up buildings and trees was not a native plant to the area. Karen called the local government and asked if they had data about why English ivy seemed to be a successful invasive species. The local officials, however, told Karen that they “did not study the ivy because there is too much of it and it’s cheaper to kill it” (observation debrief). Rather than become discouraged, Karen told her students that the county government did not know much about English ivy in their community, at which point a student raised his hand and asked, “Can we study the ivy and show the government what we find out?” (observation debrief). Karen decided to recast her unit to let students take up the role of lead investigators, telling them, like Maria, that she did not know the “correct” answer but that they would all work together as a community to figure out why English ivy was so successful as an invasive species.

The unit progressed with students acting as epistemic agents. First, students constructed small group explanatory models to theorize about the ivy's success as an invasive species. Next, Karen and her students ventured out into their community to collect samples of both English ivy and native plants that the ivy covered or grew over. While in their community, some students photographed various English ivy plants, recorded latitude and longitude for the plants, and created a GIS map. After returning to their classroom with plant samples, Karen and her students constructed a list of seven hypotheses about why English Ivy could be successfully outcompeting native plants in the students' community. Student groups volunteered to test each of the seven separate hypotheses. Before conducting the actual experiments, students conducted a peer-review of other groups' proposed experimental designs to make sure that the data from the experiment would provide both evidence for the explanatory model and would not be the result of errors in the experimental design. After students ran the experiments and gathered data, they conducted another peer review of the methods and results to make sure that the data collected matched what should have happened in the actual experimental trials. Note how Karen's role of facilitator emerged as she presented students with opportunities to act as epistemic agents rather than prescribe their every action.

To continue positioning students as epistemic agents, Karen provided an opportunity for the classroom community to revisit the strength of the seven hypotheses based on results gathered from students' experiments. Using the Red light/Green light tool, students began to synthesize hypotheses, noting the difficulty of explaining English ivy's success using a limited range of ideas and evidence. Karen was pleased by students' insistence that the final explanation of the English ivy phenomenon was complicated, noting "I'm glad they see that ecology is complex, and they couldn't have seen this without doing the science themselves" (observation

debrief). After revising their explanatory models, Karen and her students reconnected with an admittedly stunned local government official, who “had difficulty believing that high school students could engage in science beyond recalling facts” (observation notes). Karen hoped that as students took on the role of scientist in her classroom, they would see the “boundary of the science classroom and their community blurring a bit – I think students can do science that impacts their community in my class” (observation debrief). This blurring of the classroom/community boundary harks of a *hybrid space*, which I will explain in the Discussion section.

Rebecca’s genetics unit

In this section, I describe Rebecca’s genetics unit. Note how unlike Maria and Karen, Rebecca treated students’ science ideas as “misconceptions” or “right answers”, and that she tried to limit public discourse in order to “stay on track with the curriculum pacing guide” (observation debrief). Also take note of how Rebecca positioned herself, and the textbook, as the authority of canonical science knowledge. Rebecca provided opportunities for students to memorize canonical information, but unlike Maria and Karen, she did not learn *with* students about a puzzling phenomenon.

For her genetics unit, Rebecca selected “twins” as a puzzling phenomenon because she thought her students would find this topic “interesting and relevant” (observation debrief). On the first day of the unit, Rebecca tried out a practice from her university-based methods course – eliciting students’ science ideas about a puzzling phenomenon. Students, individually and silently, wrote down their theories about why twins look alike on sticky notes. They then placed the sticky notes on the dry erase board, which Rebecca collected after class, and checked to “make sure that students understood enough basics to move on” (observation debrief). Note how

Rebecca made an instructional decision – “moving on” – based on her analysis of students’ science ideas.

The following class period, as well as the next seven lessons, Rebecca lectured to students for thirty to forty minutes about various genetics topics in order to complete the standards. Each day, students sat silently and copied notes that Rebecca wrote on the board or prepared previously on Power Point slides. After each lecture, students engaged in a confirmatory activity, usually by themselves or with one partner. These activities, designed by both Rebecca and her department, reinforced canonical knowledge and texts as the standard students should strive to meet. Rebecca used activity time as an opportunity to hear and fix students’ misconceptions, as well ask questions that reinforced the classroom community’s expectation of breadcrumb epistemology.

By lecturing and positioning science as a private practice, Rebecca limited students’ participation on the public discursive plane. Students rarely spoke for more than thirty seconds at a time, and frequently collaborated to figure out “what the teacher thinks is the right answer” (student comment in observation notes). When students uttered a science idea “unrelated to the topic at hand”, Rebecca quickly shut such talk down (observation notes). For example, one student, Nick, asked a question about Punnett squares, which Rebecca outright dismissed:

Rebecca: Any questions before we move on?

Nick: Yep. In the Punnett square, there are four kids.

Rebecca: Uh, ok.

Nick: But when you have a fifth kid, where does that kid go?

Rebecca: Great question Nick. We’ll get to that next week (observation notes).

In this example, Nick was the first student during the genetics unit to ask a question seeking an answer beyond the “correct” canonical information Rebecca usually delivered. Rebecca, while acknowledging Nick’s question, dismissed his idea into some imaginary time – “next week.” When I asked Rebecca after class why she treated Nick’s idea as she did, she replied “it just shows that he clings to misconceptions and that the class needs to do more Punnett square practice” (observation debrief).

By the end of the unit, Nick’s query remained unanswered and students no longer asked “unrelated” questions. Students witnessed Rebecca’s reaction to Nick’s question and subsequently internalized Rebecca’s expectation that any talk on the public plane should be “right.” In other words, students came to understand Rebecca’s epistemic expectations, and this public display solidified students’ roles as passive recipients of information for the remainder of the year.

As the cases of Maria, Karen, and Rebecca illustrate, the participants and their students negotiated different epistemic communities over time as they placed value on science ideas, defined epistemic roles of teachers and students, and positioned science as a public or private practice. For example, Maria’s roller coaster unit exemplified how her personal epistemology of science around “tinkering” shaped classroom science activity. Maria and her students negotiated that theory-building and other epistemic work could occur while manipulating materials. However, Karen did not see “tinkering” as important in her own practice (personal epistemology interview). Instead, Karen and her students moved beyond the classroom walls, taking their epistemic work into their community and building science knowledge through a more linear process of hypothesis creation, testing hypotheses through experimentation, and using evidence to support or refute hypotheses. Both teachers, however, worked to create a classroom space in

which students could learn science-as-practice. Rebecca negotiated a different epistemic community with her students, influenced by the “organizational” aspect of her personal epistemology of science. Rebecca’s organization included keeping pace with curricular standards (i.e., making sure students got all of the “answers” they needed to complete their work), and helping the class “move on” when they got “distracted” (observation notes).

Idea maps

To visually illustrate how the participants’ classroom epistemic communities differed, I created “idea maps.” These maps include a physical representation of the *introduction* of science ideas (where ideas come from – teachers, students, canonical texts) and their *treatment* (how ideas change over time). To show an example of the difference between classroom epistemic communities, I provide an idea map segment encompassing five minutes of class time that is representative of one day of Maria’s roller coaster unit and Rebecca’s genetics unit. For each map segment, note the following key features:

- The epistemic press on students’ knowledge claims by teachers
- How students contribute to science activity
- How teachers and students maintain or cut off science ideas

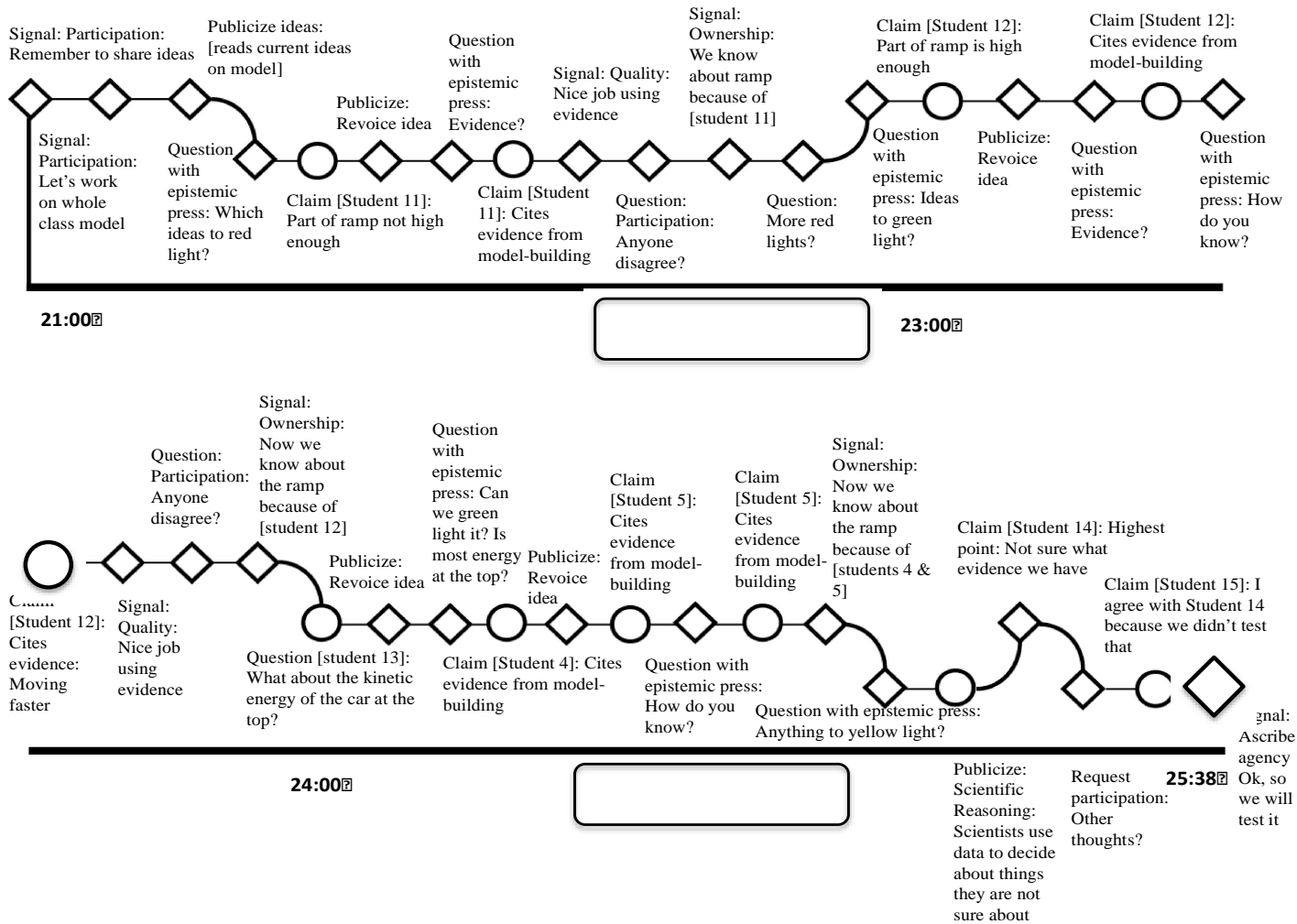
These features of the episode provide insight into the different classroom epistemic communities that Maria and Rebecca negotiated with their students over time. Note that all quotes from Maria, Rebecca, and their students come from transcriptions of videotaped classroom observations.

I designed the idea maps using specific symbols to trace the origin and treatment of science ideas over time. Here, I provide the key for the symbols and describe their significance in order to facilitate reading the idea maps:

- Diamond: Indicates a teacher's public statement.
- Circle: Indicates a student's public statement. The number of the speaker indicates which student has spoken during the class period. For example, if a circle has the number 11 inside it, the map is showing the comment of the eleventh student to speak in that class period.
- Time: The point of time during the class period in which someone spoke or another action occurred.
- Straight line between symbols (for example, connecting a circle and a diamond): One actor builds on the science idea of the previous actor and continues the current thread of conversation.
- Curved line between symbols: One actor builds on the science idea of the previous actor but redirects the thread of conversation to a related but different course of talk.
- Dotted line connecting symbols: One actor resurrects a science idea of a previous actor after the idea has been "buried" in the conversation (e.g., not discussed publically for several turns of talk).
- Square: Indicates when, how, and by whom a science idea was inscribed.

Figure 5.

Idea Map of Maria's Class



Maria's idea map

In this segment on the ninth day of the unit, Maria and her students were engaged in a whole class discussion about her roller coaster model using the Red Light/Green Light face-to-face tool. Up to this point in the lesson, Maria and her students talked about relationship between energy, speed, and distance. In this time segment (minutes 21:00-25:38 of the class period), the class revisited and discussed the whole class model Maria drew the previous day.

Maria began this time segment by discursively signaling her expectations for student participation, indicating that students would use their ideas to revise the whole class model. Immediately following the expectations, Maria asked a question with an epistemic press: "Which ideas about energy can we red light?" By asking this question, Maria expected students to disprove aspects of the whole class model that did not hold up to the roller coaster experiments and subsequent evidence. A student then made a claim about how one part of the whole class model was incorrect because the car would not have enough potential energy to make it through the loop twice. Maria immediately responded by both revoicing the student's idea and then pressing on the student epistemically: "Why is that not true?" After the student responded with evidence that the potential energy needed to be higher in order to change into enough kinetic energy to travel through the loop twice, Maria asked the class if they agreed with the student's claim and evidence. When students verbally agreed, she ascribed ownership of the "needs to be higher" idea to the student. Next, Maria noted that the class community learned something about the phenomenon: "We as a class agree that energy is changing." Note that Maria both positioned the community as the "knower" and framed science as a public practice.

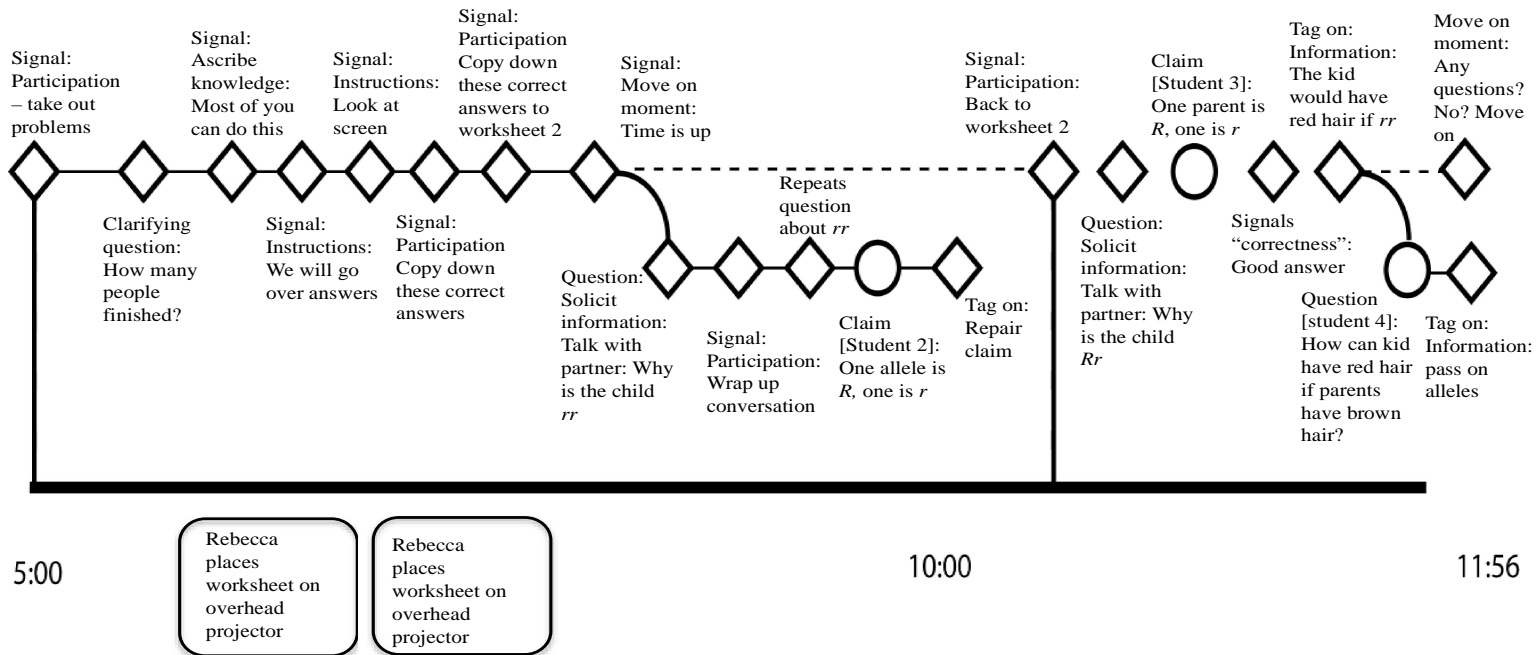
After asking students about pieces of the model to red light, Maria posed another epistemic question: "Which ideas about energy can we green light?" When a different student

stated a claim, the discursive routine of the red light segment repeated: Maria's epistemic press, the student citing evidence, Maria revoicing the idea and ascribing ownership to the student, and finally, adding the information to the community's knowledge. Note that the idea of energy in the roller coaster that started with Maria's press for red lights traveled through two connected threads at this point.

Next, a student continued the energy idea thread by stating a claim about potential energy and the starting height of the roller coaster car. Again, Maria and her students engaged in the same discursive routine of an epistemic press, evidence, and ascribing ownership of the idea to the student and classroom community. To end this segment, Maria asked for energy ideas to "yellow light", meaning energy ideas in the whole class model that students needed more evidence to confirm or disprove. A student asked about the potential energy of the roller coaster car at a lower height, and again, Maria and her students engaged in the epistemic discourse. Note that at the end of the five minute segment, Maria and her students engaged in four related thread of talk around energy in the whole class roller coaster model.

Figure 6.

Idea Map of Rebecca's Class



Rebecca's idea map

In this segment on the sixth day of the unit, Rebecca and her students were engaged in a whole class discussion about Punnett square practice problems from worksheet. Up to this point in the lesson, Rebecca reviewed vocabulary students needed to “know to pass the test”, such as allele, trait, and DNA. In this time segment (minutes 5:00-11:30 of the class period), the class compared their answers to the Punnett square problems to the correct answers Rebecca placed on the overhead projector.

Like Maria, Rebecca began this segment by signaling her participatory expectation, that students take out and red over their Punnett square problem worksheet from the previous class period. Rebecca then ascribed knowledge to her students, reminding them “most of you know how to do these problems.” Next, Rebecca placed her answers, the “correct” answers, on the overhead projector, and asked students to check their answers.

After a few seconds of silence, Rebecca asked students to “to turn and talk to your partner about why one part of the Punnett square has a gene rr .” The students conversed for thirty seconds, and then Rebecca signaled that student should again pay attention to her. Rebecca repeated her question about rr , and a student responded “Because one parent is R and the other is r .” Rebecca quickly “fixed” the student’s answer: “No, a R parent could not pass a little r allele. For that gene, both parents would have to pass down a r to their child.” Note that unlike Maria, Rebecca did not press the student for evidence about their answer, nor did she ask the class to respond. Instead, Rebecca “repaired” the student’s “misconception.”

Rebecca then repeated the discursive pattern, asking students to check their answer, discuss another scenario with a partner, refocus their attention back on her, and provide an answer her original scenario. However, rather than offer an answer, a student asked a question:

“How a kid can have red hair if the parents have brown hair”? Rather than pose the question to the class or press on the student to unpack their question, Rebecca offered an answer: “If both the parents had the red hair allele, they could pass it on to their child.” Rebecca then enacted a “move on moment”, asking students if they “have any more questions.” When no students respond, Rebecca announced that the class needed to take out their notebooks for a “journal check.”

Revisiting the three key features of Maria and Rebecca’s classroom epistemic community illustrates their similarities and differences. First, both teachers enacted an epistemic press on students’ knowledge claims. Maria pressed students to use evidence after making a knowledge claim; in fact, there are *no instances in any of Maria’s classes I observed in which she does not ask students for evidence when they make a claim*. Rebecca pressed students to produce “correct” answers, thus illustrating that the epistemic norm of talk was to reproduce canonical information. Second, students in both Maria’s and Rebecca’s classes contributed to the science activity. In Maria’s class, students took up the role of active epistemic agents. They built off of each other’s ideas or Maria’s ideas, took the conversation in a direction without asking Maria’s permission first, and added evidence from activities to the classroom community’s understanding of the puzzling phenomenon under investigation. In Rebecca’s class, students answered questions posed by the teacher, thus providing evidence of they understood a topic well enough to “move on.” Third, Maria, Rebecca, and their students played different roles in maintaining or cutting off students’ science ideas. Maria asked all students to contribute to whole class model, and students discussed science ideas without her mediating talk in between each comment. Rebecca responded immediately and purposefully to each student comment, particularly when a student asked a question Rebecca deemed “off topic” (observation debrief). When students ask a

seemingly tangential question, Rebecca immediately shut down the “incorrect” thread of talk with a “move on moment.”

Discussion

In this section, I describe why the participants’ negotiation of epistemic communities with students resulted in differing opportunities for students to become epistemic agents (or not). I first revisit learning science-as-practice, demonstrating how Maria, Joseph, and Karen’s classrooms provided students with opportunities to legitimately participate in science work. Next, I describe why placing value on science ideas, treating science as public or private work, and the participants’ personal epistemologies of science shaped opportunities for students to engage in science in the classroom. Finally, I discuss why using lenses from STS and HPS literature open up new possibilities for analyzing classroom spaces and science practice in K-12 settings.

Revisiting science-as-practice

Since science-as practice must, by definition, include opportunities to for students to participate in science work, learning science cannot be reduced to the assimilation of facts, the mastery of skills, or the “correction” of misconceptions. Maria, Joseph, and Karen’s classrooms represented what Engle and Conant (2002) suggested as a framework for learning science-as-practice through *productive disciplinary engagement*. In this study, Maria, Joseph, and Karen presented students with opportunities to:

- *Problematize typical classroom science*: Maria, Joseph, and Karen encouraged students’ science ideas, including their experimental proposal and challenges to the teacher’s knowledge, rather than expecting that they should simply assimilate facts, procedures, and other “right answers.

- *Take and use cognitive authority:* Maria, Joseph, and Karen provided students with opportunities to define, address, and resolve science problems. In addition, all members of the classroom epistemic community had cognitive authority agents to shape science activity.
- *Hold each other and the teacher accountable:* Maria, Joseph, and Karen negotiated an epistemic community in which students held each other and the teacher accountable to others and to the emerging science learning norms.
- *Use resources:* Maria, Joseph, and Karen provided students with the necessary intellectual and material resources to engage in science. These resources included sufficient time to pursue a problem in depth, inscribing students' science ideas on face-to-face tools to travel over time and space, and supporting discourse that created a safe environment to share and work on science ideas.

Unlike Rebecca and Lucy's classes that promoted a view of science-as-accumulated-knowledge, students in Maria, Joseph, and Karen's classes had more opportunities for learning science through their legitimate participation in their classroom's way of making sense of, evaluating, and representing the world as epistemic agents (Longino, 1990; Warren & Rosebery, 1995).

STS and HPS lenses into learning science-as-practice

As I have noted at the beginning of this article, there are few studies that try to understand how and why students can learn science-as-practice in K-12 classrooms, and therefore, few analytical tools in science education to help unpack why Maria, Joseph, and Karen's epistemic communities became so different than Rebecca and Lucy's classrooms. In this

study, using lenses from STS and HPS literature helped illuminate features of Maria, Joseph, and Karen's classrooms that might otherwise have gone unnoticed.

Classroom context matters

STS and HPS scholars note that science practice can only be understood by analyzing the larger systems of activity that surround it. Revisiting the idea of epistemic communities, Hankinson-Nelson (1990) noted that any science practice involves a “network of theories and beliefs, including standards of evidence, practices, and experiences” that are decided upon by actors” (p. 296). Over the course of the school year in this study, the science practice that emerged in each of the classrooms varied because *who* was in the spaces was different. Maria, Joseph, and Karen set up different kinds of epistemic communities than Rebecca and Lucy because they helped position students as epistemic agents in negotiating “what counted” as science in their classroom.

Trust

Maria, Joseph, and Karen trusted students as epistemic agents, capable of working on ideas even when the teacher was not present. The process of trusting others as epistemic agents can be glacially slow, as Knorr-Cetina (1999) noted in her studies of two science labs. Knorr-Cetina documented that trust between actors is critical for making science knowledge, and that this trust is slowly granted over time from those with authority to those without. Once those with authority see that other actors are “trustworthy” to do experimental work, collect data, report results, and revise models, the labs “downgrade the individual as an epistemic subject and instead emphasize communitarian mechanisms like collective ownership and ‘free’ circulation of work (p. 167). Over time, Maria, Joseph, and Karen trusted what students said and did as

epistemic agents, whereas Rebecca and Lucy did not place the same trust in students, constantly correcting students' ideas and experimental procedures.

Epistemic community counteracting "individualizing forces"

Another purposeful move by Maria, Karen, and Joseph to negotiate an epistemic community with students was to publically position the community as the knower. This finding aligns with Knorr-Cetina's (1999) assertion that productive labs are places where "Lab leaders counteract and dissipate the individualizing forces and the social power accumulated by certain individuals and groups" (p. 186). In this study, Maria, Karen, and Joseph worked to make *all students'* science ideas important, and over time, the science work of the classroom became more student-driven. This finding counters research in STS and HPS that shows most labs privilege individuals by awarding grants, prizes, money, and other tokens at the expense of other actors, even if the actors participated in the work (Knorr-Cetina, 1999).

Embracing "the mangle of practice"

As Maria, Joseph, and Karen came to understand, positioning students as epistemic agents was "messy work" (Joseph, final interview) because they, as teachers with instructional authority, had to make in-the-moment decisions that required, in some cases, recasting an entire unit of instruction. These quick decisions to change instruction led to the classroom science activity resembling what Pickering (1995) called the "mangle of practice" (Pickering, 1995). Given the unpredictability of contextual factors, Pickering argued "Just as we do not know what [a] new machine will do, we do not know what other people, or even ourselves, will do next....The goals of scientific practice emerge in the real time of practice" (p. 18, 19-20). In this study, rather than panic when activities did not work or students veered in unplanned conceptual directions, Maria, Karen, and Joseph publically told students that science was often done in such

fits and starts. Rebecca and Lucy, however, portrayed science as a linear process: science was orderly, objective, and knowledge was fixed and could be confirmed by asking an authority. By positioning science as an individual and orderly practice, Rebecca and Lucy placed value on efficiency and task completion rather than on students' scientific reasoning. They also separated science into two separate aspects (sometimes using the physical layout of the room) that are rarely related: processes (*the scientific method*) and product (factual information).

Why teachers' personal epistemology mattered for epistemic communities

The participants' personal epistemologies of science – the individual teacher's understanding of what science is, how scientists know what they know, and how science "works" shaped classroom science practice. Like Smith et al. (2000), this study showed that teachers with different personal epistemologies of science aimed to help their students learn and do science differently. This is in part due to the teachers' science experiences. While Maria, Karen, and Joseph participated in many aspects of science practice, Lucy and Rebecca learned science only through science from textbooks and tend to hold conceptions of the discipline and of how students learn science that are inconsistent with how science knowledge actually unfolds through ongoing investigations by scientists (Gess-Newsome 1999; Smith et al., 2000).

In this study, the opportunities for students to learn science ultimately depended on what the teachers thought science was and how it should be presented in a classroom space. Lucy and Rebecca tried to control the space by controlling the work – as authorities, they wanted to assume control of the instruments, talk, and knowledge of science practice (Fabian, 2000). Maria and Joseph also wanted to control the space, but they wanted to exert instructional authority to make their classroom space a place where the “mangle of practice” could happen.

Power and the treatment of knowledge – the heart of science practice

One analytical lens emerging from STS and HPS literature illuminated issues of power associated with science in classroom epistemic communities. Historically, debates about who is permitted to “do” science, what kind of science actors are permitted to engage in, and what kinds of explanations society wants produced, do not enter K-12 classroom spaces. Yet as Hankinson-Nelson (1990) noted, “Social and political concerns have been found to play a significant role in shaping the directions of scientific interest and research: the questions addressed, methodologies adopted, and the hypotheses and theories accepted and rejected. It has also become increasingly clear how extensively the theories, research programs, and methodologies we consider or adopt in the sciences shape, in turn, our social, political, and moral perspectives and experiences” (p. 9). Typical school science, then, presents an image of science that misrepresents how the discipline unfolds in the world.

If students come to think of science as a static set of procedures and facts, as conservative classroom activity supports, they will believe that they can only participate in science as “technicians”, those who repeat experiments and reproduce knowledge that someone else described long ago. As Longino (1990) noted: “While the official picture of a field presented in its textbooks is the picture of a uniform and consistent understanding, the background from which this understanding emerges/is selected contains alternative interpretations of the data included in the textbook picture as well as data inconsistent with it. The selection represents...what a society (those in society with the power to effect their preferences and privilege their needs) thinks it should know or wants to know” (p. 186). In other words, society, thus far, wanted to make students think that they needed to learn to participate in science as it currently exists in practice.

However, Maria, Karen, and Joseph worked toward a different kind of science in their classrooms, a practice in which *all students* shape the work that is done – in other words, Maria, Joseph, and Karen thought that *students could and should take up the role of epistemic agents in classroom science rather than participate passively*. Warren and Rosebery (1995) refer to this stance as “equity in the future tense”, in which teachers work to problematize the asymmetric power structures between teachers and students. As Warren and Rosebery (1995) note, “we believe that the remaking of science education into a more egalitarian sense-making practice entails deep transformations of identity for teachers and students alike, transformations that empower them to think, talk, and act scientifically (p. 27).” To undermine this power difference means that teachers and students, together, dismantle an entrenched message about American society – while society claims to value competition and individuality, STS and HPS literature shows that science is, in fact, the product of many individuals working in concert (Hankinson-Nelson, 1990; Longino, 1990).

This is a particular value – the power of community rather than the importance of the individual – that teachers can help students understand through learning participation in science-as-practice. As Longino (1990) notes, “When we recognize that communities are knowledge “acquirers” and give up the long-standing focus on individuals, we find ourselves taking into account the relationship between communities and values. Values emerge within and shape a community's practices and theories, and many of these values are political in nature and consequence” (p. 14). Value placed on the community has direct implications for the division of cognitive labor. Rather than science, and society, becoming a hierarchy of cognitive authority in which technicians (i.e., students) and others are put in “lower” and *less powerful* positions, science can teach students that their ideas can and should *have a bearing on how and what*

knowledge develops within science communities and how that knowledge is communicated to and received by the society at large (Addelson, 1983). Positioning students as epistemic agents in a classroom community disrupted the current reality of most science classrooms and the “real world” in which those with cognitive authority do not redistribute it to those without power.

Karen’s hybrid space

Maria, Joseph, and Karen’s classes are unique because they are examples of equity in the future tense – what happens when students both learn science practice and press on those with authority to change the practice in classroom spaces. Karen’s class became even more unique because she and her students negotiated a different kind of epistemic community than Maria and Joseph – a hybrid space. Barton and Tan (2009), and Moje et al. (2004), speak of hybrid classroom spaces as places that both link traditionally marginalized funds of knowledge and Discourses to academic funds and Discourse, and destabilize and expand the boundaries of “official” school activities. Karen’s class was a hybrid space because students did not just memorize science, nor did they merely engage in science practice contained within their localized classroom community. Karen’s students suggested that they go out into their community, a place that was typically marginalized as a space in which science does not happen, and they investigated a phenomenon, the English ivy, that was dismissed by the local government. Karen and her students, as co-learners, produced knowledge claims that did not exist before creating new ways of looking at a local phenomenon that did not exist before that ecology unit while simultaneously blurring the boundaries between the classroom and community (Barton & Tan, 2009).

Conclusion

I hope my study initiates a conversation in science education about what science teaching and learning can become in K-12 schools for two reasons. First, this study could be a step forward in unpacking ambitious teaching by helping the field imagine new forms of expertise in terms of teacher responsiveness to students' science ideas and the general orchestration of classroom epistemic communities. Second, this study unpacks how teachers work to create classrooms like those of Minstrell's and the CheChe Konnen project to support students' participation in science practice.

One fundamental issue to address is the role of teacher preparation in supporting novices for such work. This study demonstrated that teachers can help students take power to shape the norms, values, and practice of their classroom epistemic community. However, the participants' personal epistemologies of science provided evidence that they need opportunities to learn science-as-practice themselves – to get involved in the conceptual, epistemic, social, and material aspects of science practice. As Hankinson-Nelson (1990) points out “Changing science requires changing the practice of the scientists” (p. 6). Rebecca serves as an example of a teacher who sat in large lecture classes and conducted confirmatory experiments in lab sessions as an undergraduate science major. Her experiences shaped how she structured her classroom science practice. However, Maria, Joseph, and Karen all engaged in science-as-practice before becoming teachers, and their insights into the discipline shaped how they learned to teach.

I hope this study serves as an example of what is possible when teachers do not underestimate what students are capable of, instead supporting them as intellectuals, scientists, and epistemic agents. Yet a question remains about the science practice in classrooms when students take on the roles of epistemic agents. Maria, Joseph, and Karen's students did not

conduct Nobel prize-worthy experiments. However, in their localized classroom context, the students did advance their community's understanding of science, and in Karen's case, presented their own evidence-based theories to scientists in the local government. I believe that these cases provide an opportunity for the field to confront the question of what science is possible in K-12 classroom spaces. We need to move beyond thinking that students can mirror or mimic science and try to understand what science kids can do in classrooms. Karen's class is certainly unique, but it showed a kind of science practice that can emerge from ambitious instruction. Her students provided a compelling example to challenge society's notions about what is possible in K-12 schools.

SECTION 3

Theoretical, methodological, and practical considerations for practice-based teacher education and research

Recent trends in teacher education literature herald a turning point in the field as researchers frame teachers' preparation and learning around *ambitious practice* and the *core practices* comprising such instruction (Ball, Sleep, Boerst, & Bass, 2009; Grossman, Compton, Igra, Ronfeldt, Shahan, & Williamson, 2009; Grossman, Hammerness, & McDonald, 2009; Lampert, 2010; Kazemi, Franke, & Lampert, 2009; Windschitl, Thompson, Braaten, & Stroupe, 2012). Teachers enacting ambitious practice provide opportunities for all students to legitimately participate in the authentic work of the discipline as they adapt and innovate pedagogical routines and tools to meet students' emerging needs (Ball & Forzani, 2011; Ball, Sleep, Boerst, & Bass, 2009; Duschl, 2008; Kazemi, Franke, & Lampert, 2009; Lampert & Graziani, 2009).

In this essay, I reflect on both the literature and my experiences as a researcher studying how and why beginning teachers learn from attempts at ambitious practice. Based on my dissertation experiences, I argue that redefining the teaching profession around ambitious practice has four implications for research that could be done with regards to beginning teachers:

- The timescale for studying beginning teacher learning from practice needs to extend in order to see their “fits and starts” across contexts and over time.
- Beginning teachers may try out different “grain sizes” of practices, from “elemental” moment-by-moment talk moves to larger planning and instructing routines. Researchers need to theorize about the grain size of practice they are studying when examining the talk, tasks, and tools at play in the classroom.

- Beginning teachers constantly experiment with practices in order to be responsive to their students. Researchers need to ask about and pay attention to what novices experiment with and why.
- Many studies of beginning teachers use binary language to characterize novices' learning and practice: for example, teachers are “ambitious” *or* “conservative”, “effective” *or* “ineffective”, have *or* don't have subject matter knowledge. Researchers need to better tell the complex stories of beginning teachers' learning and practice as the novices make sense of a variety of competing messages about “what counts” as instruction in their school contexts.

My intent in this essay is not to unpack various models of how to “best” learn a professional practice (i.e., apprenticeship, residency, progressing on an inbound trajectory in a community of practice, etc.); rather, I describe how researchers who study and support beginning teachers can better understand how and why novices come to know and participate in ambitious practice.

Critiques of teachers' preparation and research about teacher learning

To begin a conversation about research implications for beginning teachers and ambitious practice, I situate my essay in the larger context of the field, specifically with regards to critiques about both teachers' preparation, learning, and attempts to study both phenomena.

Debates about what teachers should learn in preparation programs have a long history in America, leading to three main critiques of teacher education. The first critique is that there is little agreement about a technical core of instruction or a definition of skilled practice (Levine, 2006; Lortie, 1975; Shulman, 1998). The lack of agreement about what teaching is, and is not, has resulted in the second critique – there is little consensus about how to prepare beginning

teachers for their professional work. Those preparing teachers do not agree about language, tools, supports for beginners, nor is there a professional community to monitor quality and aggregate knowledge (Ball et al., 2007; Gess-Newsome & Lederman, 1995; Ingersoll, 1996; Levine, 2006; Shulman, 1998). The third critique is that a “gap” exists between what new teachers learn in preparation programs and the knowledge and skills they need to be successful in their daily classroom realities (see Cochran-Smith & Lytle, 1999; Kennedy, 1987; Levine, 2006; Wilson, 1994). This “gap” is sometimes attributed to teacher educators. Such instructors are frequently stereotyped as being far removed from realities of classroom practice and focusing on management and “survival” strategies, rather than on instruction geared to supporting students’ participation in authentic disciplinary practices (Ball & Cohen, 1999; Levine, 2006; Wilson, 1994).

Addressing the critiques

I argue that the three critiques of teacher preparation persist in part because research about teacher education and learning have not yet made the turn to studying *practice*. Broadly speaking, learning a practice is a process of people's changing participation in valued activities in their communities, in which they take on new roles and responsibilities over time (Rogoff, 1995, 1997, 2003). Context is critical in understanding how people learn and participate in practice, because actors (both fellow practitioners and the clients/audience they serve), historical norms for participation, tools, resources, and the constant flow of information from other contexts shape “what counts” as the valued work of a community (Greeno, 2006; Shulman, 1998; Wenger, 1998; Yinger, 1990).

Many studies of teacher learning, however, utilized “*decontextualized*” methods, attempting to remove the practice of teaching from the context in which teachers engage in their

work (See Table 5 for examples of these studies). By “decontextualized”, I mean that such studies often isolate teachers from their schools to try and measure their knowledge acquisition independent of the context of its use (see Carlsen, 1999; Engeström, 2000a, 2000b; Grossman & McDonald, 2008; Johnson, 2006; Kelly, 2006; Pressini et al., 2004; Rogoff, 1997; Wilson & Berne, 1999). In other words, such studies attempt to understand what information teachers take from one context and apply it to another setting; for example, measuring the knowledge novices acquired in a university-based course and subsequently transferring the information to their school (see Grossman & McDonald, 2008, Kelly, 2006; Konkola et al., 2007).

Table 5.

“Decontextualized” Teacher Learning Studies

Literature	Methods	Claims	My critiques
<p>Van Driel et al. (2002) conducted a professional development (workshop) for preservice teachers to increase chemistry Pedagogical Content Knowledge (PCK – teachers’ understanding of how to teach subject matter) for the purpose of making better teaching decisions</p>	<p>Semi-structured interviews to capture preservice teachers’ experiences workshop.</p> <p>Semi-structured interviews to capture mentor teachers’ assessment of preservice teachers’ development</p> <p>Preservice teachers completed questionnaires about their PCK development</p>	<p>Participation in workshop increased preservice science teachers’ PCK</p>	<p>Never observed preservice teachers plan for, teach, or reflect about actual students, though PCK is seemingly developed as teachers consider how to teach their own students</p>
<p>Friedrichsen et al. (2009) investigated whether teaching experience matters for preservice teachers’ PCK development and instructional decisions during teacher education</p>	<p>Preservice teachers submit lesson plans for imaginary classroom and students</p> <p>written assignment asking them how they would teach a particular problem to a student</p>	<p>PCK develops in teacher education, particularly if participants had taught something before</p> <p>Participants relied on PCK when planning lessons</p>	<p>Preservice teachers plan for and write about decontextualized classrooms with imaginary students. Teachers’ written responses are about imaginary students rather than their own students</p>
<p>Nathan et al. (2003) examined the “expert</p>	<p>Teachers ranked 6 problems based</p>	<p>Teachers with more math knowledge</p>	<p>Researchers assumed teachers had deep</p>

<p>blind spot” – teachers with a more advanced understanding of mathematics “see” different aspects of mathematics as important for learning</p>	<p>on what they thought would be most difficult for their students to solve</p> <p>Teachers completed a 47 item belief survey about reform mathematics teaching, student knowledge, problem solving, and mathematical learning</p>	<p>had difficulty teaching representations</p> <p>Teachers with more knowledge reported more difficulty in making sense of students’ partial understandings of mathematics ideas</p>	<p>content mastery because they counted their college math classes. Researchers did not watch teachers interact with students to see how they use content knowledge in the course of a math class</p>
<p>Kersting et al. (2010) observed teachers analyzing classrooms teaching episodes to see how they used content knowledge</p>	<p>Teachers watched videos of classrooms and talked out loud about interactions between teacher and students.</p> <p>Teachers completed math content assessment</p>	<p>Students of teachers with more content knowledge had higher gains on mathematics assessments</p>	<p>Teachers taken out of their own classroom contexts to measure content knowledge for teaching. Researchers did not ask teachers to analyze episodes from their own classrooms.</p>

Studying teacher learning and ambitious practice

As the field begins to turn toward practice-based teaching, research about teacher preparation and learning could use different assumptions and theoretical lenses to better understand how and why beginners navigate the tensions about their practice-based work across contexts (Ball et al., 2007; Gess-Newsome & Lederman, 1995; Levine, 2006; Lortie, 1975; Shulman, 1998). To define teaching as ambitious practice means that the field recognizes that actors interact around specific sequences of activity, which aim to support student participation and learning (Feldman & Pentland, 2003; Windschitl & Calabrese Barton, in press).

How teachers learn ambitious practice remains unresolved and undertheorized. In my dissertation, I addressed concerns about teacher learning by examining five participants' learning over time. In this section, I describe my dissertation in order to provide a foundation for four implications I share for future research about beginning teacher learning and ambitious practice.

Context of my study

In this multi-case study, I investigated five first-year teachers' learning from practice during the 2011-2012 school year. For this study, I selected participants based on two criteria: their practice history during methods class and student teaching, and their school context's instructional cultural scripts (the historic norms and messages about what counts as teaching and learning – see Sykes et al., 2010). I purposefully selected participants who demonstrated a range of practice histories during their secondary science methods class and student teaching – of whom (Maria, Joseph, and Karen) readily attempted ambitious practice, and two of whom (Rebecca and Lucy) often enacted more conservative forms of practice. I also selected participants based on their first year teaching contexts. I searched for schools whose cultural

scripts focused on conservative forms of teaching, which often included pressure to improve students' achievement on standardized tests.

I found that all participants made changes to their practice, often daily, based on student thinking. However, the three participants who readily enacted ambitious practice provided themselves with opportunities to become familiar with the breadth and depth of students' disciplinary thinking. Subsequently, these participants provided students with increasingly sophisticated opportunities to shape the classroom science activity. The two participants who frequently enacted conservative forms of teaching limited their opportunities to make students' disciplinary thinking visible. In turn, these participants constrained students' participation in science activity to reciting "right" or "wrong" utterances and completing confirmatory activities, thus aligning with their school's conservative instructional expectations.

Four implications

Now that I have defined "what counts" as learning practice and described my dissertation work, I discuss four implications future research about beginning teacher learning and ambitious practice.

Implication 1: Temporal factors

Novices constantly make sense of their practice as they interact with actors, tools, and institutional norms and messages in a context (Edwards, 2010; Grossman et al., 2009b; Kennedy, 2010; Putnam & Borko, 2000; Rozelle, 2010; Sykes et al., 2010; Thompson et al., 2013). Such interactions are magnified as some teacher education programs develop an ambitious vision and framework of teaching that differs from their school's historical cultural scripts that often promote more conservative forms of practice (Konkala et al., 2007; Sykes et al., 2010; Warren & Rosebery, 1995; Windschitl et al., 2008, 2010).

Studying how and why beginning teachers learn from practice through their interactions with contextual features is neither a linear process nor occurs in a short amount of time. Therefore the timescale for studying beginning teacher learning from practice needs to extend in order to see their “fits and starts” across contexts. Such research is rare. In mathematics education, for example, Ensor (2001) notes that there are few longitudinal studies, and apart from that of Brown (1985, 1986), these studies have largely explored the relationship between preservice teacher education and beginning teaching from cognitive learning theories (see, e.g., Cooney, 1985; Wubbels & Korthagen, 1990).

One possible reason for a dearth of research about how and why novices learn from practice over time is that such studies pose complex methodological and theoretical challenges (Littleton, 1999). Teachers’ learning simultaneously reflects their evolving decision-making, their sense-making around norms for participation, and their actions in a vibrant daily classroom reality. Therefore novices’ learning cannot be understood only as a series of discrete educational events. As Mercer (2008) notes:

“Although the efforts of the... teacher...in each lesson may be focused on specific learning outcomes, there is a cumulative quality to the educational process. Particular tasks will be set in the context of an overarching curriculum, some topics will take more than one session to pursue, and the achievement of some kinds of skills and understanding may be prerequisites for more advanced work. In addition, the same act repeated cannot be assumed to be ‘the same’ act in repetition, because it builds historically on the earlier event. For example, the question ‘What causes rusting?’ would have very different meanings and functions if asked by a

science teacher in an introductory whole-class discussion before any work on oxidation had been done by the class, at the end of a series of group-based experiments, or in a revision session just before a public examination” (p. 34).

As Mercer implies, researchers must conduct long-term observations to see how and why beginning teachers learn – how they develop professional identities, how they use, adapt, and create tools, and how their pedagogical decisions and teaching vision change as they interact with multiple generations of actors, tools, and practices (Roth, 2006). This research involves collecting evidence of teacher learning from different data sources, including classroom observations, journals, assessments, interviews over time (Ensor, 2001).

To conduct such longitudinal studies, I argue that researchers could use sociocultural learning theories to analyze the complexity of how and why beginning teacher learning from practice in a context. In the 1990s, a bevy of research, framed around sociocultural learning theories, problematized cognitive learning assumptions that guided research in teacher education (see Carlsen, 1999; Engström, 2000a, 2000b; Lave & Wenger, 1991; Lave, 1996; Wenger, 1998). As Nardi (1995) argued, sociocultural learning theories could help researchers view human learning as more than an unaided and autonomous individual acquiring facts; rather, such learning theories claim all learning is evidenced by an individual’s changing participation in valued practices of a community over time (Carlsen, 1999; Engström, 2004a, 2004b; Greeno, 2006; Lave & Wenger, 1991; Nardi, 1995; Rogoff, 2003; Wenger, 1998). For teaching, this means studying how novices change participation in teaching activities – planning, instructing in-the-moment, and reflection – over time (Greeno, 2006; Rogoff, 2003).

Using sociocultural learning theories to frame studies about teacher learning requires that researchers pay closer attention to the temporal element of learning practice. For example, one participant in my dissertation, Lucy, embodied conservative science teaching at the beginning of the school year. She lectured, asked students to complete rote tasks, and asked questions that required students to provide “correct” answers (Kane & Staiger, 2012; Pasley, 2002; Roth et al., 2006; Weiss et al., 2003). However, by the end of the school year, Lucy attempted elements of ambitious practice – letting students construct small group models, creating a whole class model, and selecting a puzzling phenomenon for students to explain. Since I observed Lucy over her entire first year of instruction, I could theorize about why she eventually attempted ambitious practice given the breadth of data I collected. By the end of the school year, I contextualized her attempts at ambitious instruction with the rest of her practice history because I identified key moments in Lucy’s learning trajectory that shaped her teaching.

Implication 2: “Grain size” of practices

Since professional practice involves historical norms for participation, valued activities, and changing participation, learning practice is a process of “doing” – participating in practice over time. While many variations of “participating” exist in the literature, researchers have engaged in conversations about practices that best serve student learning for decades (Shulman, 1992). These routines, called “core practices” (Grossman & McDonald, 2008), “generative practices” (Franke & Chan, 2007; Franke & Kazemi, 2001), and “high leverage practices” (Hatch & Grossman, 2009; Sleep, Boerst, & Ball, 2007 in teacher education literature, are routines that practitioners enact constantly and habitually that promote student learning.

However, conversations about foundational teaching practices have only begun to describe and unpack critical activities that support student learning. In fact, researchers, and

teachers, prioritize different “grain sizes” of practice to study and enact, often on a daily basis. I argue that researchers need to theorize about the grain size of the practice they are examining because what practices they chose to pay attention to shape how they examine the talk, tasks, and tools at play in a classroom.

Some mathematics education researchers, for example, examine what I call “elemental practices” – moment-by-moment pedagogical moves that occur on a daily basis. In these studies, researchers pay attention to minute pedagogical and discursive details of the moment-by-moment interactions between teachers and students. Boerst and Sleep (2007), for example, break apart a larger practice – whole class discussions – into smaller routines, such as eliciting students’ ideas. Smaller still are practices that promote student participation in the larger practices, such as “revoicing” or using “wait time.”

The research group I have been a part of at the University of Washington considered core practices on a larger scale (see Windschitl et al., 2012). We focused on teacher-student interactions, generally occurring over a class period and a unit of instruction. Teachers in our study thought of core practices as providing opportunities to integrate multiple activity structures both within a class period (e.g., warm-up, small-group work, whole-class sense making) and over the course of a unit. Ideas and discourse from each of these smaller episodes necessarily build upon one another to support a particular learning goal in one class and over time (e.g., helping students use evidence from activities to construct scientific explanations).

In my study, each teacher considered different practice grain sizes depending on their analysis of student thinking and needs. In one case, Maria focused on larger core practices at the beginning of the school year, trying to establish unit-long instructional routines that students could feel comfortable with over time. By the end of the school year, Maria and her students

understood how a unit would progress in their classroom. Maria subsequently decided to “zoom in” to more elemental practices, trying to support all students’ participation in various aspects of the larger core practices. For example, Maria tried to ask focused questions during small group discussions so that she could provide opportunities for all students to theorize about the science activity. Joseph and Karen also transitioned from larger core practices to more elemental practices as the year progressed. As a researcher, I could understand why each participant focused on larger or more elemental practices at different points of the year because I paid attention to how the grain size of the practice helped the teachers work through perceived problems of practice.

Implication 3: Novices’ experimentation with practice

As I have argued, teachers make decisions about tasks, talk, and tools used in the classroom to support various “grain sizes” of practices. As teachers enact these practices, they begin to see that certain features of the pedagogical routines support student learning in their school context. In other words, I contend that teachers constantly experiment with their practice over time to serve students’ needs. By experiment, I mean that teachers try out practices to constantly improve their instruction in order to be responsive to their students. However, experimentation could take different forms depending on what the teacher, and researcher, view as practice and learning. Therefore, researchers need to ask about and pay attention to what novices experiment with and why.

For example, many science teachers are prepared and supported to merely manage material activities and students’ behavior at the expense of learning to provide opportunities for students to reason about science ideas (Adams & Krockover, 1997; Freese, 2006; Grossman et al., 2009b; Levine, 2006). In my study, Rebecca is an example of a teacher who experimented to

better deliver information to students by constantly making adjustments to Power Point lectures, the grammar structure of written directions, and the routines she used to call on students to state “correct” answers on the public plane. Maria, Joseph, and Karen, however, experimented by trying out ways to provide students with opportunities to share their science ideas.

Often, Maria’s, Joseph’s, and Karen’s experimentation reflected their conversations with colleagues around similar problems of practice. For example, Maria spoke with a colleague at a professional development workshop about scaffolding students’ use of evidence in explanations. The colleague invented a tool called a Red Light/Green light poster, which provided a framework for conversations between students about evidence. Maria decided to experiment with the Red Light/Green Light poster in her classroom during the next unit, and after adapting the tool for her school setting, found that her students constructed more sophisticated evidence-based explanations. Maria then attended another professional development workshop in which Karen was also a participant. Karen expressed her desire to scaffold students’ evidence-based explanations with Maria, and they subsequently discussed Maria’s version of the Red Light/Green light tool. Karen, like Maria and the original colleague, experimented with the tool in her class and used it to scaffold students’ evidence-based explanations. Note that I observed and theorized about several features of the participants’ experimentation – why the participants wanted to try a tool given their problem of practice in their school context, where the participants first learned of the Red Light/Green light poster, and how each participant tried the tool in their classroom over multiple units.

Implication 4: Problematizing binary language about teacher learning and practice

As I noted in when discussing “decontextualized” teacher learning research, many studies of beginning teachers use binary language to characterize novices’ learning and practice: for

example, teachers are “ambitious” *or* “conservative”, “effective” *or* “ineffective”, they have *or* don’t have subject matter knowledge. However, my dissertation illustrates that how beginning teachers learn from practice involves complex relationships between individuals and their school contexts over time.

In my study, I found that each teacher’s learning was too complex to be easily categorized. I could, for example, label Rebecca as a “conservative teacher”, one whose instructional practices are disservice to student learning. However, characterizing Rebecca as “conservative” does not describe her learning, vision of practice, and hard work to become a teacher. Rebecca often attempted pieces of ambitious practice – eliciting students’ science ideas, attempting to make her genetics unit “relevant and interesting” for her students, and framing each unit around a puzzling phenomenon that the students had to explain. Rebecca navigated her vision of practice with her school’s conservative instructional expectations, and emerged from navigating the tensions around “what counts” as teaching as a great teacher according to her school’s values. Over time, Rebecca learned what her department valued, and she frequently exceeded her administrators’ expectations for new teachers. Rebecca also valued students as learners; she genuinely felt that she was helping students by enacting the practices her department cited as beneficial given a bevy of standardized testing data.

Rebecca illustrates the difficulty of using binary language to describe teachers. As a researcher, I realized when observing Rebecca that I too was influenced by such binary language – when coding, writing, and talking about Rebecca, I resisted the urge to call her “conservative” or “not ambitious”. Instead, I tried to understand how Rebecca felt supported to make particular kinds of instructional decisions that led to learning opportunities given their school context and vision of practice.

Epilogue

I had the privilege of frequently observing five novices during their first year of teaching, watching them navigate the complexity of learning from attempts at ambitious practice in their school context. However, the complexity of teacher learning evident in my dissertation echoed a question that Lampert (2010) also posed: Is it possible to prepare novices for ambitious practice in a way that will enable them to work in any school, anywhere? While ambitious practice provides a framework for teacher preparation and learning over time, we, as teacher educators, need to better understand how our community can study and support beginning teachers.

I conclude with one suggestion for teacher educators. Those that prepare teachers need to be ready to learn from their research about novices to further advance ambitious practice based on what happens in actual classrooms. Windschitl et al. (2012), for example, found that once their participants (methods students) began using high-leverage practices in classrooms, they began to reshape the practices and tools to support their work to better serve their immediate and valued goals. The researchers did not dismiss these adaptations and advances; rather, they reshaped their methods class based on lessons learned from research. As teacher educator, I constantly ask myself: How does my own understanding of teaching change as my students learn from practice? How do I make changes to methods classes, and a teacher preparation program, based on what I learn from my students? What kinds of support do they need to enact ambitious practice, and how I can adapt my own class to better support the next cohort of beginning teachers? As I conduct more research about ambitious practice, I hope to contribute to the field's understanding of how and why we can support beginning teachers' learning over time and across contexts.

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APPENDICES

Appendix A.

Semi-structured interview one: Unit interview including resource card sort

Time Period	Question about Participant's Science Understanding	Question about Participant's Unit Planning and Pedagogical Reasoning	Question about Science Activity and Science Ideas during Class	Question about Reflection and Pedagogical Reasoning
Initial Unit Planning	<p>What science are you teaching about this unit?</p> <p>What is difficult to understand about the science? Why do you think so?</p>	<p>How are you planning to teach the science?</p> <p>What do you want to make sure that students understand?</p> <p>For this unit, you have several resources to draw on as you plan and teach lessons—such as your department, curriculum, ideas from university-based science methods class, the tools from methods perhaps some others I did not name. How would you rank the influence of these on your planning, teaching and reflecting? Did this change over time? Why?”</p>	<p>Describe your first days of this unit. What will I see when I come in? (Prompt and listen for: Teacher's role, students' role)</p> <p>How will you distinguish between a science idea and a non-science idea? (Listen for: What do you value/what is important to you about science ideas?)</p> <p>What do you want to happen to science ideas during class? To non-science ideas? (Listen for: who gets to decide what is/is not a science idea, how they travel).</p>	<p>After your first lessons, what aspects of your teaching and students' ideas will you reflect about and why?</p> <p>(Prompt if needed to see their reasoning about future planning and adapting instruction: After reflecting, what will you do?)</p>
Middle of Unit	<p>What science are you teaching about this unit? (Listen for: What is understanding now? How did it change and why?)</p> <p>What is difficult to understand about the science? Why do you think so?</p>	<p>How is your unit unfolding in relation to your original plan?</p> <p>Have you/do you need to change anything about teaching the science for this unit? Why or why not? “For this unit, you have</p>	<p>Describe how science ideas are being treated during class so far. What, if anything, do you want to change and why? (Listen for: How might they assert instructional authority to change science practice)</p>	<p>What are you reflecting about your teaching and students' ideas now and why? (Prompt if needed to see their reasoning about future planning and adapting instruction: After reflecting, what will you do?)</p>

		<p>several resources to draw on as you plan and teach lessons—such as your department, curriculum, ideas from university-based science methods class, the tools from methods perhaps some others I did not name. How would you rank the influence of these on your planning, teaching and reflecting? Did this change over time? Why?”</p>		
End of Unit	<p>What science did you teach during this unit? (Listen for: What is understanding now? How did it change and why?)</p> <p>What is difficult to understand about the science? Why do you think so?</p>	<p>How did your unit unfold in relation to your original plan? Did you need to change anything about teaching the science for this unit? Why or why not? (Listen for: What prompted changes (if any)</p> <p>“For this unit, you have several resources to draw on as you plan and teach lessons—such as your department, curriculum, ideas from university-based science methods class, the tools from methods perhaps some others I did not name. How would you rank the influence of these on your planning, teaching and reflecting? Did this change over time? Why?”</p>	<p>Describe the science activity during the unit. Did it meet your expectations for science? (Listen for: How they might shape activity for next units)</p>	<p>What are you reflecting about your teaching and students’ ideas now and why? (Prompt if needed to see their reasoning about future planning and adapting instruction: After reflecting, what will you do?)</p>

Appendix B.

Semi-structured Interview Two: Reflection on First Year Teaching

- 1) You've had a chance to teach a number of units this year, and gained a lot of experience from that. I'd like you to think back over the past year—Can you give me an example of 2 units from this year that you would say were “effective”? Describe why you thought they were effective. (Listen for student thinking focus and for how the big idea is described or what they think is important for a unit.)
- 2) In teaching there are science ideas and there are kids' ideas. How do you think about the relationship between the two?
- 3) What do you do with kids' ideas across a unit?
- 4) In coding your lessons I noticed that you tend to do X,Y & Z practices fairly routinely. Would you say these are a key part of your teaching? Could you comment on what you see as the purpose of these practices and why they have become a part of your repertoire?
- 5) Over the last year you had several resources to draw on as you planned and then taught lessons—such as your department, curriculum, ideas from Methods, the tools from Methods and coaches. How would you describe the relative influence of these 4 on your planning, teaching and reflecting? Did this change over time?
- 6) In what ways were the goals of your school and ideas from Methods aligned? Or not?
- 7) What kinds of interactions with other people best supported your learning around what and how to teach? Were there particular tools or routines that colleagues or coaches used that best supported your learning?
- 8) Can you talk about how you used the tools OR concepts from the tools—the big idea tool and the discourse tools—when planning & teaching? [seek out what “residue” there is from the tools?, they will not be using them anymore, but may be using HEURISTICS that evolved from them]
- 9) Did you use any of the tools like: explanation checklist, whole class models, small group models, evidence buckets, lists of hypotheses, summary table, back-pocket questions. Describe.
- 10) . Can you describe the tools you used/made/adapted? Why did you feel you wanted to create these? How did you use them, and to what effect with students (get at how the tools either supported intellectual work, discourse, or other interactions among kids)? What might you change about each tool?
- 11) I'd like you now to think back to when you first started the program (show continuum below), from that point until now, what core ideas have shaped your teaching and learning? WHY are these valuable to you? WHAT do they afford for you? The way to think about what is core to you is to think about how you think about your teaching on a day-to-day basis. What tends to run through your mind when teaching or while reflecting on your teaching? Can you give me an example of **how this idea plays out in your teaching**? When did the idea originate? Did these ideas change over time? How? OR Did they become solidified or more sophisticated/nuanced? How? When did the shifts/solidification happen? What experiences or people helped? (probe for connections among contexts & re-emergences) [OPTIONAL- use if not addressed earlier] What ideas might you carry over into your next year of teaching?

- 12) What might you say were your school's core theories of teaching and learning? How did these shape your teaching this year?
- 13) We would also like to ask about certain practices we have seen in your classroom—and the ways in which they have evolved. Take a look at this performance progression and talk about how your teaching or visions of teaching have changed over student teaching.
- 14) What do you feel that you have yet to work out about teaching science or about student learning in science? Are there some particular teaching practices you would like to focus on for next year?

Appendix C.

Semi-structured Interview Three: Personal Epistemology of Science

Teachers' own science experiences "doing" and learning science:

- 1) What science did you major in during college and why?
- 2) Describe your experiences as a science learner in middle and high school (Listen for what seems important/meaningful and unpack: Example: All lecture? Labs? If so, what was your role?)
- 3) Describe your experiences as science learner in college (Listen for what seems important/meaningful and unpack: see above)
- 4) What do you change about your science learning experiences in school (if anything)?

How and why is science knowledge made and treated?: To help me understand the teacher's role in shaping science practice in classrooms:

- 1) How do you think scientists come up with their ideas?
- 2) When scientists do not agree on an explanation or theory, what should they do? (Listen for teachers' descriptions of how and why people confront discuss new ideas, and how they use evidence to make claims to support their preferred theory).
- 3) Why do some science theories stay with us and others do not? For example, humans used to think the earth was the center of the universe, but now we do not. (Listen for how teachers talk about the "correctness" of theories – do they think that scientists discard the incorrect for the correct or that there are more cultural/historical/etc. processes involved).

Science in classrooms:

- 1) What do you want your students' to learn about science? (Listen for how they think about content and epistemology).
- 2) As you have read, science standards have all sorts of terms to describe what students should be doing with regards to science – "hands on", inquiry, investigations, etc. What does "doing science" look like in your classroom? How do you know when students are "doing" science in your classroom?
- 3) What is your role in the science that happens in your class, and how does it change over the course of the year (if at all)?

Appendix D.

Participants' Critical Discourses and their School's Cultural Scripts

Note: An "X" in a cell indicates that the participant discussed that critical or contextual discourse across multiple data sources

Discourses	Participants				
	Karen	Joseph	Maria	Lucy	Rebecca
Critical Discourses					
Funds of knowledge – recognizing students' lives and experiences as central to instruction	X	X	X		
Students' ideas are "valid" science ideas – they are based on evidence and have explanatory power for the students given their understanding of the natural world	X	X	X		
"Trusting" students to take over the class – redefining their role as actual scientists, not just students searching for "The Answer"	X	X	X		
Science as a practice, not as a set of vocabulary and facts	X	X	X		
Holding students accountable intellectually – pressing them for evidence-based explanations	X	X	X		
Authentic science work: "I want them to be confident and feel like they are scientists, or they could be. They're on that path"	X	X	X		
Students should share ideas publically: "trying to get the students to communicate more information to me. And to each other"	X	X	X	X	
Science work should be "relevant" – what problems or phenomena are puzzling and worth solving to me, a student, sitting in this class right here today?	X	X	X	X	X
Recognize myself as a middle class teacher and cultural being with power and privilege and need to rethink my role in the classroom and community	X	X	X		
Building a safe and collaborative community for students to share and learn from each other's ideas	X	X	X	X	X
Every student's idea is a resource	X	X	X	X	X
My biggest value around science teaching...is not to flat ignore the guy in the big white coat with the big fluffy mustache who's white, rich, and dead, but to turn down his volume	X				
My job as a teacher is to help students realize that their ideas are valuable and worth sharing and working on	X	X	X		
First year of teaching is about "surviving" – focusing on "making it" this year, and I will try out methods class ideas next year				X	X
Students should be "engaged" and interested in class				X	X
Students should "do" science methods				X	X
Building a safe and collaborative community for students to "be successful"				X	X
"I'm an organizational freak": need students to be organized both physically (even rows, clean notebooks) and conceptually (need to understand science as a body of organized facts)					X

Holding students responsible for organization and completing learning goals					X
Need a “responsive” classroom where all students participate				X	X
Students should share ideas publically: learn correct science from each other					X
School Cultural Scripts					
School’s theory of teaching: “Imparting knowledge to students”	X	X	X	X	X
Department: Use students’ ideas to see what their misconceptions are so we can fix them		X	X	X	X
“hit all of the standards”	X	X	X	X	X
Students’ role in science activity: “mirror” work of scientists but in the end, come to the “correct” answer		X		X	
Increase standardized test scores	X	X	X	X	X
Science has two features: true facts and “the scientific method”		X	X	X	X
When exposed to ambitious practice, department says “I just can’t, so I’m just going to do it by the book. I just can’t.”		X	X	X	X

