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Examining Classroom Science Practice Communities: How Teachers and Students Negotiate Epistemic Agency and Learn Science-as-Practice

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ABSTRACT: The Next Generation Science Standards and other reforms call for students to learn science-as-practice, which I argue requires students to become epistemic agents—shaping the knowledge and practice of a science community. I examined a framework for teaching—ambitious instruction—that scaffolds students' learning of science-as-practice as they act as epistemic agents. Using a situative theoretical framework and analytical tools from science studies literature, I conducted a multicase study of five beginning teachers. I found that (a) teachers and students negotiated their roles as they decided on "what counted" as science ideas. 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"; (b) the participants worked to make science a "public" or "private" enterprise. The framing of science then influenced how teachers and students participated in their science practice community; (c) the negotiation of "what counted" as science ideas and the framing of science as "public" or "private" influenced (i) the percentage of students sharing ideas on the public plane, and (ii) the number of science ideas initiated and kept in play on the public plane. © 2014 Wiley Periodicals, Inc. *Sci Ed* **98:**487–516, 2014

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INTRODUCTION

Debates about the purposes of teaching and learning in American K-12 schools stretch back over 100 years (Rudolph, 2002, 2005). Generally, scholars in the field of science education agree that students should learn both conceptual information and the methods of science (Abell, 2007; National Research Council [NRC], 2011). Recent efforts, such as the Next Generation Science Standards, expand 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 dimensions of science (Achieve, Inc, 2013; Duschl, 2008; Engle & Conant, 2002; 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). Therefore, I argue that reframing students' learning expectations around legitimate participation in science-as-practice requires that they take on a new role as *epistemic agents*—individuals or groups who take, or are granted, responsibility for shaping the knowledge and practice of a community (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, which I refer to as "conservative," positions the teacher as the sole instructional, knowledge, and practice authority—the only epistemic agent in a classroom. As documented in large-scale observational studies of American classrooms, conservative science teaching prevents opportunities for students to become epistemic agents by promoting the completion of curricular activities 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 (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).

In this study, therefore, I examined classrooms in which teachers enacting *ambitious instruction* aimed to provide students with opportunities to take up the role of epistemic agents and learn science-as-practice. Unlike conservative forms of teaching, ambitious instruction supports all students' learning across ethnic, racial, class, and gender categories while scaffolding their legitimate participation in authentic disciplinary work (Ball & Forzani, 2011; Ball, Sleep, Boerst, & Bass, 2009; Duschl, 2008; Kazemi, Franke, & Lampert, 2009; Lampert & Graziani, 2009; Windschitl, Thompson, Braaten, & Stroupe, 2012). I argue that ambitious teaching also redefines skilled instruction as the work of providing opportunities for all students to learn science-as-practice by acting as epistemic agents (Engle & Conant, 2002; Minstrell, 1982; Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001; Warren & Rosebery, 1995).

PROBLEM FRAMING

To examine relationships between instructional frameworks (ambitious or conservative) and opportunities for students to act as epistemic agents and learn science-as-practice, I conducted a study with two overlapping purposes. First, I propose and support the argument that ambitious instruction involves shifting students' roles from passive information recipients to epistemic agents. Second, I describe the instructional and discursive moves that teachers enacting ambitious instruction used to redefine epistemic agency in their classroom to provide students with opportunities to learn science-as-practice.

However, two potential barriers arise when trying to understand how these processes unfold. First, there are few studies in science education that examine ambitious instruction as a framework for supporting students' learning science-as-practice. Therefore, the methods for collecting data and analytical tools for understanding the affordances and constraints of ambitious instruction are limited. The second potential barrier is that science as a discipline in the "real world"—outside of K-12 classrooms—rarely provides opportunities for those without epistemic agency to gain access to the social, epistemic, and material dimensions of science practice. In other words, scientists who have, or take, the power to make and verify knowledge claims, ask particular research questions, and direct experiments, rarely grant such authority to others (Addelson, 1983; Longino, 1990; Pickering, 1995). Science teachers, as participants in some form of "real-world" science during their academic experiences, could chose to maintain typical science power structures in classrooms. I argue, however, that such a redistribution of power, and therefore epistemic agency, is embedded in ambitious science teaching and students' legitimate participation in science-as-practice. Therefore, I examined classrooms in which the teachers and students disrupted science practice expectations found in most other settings.

Since issues of power and epistemic agency as they relate to learning science-as-practice are undertheorized in the field of science education, I used literature from science, technology, and society (STS) and the history and philosophy of science (HPS) to guide my study. Such literature describes science as a human-made endeavor in which features of disciplinary work, such as epistemic agency, are negotiated between people in contexts over time. Given the descriptions of science from STS and HPS, I framed classrooms as a *science practice community*—a context in which teachers and students negotiate particular forms of disciplinary activity and knowledge. A science practice community includes the people, tools, and culture of science practice (Hankinson-Nelson, 1990; Harding, 1991; Knorr-Cetina, 1999; Longino, 1990).

In this study, I examined science practice communities negotiated in both conservative and ambitious classrooms. I focused on two dimensions of science practice communities that HPS and STS researchers apply to examine how science is made and done, and who has epistemic agency to shape the disciplinary work. One dimension of a science practice community was "*who knows*"—whether science practice was framed as a private enterprise engaged in by individuals, or if science was a public practice continually constructed and negotiated by a larger community. A second dimension was *cognitive authority*—the power granted to, or taken by, certain individuals whose understanding of factual matters and the nature of the world becomes "expert" knowledge (Addelson, 1983). By utilizing these two dimensions from STS and HPS literature, I aimed to better understand how particular instructional routines and discursive moves enabled teachers and students to negotiate their roles as epistemic agents, and learn science-as-practice, in their classroom science practice communities.

Research Questions

Using a situative theoretical framework, I conducted a multicase study of five beginning teachers and their classroom science practice communities during their first year of instruction. Though teachers and students negotiated science practice communities in all classrooms, I investigated how opportunities to learn science-as-practice changed as the teachers' and students' roles evolved. Specifically, I asked the following questions:

- How do teachers and students negotiate "what counts" as a science idea in a classroom science practice community framed around ambitious or conservative instruction? How is value assigned to science ideas and by whom?
- How is science framed as a "public" or "private" practice in classrooms that feature ambitious or conservative instruction?
- Over time, how and why does teachers' and students' participation evolve in their classroom science practice community as they negotiate "what counts" as a science idea and frame science as a "public" or "private" practice?

BACKGROUND

In this section, I begin by summarizing how Lehrer and Schauble (2006) define science-as-practice in comparison to other frameworks for science teaching and learning—science-as-logic and science-as-theory change, to which I add science-as-accumulated-knowledge. Next, I discuss how ambitious instruction positions students as epistemic agents to learn "science-as-practice" and give examples of such opportunities from previous literature—the CheChe Konnen project and Jim Minstrell's classroom-based research. Finally, I turn to STS and HPS studies about science practice communities to describe how that literature informed my examination of epistemic agency in ambitious and conservative classrooms.

Relating "Typical" Frames of Science Learning to "Conservative" 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 describe how Lehrer and Schauble (2006) summarized frameworks for 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 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. In such classrooms, students acquire strategies for coordinating theory and evidence, identify and reason about experimental design, and distinguish patterns of evidence that do and do not support a definitive conclusion (Chen & Klahr, 1999).

Classrooms framed around *science-as-theory change* embody Kuhn's (1962) theory of "scientific revolutions," viewing students' learning as conceptual change (Carey, l985a; Samarapungavan, 1992). A student's development of scientific reasoning is like Kuhn's theory of the development of scientific knowledge—students' disciplinary knowledge evolves through 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 1700s 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 preorganize the information for public consumption.

I argue that conservative science instruction, often framed around science-as-logic, science-as-theory-change, and science-as-accumulated-knowledge, promotes a vision of the discipline that does not represent how actual science is practiced in the world. In conservative classrooms, students engage in science as a linear process of "domain-free" problem solving, and learn that their science ideas contain "misconceptions" that must be "corrected" through the passive accumulation of facts (Lehrer & Schauble, 2006).

Conservative classroom 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 scientific information and methods privileged by the teacher or other instructional authority (Cuevas, Lee, Hart, & Deaktor, 2005; Driver, Newton, & Osborne, 2000; Reveles, Cordova, & Kelly, 2004). The implicit assumption of these classrooms 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, 2012; Warren & Rosebery, 1995). Therefore, teachers often implicitly or explicitly limit the role of students and their ideas in classroom science practice communities.

Ambitious Teaching and Science-as-Practice

To understand the possibilities for instruction beyond the conservative framework of most science classrooms, I turned to researchers who redefined teaching and learning as students' increasingly active participation in disciplinary work. 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 instruction*. Teachers enacting ambitious instruction support students' learning across ethnic, racial, class, and gender categories while scaffolding their legitimate participation in science (Ball & Forzani, 2011; Ball, Sleep, Boerst, & Bass, 2009; Duschl, 2008; Kazemi, Franke, & Lampert, 2009; Lampert & Graziani, 2009; Windschitl et al., 2012).

Two key features of ambitious instruction are important to highlight for this study. First, 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. Second, teachers enacting ambitious instruction work with, and on, students' science ideas over time. Working on students' ideas does not imply "fixing misconceptions" or unearthing "correct" answers; rather, teachers use students' science ideas as resources for the purpose of adapting instruction. Thus, teachers enacting ambitious instruction constantly revise the kinds of opportunities students have to revisit and deepen their understanding of the natural world as they engage in authentic disciplinary work (Ball & Forzani, 2011; Ball, Sleep, Boerst, & Bass, 2009; Duschl, 2008; Kazemi, Franke, & Lampert, 2009; Lampert & Graziani, 2009; Windschitl et al., 2012).

Providing students with opportunities to engage in "authentic disciplinary work" problematizes conservative teaching and learning in classrooms. Unlike conservative forms of instruction, ambitious teaching redefines skilled instruction as the work of providing opportunities for students to learn *science-as-practice* (Lehrer & Schauble, 2006). The science-as-practice framing describes 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 science-as-practice 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). Thus, teachers enacting ambitious instruction, in which students learn science-as-practice, help reframe students' roles from knowledge recipients to *epistemic agents*—individuals or groups who take, or are granted, responsibility for shaping the disciplinary knowledge and practice of a community (Ahlstroms, 2010; Damsa, et al., 2010; List & Pettit, 2006; Pickering, 1995; Rupert, 2005; Scardamalia, 2002; Tollefsen, 2002, 2004).

Examining Students' Participation in Disciplinary Practice

While studies of classrooms framed around science-as-practice in which students act as epistemic agents are rare, some researchers have highlighted how students learn disciplinary practice more deeply when their teachers provide them with opportunities to engage in authentic disciplinary work. For example, Gresalfi, Martin, Hand, & Greeno (2009), researchers in mathematics education, demonstrate how students become positioned as "conceptual agents" or information recipients depending on their classroom context. In science education literature, both Engle and Conant (2002) and Ford (2008) call for teachers to provide students with opportunities to learn science through "productive disciplinary engagement" by taking up "disciplinary authority."

Two examples of classroom-based research in which students and teachers learn through participation in science practice provide a backdrop for this study. 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); and

- 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 stories of classrooms framed around science-as-practice, they did not describe why the teacher's underlying instructional moves redefined students' roles as epistemic agents.

In this study, therefore, I aimed to build on the work of mathematics and science education researchers who call for a better understanding of how and why certain teaching frameworks, such as ambitious instruction, enable teachers to shift epistemic agency toward students to provide them with opportunities to learn science-as-practice.

STS and HPS Lenses into Classroom Science Practice

To examine how teachers provide opportunities for students to learn science-as-practice by acting as epistemic agents, I used lenses from STS and HPS literature since such researchers study how science develops in various contexts. Studies from STS and HPS frame spaces in which actors negotiate particular forms of activity as a *science practice community* (Hankinson-Nelson, 1990; Haraway, 1988, 1991; Harding, 1991, 1993; Knorr-Cetina, 1999; Latour, 1987; Livingstone, 2003; Ochs, Jacoby, & Gonzales, 1996; Owens, 1985). Examinations of science practice communities 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 dimensions (e.g., how and why actors discuss ideas and explanations for natural phenomena) (Foucault, 1984; Haraway, 1988; Harding, 1991, 1993; Harkness, 2007; Knorr-Cetina, 1999; Latour, 1987, 1999; Livingstone, 2003; Ochs et al., 1996; Shapin, 1988; Smith & Agar, 1998). STS and HPS literature also note 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 how to participate as a scientist in a context, they can, in turn, influence science practice over time as they bring their experiences and expectations for disciplinary work into a setting (Addelson, 1983; Hankinson-Nelson, 1990; Longiono, 1990).

While STS and HPS literature examine science practice communities in the "real world," such studies rarely include science classrooms in K-12 schools as spaces for authentic science activity. Since ambitious and conservative forms of instruction promote different visions of students' roles in science activity, I decided to use STS and HPS lenses to better understand the science practice communities that teachers and students negotiated over time. In this study, I used two dimensions of science practice communities from STS and HPS literature to analyze classrooms: cognitive authority and "who knows." Both aspects relate to instruction 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 and the disciplinary practice that is undertaken in a context (Hankinson-Nelson, 1990; Knorr-Cetina, 1999; Longino, 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 practice communities and how knowledge is communicated to and received by the society at large. I argue that 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' roles as epistemic agents place *their* science ideas as central to classroom science practice community.

Who Knows. The second dimension of science practice communities I considered as a lens into understanding how ambitious or conservative forms of instruction shaped students' opportunities to learn science-as-practice was *who knows*—whether an individual or community is considered to be the unit of "knowing" and practice. Some researchers frame science as an individual enterprise in which lone scientists discover truths about the world (Hankinson-Nelson, 1990; Longiono, 1990). This view of science positions individuals and their actions as independent of a contextual influence (Grene, 1985; Hankinson-Nelson, 1990; Longino, 1990). Other scholars, 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).

I argue that in conservative 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 classroom community, and that each person, as an epistemic agent, is permitted to work on science ideas that emerge onto the public plane.

Theoretical Framework

To address the complexity of examining science practice communities in classrooms, I used situative theory as a theoretical framework. 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, Bird, & Kennedy, 2010). For this study, a situative perspective framed my analysis of the classroom science practice community negotiated between teachers and students over one school year.

METHODS

Participants and Context

In this multicase study, I examined the science practice that communities developed in the classrooms of five first-year teachers. Each participant—Maria, Joseph, Karen, Rebecca, and Lucy—holds a bachelor's degree in a science field and was a full-time secondary science

TABLE 1
Description of Participants

Pseudonym and Education	First-Year Teaching Assignment	Reasons for Selection in Study
Maria (BS in biology)	Eighth-grade general science in urban middle school	History of planning for enacting and reflecting about ambitious practice during methods class and student teaching
Joseph (BS in chemistry)	Biology and algebra teacher in new project-based learning suburban high school	History of planning for enacting and reflecting about ambitious practice during methods class and student teaching
Karen (BS, MS, Ph.C. in biology)	Biology in urban high school	History of planning for enacting and reflecting about ambitious practice during methods class and student teaching
Rebecca (BS in biology)	Biology in urban high school	History of planning for enacting and reflecting about conservative practice during methods class and student teaching
Lucy (BS in biology)	Ninth-grade physical science in suburban high school	History of planning for enacting and reflecting about conservative practice during methods class and student teaching

teacher in the Pacific northwest region of the United States (see Table 1 for descriptions of the participants and their school contexts). 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 selected participants based on two criteria. First, all five teachers were beginning their initial year of full-time instruction in public schools, and therefore recently completed a secondary science methods class framed around ambitious instruction (note that I describe the methods class in greater detail in the following section). I thought that the participants might be more likely to try out ambitious instruction in their school than veteran teachers who might follow more conservative department and school pedagogical expectations. In addition, I selected beginning teachers to examine how they enacted ambitious instruction to problematize a myth that first-year teachers merely "survive" in classrooms.

A second selection criterion was the participants' practice history during methods class and student teaching. I purposefully selected three participants who readily attempted ambitious instruction (Maria, Joseph, and Karen), and two of which typically enacted more conservative forms of practice (Rebecca and Lucy). The ultimate purpose of both selection criteria was to help develop a theory of science-as-practice in classroom spaces that could have implications for science teaching and learning, and not to generalize unproblematically to similar "populations" of teachers, students, and classrooms.

Participants' University-Based Science Methods Class

The participants' classroom science practice communities cannot be understood without some background into their university-based science methods course that I taught. One goal of the secondary science methods class in promoting ambitious instruction was to frameshift 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 organized the class around four practices considered to be central to ambitious science teaching: constructing a "Big Idea" (determining a relevant, observable, and puzzling phenomenon for the students to explain, and constructing a causal explanation for the observable phenomenon involving unseen processes or characters), 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 (Windschitl et al., 2012).

Data Sources and Collection

In this qualitative multicase study of five beginning teachers, findings were drawn from two main data sources: my observations of participants' classrooms (one observation in October, an entire unit of instruction during a January–April time frame, and one observation in May/June) and two semistructured interviews I conducted with participants.

To collect data for classroom observations, I video-recorded all each lesson using a handheld camera, I wrote questions and notes as the class unfolded, I informally debriefed with teachers after each lesson, and I collected teacher- and student-created documents related to planning, instruction, and science activity for each lesson and unit I observed.

I conducted two semistructured interviews with the participants at the beginning and end of the school year. The purpose of the interviews was to capture how the teachers' vision of instruction and their classroom science practice community developed over time. Using a semistructured interview 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 1-hour interview (Dilley, 2000; Merriam, 2009; Patton, 2003). Interviews were digitally audio-recorded and then transcribed.

Data Analysis

As the sole data collector and analyst, I coded multiple sources (artifacts, interviews, observations) to characterize and analyze the data. I created two coding categories: *Who knows* (whether science is framed as a private or public practice) and *cognitive authority*. As I used the coding categories to examine the data, I consulted with other science education colleagues to discuss and unpack patterns and ideas that emerged from my analysis. The reflexive processes of coding, consulting with colleagues, and reflecting on my analysis allowed me to address the research questions simultaneously. In other words, I did not answer the research questions in a linear fashion—my analysis and reflection informed my concurrent ideas about the overall goals of the study.

Triangulating Data Sources and Hypothesis Testing

When analyzing fieldnotes, transcripts, videos, and inscriptions, I looked for patterns in the codes over time. For written text (teacher- and student-created artifacts and transcriptions of audio files), I used the codes to identify patterns in participants' discourse and instructional decisions. For videos, I reviewed the observations in real time, pausing them if necessary to write the equivalent of fieldnotes (Erickson, 1986). I used the codes on the video notes, identifying overall trends (see Alozie, Moje, & Krajcik, 2010).

As I analyzed individual pieces of information, 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). For all hypotheses—both initial and those that emerged from the data—I sought confirming and disconfirming evidence. By disconfirming, I mean that I purposefully looked in the data for evidence that could have problematized my hypotheses and analysis.

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 semistructured interviews. I asked participants to respond to my interpretation of the data, with the freedom to clarify, expand, or refute my interpretations during our semistructured interviews (Merriam, 2009; Patton, 2003).

Limitations

Despite having a principled design and engaging in thorough data collection and analysis, my study made several assumptions and was constrained by some inherent limitations. For example, as the sole researcher, I was bound by time and resource constraints to examining the classrooms of five teachers. This fixed number of participants bounded my understanding of the phenomena around the data I collected from their classrooms. In addition, my interpretation of the data was filtered through my stance as an advocate of ambitious instruction. Both of these examples illuminate larger methodological conundrums inherent in qualitative research. For this study, therefore, my intention was not to generalize to other specific populations of teachers; rather, I hoped to add evidence to build stronger theories about classroom science teaching and learning.

FINDINGS

In this section, I organize the findings around three assertions that emerged from my analysis of the data:

- The negotiation between teachers and students about their roles in the classroom science practice community centered on defining, discussing, and placing value on science ideas. The participants played a key role in publically and purposefully assigning value to science 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." As the participants assigned value to students' science ideas, they worked to redistribute or retain cognitive authority. Subsequently, students in ambitious classrooms began using similar discursive moves to their teacher when publically working on science ideas.
- Over time, the discursive moves made by the participants and students to place certain value on science ideas for the purpose of redistributing or retaining cognitive authority represented their effort to define "who knows" in a classroom science practice community; in other words, the participants actively worked to make science a "public" or "private" enterprise. The public or private framing of science then influenced how teachers and students participated in their science practice community.
- The negotiation of "what counted" as science ideas between the participants and their students and the framing of science as "public" or "private" 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.

Science Ideas

Across all participants' classrooms, science ideas became known as any utterances about 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" and "Where do I write my name on this assignment?").

How science ideas were treated, and by whom, differed between classrooms in which teachers enacted ambitious instruction and those that frequently engaged in conservative forms of teaching. In Maria, Joseph, 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.

Teacher's Role in Assigning Value to Ideas

I now describe how the participants 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, the participants made discursive moves to encourage or discourage student participation. In Table 2, I describe the different kinds of discursive moves that I categorized during data analysis: an epistemic press on students' science ideas, questions, signals, publicizing private ideas, instructions, tagging on, pushing or pulling ideas, and "move on" moments. Note that all participants used similar discursive moves. However, the purpose of such moves differed depending on the participant's ambitious or conservative instructional framework that guided their planning and action.

Maria, Joseph, and Karen made public discursive moves to treat science ideas as resources for the community's science work rather than position them as "right" or "wrong." Thus, Maria, Karen, and Joseph promoted productive puzzlement and reasoning while simultaneously signaled that such contributions were welcome on the public plane. Rebecca and Lucy, however, used discursive moves to assign a "truth value" to ideas, which precluded interrogation of the idea itself by the science practice 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.

As the participants assigned value to students' science ideas, they worked to redistribute or retain cognitive authority. Maria, Joseph, and Karen purposefully and publically redistributed cognitive authority to their students, resulting in opportunities for students to act as epistemic agents. By continually shifting cognitive authority to students, teachers reframed "what counted" as student learning; rather than have students reproducing canonical facts found in textbooks, teachers supported students' participation in science-as-practice.

TABLE 2
Participants' Discursive Moves to Assign Value to Science Ideas

Discursive Move Category	Examples From Ambitious Classrooms	Examples From Conservative Classrooms
Epistemic press on students' science ideas: A public statement about the knowledge status of a science idea.	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."	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?"
Question: A public question about an idea or a question designed to prompt idea sharing or emergence.	*Clarify* (Asking students to unpack their thinking)—Karen: "What do you mean? Please tell me more about your idea." *Soliciting information* (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?" *Participation* (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." *Metacognitive* (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."	*Clarify* (Used to "diagnose" misconceptions): Lucy: "What do you mean? Do you really mean something else?" *Soliciting information*: Rebecca: "How many of you have ever seen twins?" *Asking students to participate*: Rebecca: "Can you please to pay attention so we can finish this practice problem?" *Rhetorical* (a question posed typically at the end 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."
Signal: A public statement indicating how students and the teacher should participate in the classroom community.	*Participation* (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."	*Participation in classroom and/or science community* (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."

(Continued)

TABLE 2
Continued

Discursive Move Category	Examples From Ambitious Classrooms	Examples From Conservative Classrooms
	Quality of idea (the value of an idea): 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." *Ascribing ownership of ideas* (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." *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."	*Quality of idea* (the value of an idea) Lucy: "That is correct." Rebecca: "Nope, try again." *Ascribing ownership of ideas* (Using students' ideas as resources during class time): Rebecca: "Did everyone see how Jonas said that? That's the way your explanation should sound." *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."

(Continued)

TABLE 2
Continued

Discursive Move Category	Examples From Ambitious Classrooms	Examples From Conservative Classrooms
	Reasoning (pedagogical and scientific—Teacher explains why they engage in certain actions or answered a question in a particular way): 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."	
Instructions: How to begin and complete a task, routine, or discussion. Often include participatory norms.	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."	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."
Tagging on: Teacher or student injects facts or information to a conversation.	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?"	Student: "Carbon has four valence electrons." Lucy: "Because it already has two electrons in the inner shell."
Push or pull ideas: Dismissing (pushing) or extracting (pulling) students' science ideas during discussion.	*Pulling ideas:* 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."	*Pulling ideas*: Rebecca: "Where is DNA?" Student: "In a cell." Rebecca: "Where?" Student: "Inside." Rebecca: "Where?" Student: "In the nucleus." Rebecca: "Good." *Pushing ideas:* Student: "Why do some parents have triplets?" Rebecca: "That doesn't have to do with our conversation about twins right now." Student: "What about valence electrons of middle elements? "Lucy: "We might get to those next week."

(Continued)

TABLE 2
Continued

Discursive Move Category	Examples From Ambitious Classrooms	Examples From Conservative Classrooms
"Move on" moments: Teacher cuts off conversation or idea sharing for the purpose of advancing through an agenda/schedule/ curriculum.	*Providing space for "tangential" talk* (Teacher lets student ask question or share their idea and provides them with a way to keep idea in play): 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."	*Refocusing "tangential" talk* (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." *Cutting off ideas* (Teacher abruptly stops student from discussing their idea more in public): Student: "How do scientists know that alleles are alleles" Rebecca: "That's enough of that. We need to move on."

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, it means that 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.

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 and his students choose problems to work on together, and students frequently planned and enacted experiments to answer their questions and test hypotheses. During one activity in unit about homeostasis (framed around the puzzling question: "Can students 'fake a fever' to miss school?"), an unexpected result emerged: Students' body temperatures dropped rather than increased during an exercise activity. Joseph did not know the "correct answer" and publically told his students that he was unsure of the explanation. However, he made it clear that their classroom science practice community would find out together—redistributing the cognitive authority to students: "Even though I don't know the final answer, we will find out together. That's why we are a team who learns science as a group, me right along with you" (observation notes).

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 a hypothesis 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's was canonically "correct," Maria and her students wrote his hypothesis on a poster and over time, revisited it after completing activities. As students peer-reviewed

Fernando's hypothesis in public using evidence from activities, he acknowledged 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 was focused on 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 each student was thinking, and then encouraged them to revise science ideas. For example, in a brief exchange with students, Karen stated,

Karen [to Student 1]: See, [Student 2] is using evidence.
Student: Can I add to [Student 2'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. Note how Karen presses students to engage in epistemic work and not merely to repeat information:

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: Hmmm... 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. Thus, Karen helped redistribute cognitive authority to students throughout the school year.

One unexpected finding that emerged in the ambitious classrooms was how students came to recognize and take up Maria, Joseph, and Karen's participatory expectations—to act as epistemic agents with cognitive authority—in their science practice communities. For example, one student in Maria's class noted, "In my other science classes, we are not allowed to talk. We just have to be right. But here, it's like I'm supposed to try out what I think and I'm supposed to help others think too" (observation notes). Subsequently, students began making public discursive moves that promoted *their* ideas as important for the classroom science practice community. For example, students began to assign value to science ideas—including their peers' science ideas—as they took on more cognitive authority. Rather than shutting such talk down, Maria, Joseph, and Karen encouraged students to question and probe each other's thinking, as well as to problematize the textbook explanation for a phenomenon. In Table 3, I describe the different kinds of discursive moves that students made in Maria, Joseph, and Karen's classrooms, and that I categorized during data analysis: making claims, integrated science ideas with other ideas, questioning, introducing new science ideas to pubic plane, and assigning value to ideas.

While Maria, Joseph, and Karen purposefully and publically redistributed cognitive authority to their students, Rebecca and Lucy maintained the power to shape science practice by positioning students as passive receivers of information whose role was to reproduce canonical science ideas. 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. In fact, I observed no instances during Rebecca or Lucy's lessons in which students used discursive moves similar to those found in Maria, Joseph, and Karen's classrooms.

Over time, Rebecca and Lucy's expectation for discursive interactions resembled a purposeful step-by-step question and answer process in which the teacher "led" students to the truth—what I define 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"—wandering away from the task or falling behind with the curriculum pacing guide. 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 predetermined 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.

TABLE 3
Examples of Students' Discursive Moves Illustrating Epistemic Agency

Discursive Move Made by Students	Example From Classroom Observations
Making claims (students asserted science ideas in relation to phenomenon under study)	*About knowledge/data*: "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).
	Agree/disagree with others: "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).
	Invoking evidence: "Our data shows that the speed of the roller coaster decreases constantly as it goes up a ramp" (Maria's class).
	Explanation talk: "Maybe our homeostatic responses are related—there could be a relationship between the increase in heart rate, breathing rate, and temperature" (Joseph's class).
Integrated science ideas with other ideas (students made sense of their science ideas with other science ideas brought up on the public plane)	*Personal experience*: "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).
	Invoking other student and teacher ideas: "I want to add onto James' idea about temperature. He said that the brain controls how fast temperature increases. Perhaps also the brain controls *whether or not* temperature increases at all" (Joseph's class).
	Challenge science ideas: "I am not sure about that claim. Can you please talk about the activity that made you say that?" (Karen's class).
	Predict: "When we exercise faster, our temperature will increase because we are burning energy faster" (Joseph's class).
	Propose tests/experiments: "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).
Question (students asked other students and the teacher about science ideas)	*Clarify*: "Are you saying that cells divide faster if they are cancerous?" (Karen's class).
	Press on science ideas: "Can you explain more about what you mean by 'heat energy'?" (Maria's class).

(Continued)

TABLE 3
Continued

Discursive Move Made by Students	Example From Classroom Observations
Introduced new science ideas to pubic plane (students elevated their own science ideas to the public plane they felt were missing from the community's discussion)	"Our roller coaster model is missing gravity—we haven't talked about that yet" (Maria's class).
Assign value to ideas (students gave other student's science ideas value)	"I like your idea—you back it up with evidence" (Maria's class). "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.

Note two features of Lucy's questioning that illustrate how she positioned students as "repeaters" of complex ideas. First, Lucy was not simply asking "fill-in-the-blank" questions. She expected students to state 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.

Rebecca promoted breadcrumb epistemology in a unit about cells and homeostasis as she enacted a similar pattern of asking linear 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's public discursive moves worked to maintain cognitive authority in their classroom's science practice community through the establishment of breadcrumb epistemology as the norm for science discourse.

The retention of cognitive authority by Rebecca and Lucy limited students' opportunities to engage in science-as-practice and act as epistemic agents. For example, Rebecca told students that their main role during class was to complete the required assignments and not to worry about their conceptual understanding. She frequently stated, “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. Note how Lucy uses a “move-on moment” to shut down the student’s question:

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.

Science as “Public” or “Private” Practice

Over time, the discursive moves made by teachers to place certain value on science ideas for the purpose of redistributing or retaining cognitive authority represented their effort to define “who knows” in a classroom science practice community; in other words, the participants worked to make science a “public” or “private” enterprise. Maria, Joseph, and Karen negotiated science as a “public” practice with students. As a public practice, teachers and students together engaged in the conceptual, epistemic, social, and material aspects of science work. Over time, the classroom community advanced their collective understanding of science. Rebecca and Lucy, however, negotiated science as a “private” practice with students. They positioned students as solitary individuals responsible for completing tasks alone and silently with few opportunities for collaborative learning.

To negotiate a “public” science practice community, 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 start of the school 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 and practice. 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 provided students with opportunities to connect 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 to advance the whole class’ understanding of the topic. Joseph also 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, like Joseph, encouraged students to talk to each other about ideas or questions. For example, when looking at students work in small groups, she said, “Oh [Student 1], you should talk to [Student 2]. 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). Thus, students, and not the teacher, became responsible for sharing and discussing their ideas.

Maria, Joseph, and Karen also purposefully chose to not “know” the complete explanation of the complex phenomenon they used when planning their unit because they wanted to learn *with* students. Joseph explained to a student why he chose not to know the “real answer” to a puzzling phenomenon the class community was working to explain: “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 expected them to participate as scientists, rather than pretend to be scientists, as they worked together to explain the puzzling phenomenon.

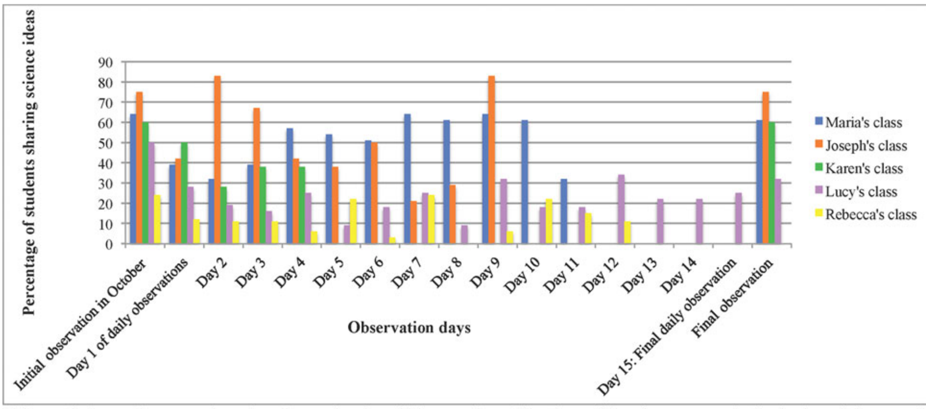
Unlike Maria, Joseph, and Karen, Rebecca and Lucy negotiated science as a “private” practice with students. One means to privatize science was for the participants to make purposeful statements about the individual nature of science work and learning. For example, Rebecca frequently told students *not 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. Rebecca also placed students in competition with each other for individual success by 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).

Given the private and often competitive framing of science work, students learned that successful participation in Rebecca and Lucy’s classrooms meant following their teachers’ explicit and tacit cues about the importance of individual success. Students spent considerable time completing assignments silently and rapidly, 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.

Students’ Participation in Class Around Their Science Ideas

In this section, I describe how the value placed on science ideas and the framing of science as “public” or “private” 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.

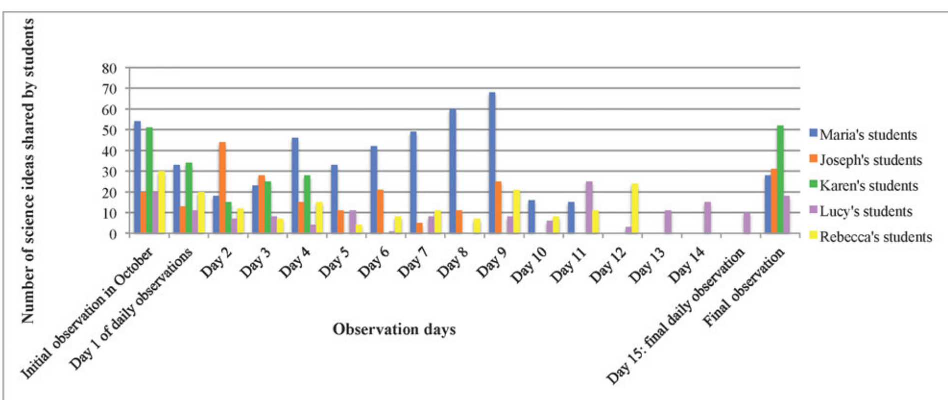
The percentage of students sharing ideas in Maria, Karen, and Joseph’s classrooms was consistently higher than the number of students participating in Rebecca and Lucy’s classrooms (see Figure 1). Please note that Karen had a class with 55 students, which skews the picture of participation. In fact, there was only one instance in Lucy’s class (my first observation in a unit about valence electrons) that more than 50% of students participated



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 1. Proportion of students sharing science ideas on the public plane.



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)

Figure 2. Number of science ideas shared by students.

by publically sharing a science idea. 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 50% of students sharing science on any day ideas was uncommon*.

In addition to the differences in student participation in ambitious or conservative classrooms, 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 2). 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.

As the figures illustrate, distinct differences emerged with regard to the percentage of students participating and the number of science ideas "in play" between classrooms in which teachers regularly enacting ambitious instruction (Maria, Joseph, and Karen) and those frequently engaged in conservative forms of science teaching (Rebecca and Lucy). Over time, teachers' enactment of ambitious or conservative instruction fostered distinctly different kinds of science practice communities in which teachers and students took on varied roles as epistemic agents or recipients of information.

DISCUSSION

In this section, I revisit the initial research questions:

- How do teachers and students negotiate "what counts" as a science idea in a classroom science practice community framed around ambitious or conservative instruction? How is value assigned to science ideas and by whom?
- How is science framed as a "public" or "private" practice in classrooms that feature ambitious or conservative instruction?
- Over time, how and why does teachers' and students' participation evolve in their classroom science practice community as they negotiate "what counts" as a science idea and frame science as a "public" or "private" practice?

I begin by describing why the participants' ambitious instruction provided opportunities for students to become epistemic agents and learn science-as-practice by redistributing cognitive authority and positioning science as a public enterprise. Next, I discuss why using lenses from STS and HPS literature opened up new possibilities for analyzing ambitious instruction in classroom science practice communities.

Revisiting Science-as-Practice

Lehrer and Schauble (2006) argue that learning science-as-practice must, by definition, include opportunities for students to legitimately participate in the conceptual, epistemic, social, and material dimensions of science work. Therefore, learning science practice cannot be reduced to the assimilation of facts, the mimicking of procedures, or the "correction" of misconceptions. In this study, Maria, Joseph, and Karen—the participants regularly enacting ambitious practice—presented students with opportunities to do the following:

- *Problematize conservative classroom science*: Maria, Joseph, and Karen encouraged students to publically share and discuss science ideas, including their experimental proposals and challenges to the teacher's knowledge, rather than expecting that they should simply assimilate facts, repeat procedures, and reproduce "correct" answers. In addition, these participants pressed on students' understandings rather than ask merely for more facts. For example, recall that Karen and her students realized that they had not yet unpacked *why* understanding the role of DNA in mutations could help them explain a puzzling phenomenon. Subsequently, Karen requested that the students continue theorizing rather than provide them with "correct" information.

- *Take and use cognitive authority*: Maria, Joseph, and Karen provided students with opportunities to define, address, and resolve science problems that had meaning in their lives. These participants also worked *with* students to learn science, rather than funnel them toward predetermined answers. Recall that Joseph decided to let students work on a puzzling question that emerged during a unit about homeostasis ("Why did we get this puzzling data in an activity") rather than dismissing such observations as irrelevant. By positioning students' ideas as important and reframing his role as a participant in a public science practice with students, Joseph redistributed cognitive authority to students.
- *Hold each other and the teacher accountable*: Maria, Joseph, and Karen negotiated a science practice community in which students held each other and the teacher accountable to the developing participatory norms. For example, students in these classes publically pressed on each other for evidence, asked for clarification, and encouraged everyone in the class to share ideas.
- *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 to travel over time and space, and supporting discourse that created a safe environment (Engle & Conant, 2002). Subsequently, students always had opportunities to share and discuss each other's 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). Subsequently, the percentage of students participating and the number of science ideas in play on the public plane reflected students' epistemic roles in their science practice community.

STS and HPS Lenses into Learning Science-as-Practice

In this study, I found that using the lenses of cognitive authority and "who knows" from STS and HPS literature helped illuminate why students had opportunities to learn science-as-practice by acting as epistemic agents in Maria, Joseph, and Karen's classroom science practice communities. I describe four aspects of science practice communities that might otherwise have gone unnoticed in the ambitious classrooms had I not used lenses from STS and HPS literature: trust, publicizing science to counteract "individualizing forces," embracing the "mangle of practice," and unpacking how power shapes practice communities.

Trust. Maria, Joseph, and Karen trusted students enough to redistribute cognitive authority to them. In doing so, students took up roles as epistemic agents, capable of discussing science ideas and positioning science as a "public" practice even when the teacher was not present, such as during small group discussions. The process of trusting other people 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 practice, 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, those without power begin to gain some traction in the practice community as agents capable of participation. Over time, Maria, Joseph, and Karen trusted what students talked about and their actions, whereas Rebecca and Lucy did not place the same trust in students, constantly correcting students' ideas and limiting their opportunities to take up cognitive authority and shape classroom practice.

Publicizing Science to Counteract "Individualizing Forces." Another purposeful instructional move by Maria, Karen, and Joseph to negotiate novel science practice communities with students was to position science as a public practice, making the class the collective "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 other words, places in which people learn science-as-practice position the community, not the individual, as the "knower." 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 the work of most places where science is done, as well as Rebecca and Lucy's classrooms, in which individuals gain prestige by winning grants, prizes, money, and other tokens at the expense of other individuals (Knorr-Cetina, 1999; Livingstone, 2003; Longino, 1990). Recall that both Rebecca and Lucy enacted discursive moves, and awarded prizes, to purposefully make science a solitary enterprise.

Embracing "the Mangle of Practice." As Maria, Joseph, and Karen learned, redistributing cognitive authority and making science public was "messy work" (Joseph, final interview). As teachers with instructional authority, Maria, Joseph, and Karen had to make in-the-moment decisions that required, in some cases, recasting an entire unit of instruction around students' ideas, such as Joseph's homeostasis unit. These rapid instructional adaptations led to the classroom science activity resembling what Pickering (1995) called the "mangle of practice." Given the unpredictability of contextual factors, Pickering argued "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" (pp. 19–20). In this study, rather than panic when activities did not work or students veered in unplanned 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.

Power and the Treatment of Knowledge—the Core of Science Practice. Historically, debates about who is permitted to "do" science, what kind of science actors are permitted to engage in, and what kind of explanations society wants produced, do not involve K-12 classrooms. 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" (p. 9). I argue that conservative school science—often the expectation of schools and districts in the current standardized testing climate—prevents opportunities for students to learn science-as-practice by acting as epistemic agents. Efforts to restrict science to a single scientific method and textbook information often results in students thinking that science is a static set of procedures and facts that they reproduce on standardized assessments. As Rebecca and Lucy's classroom science practice communities illustrate, students learn that their ideas, unless canonically "correct," are unimportant. Subsequently, their participation in classroom science decreased.

By redistributing cognitive authority to everyone, Maria, Karen, and Joseph worked toward a different kind of science practice community in their classrooms, a collaborative effort in which all students shaped the work that was done. In other words, Maria, Joseph, and Karen actively promoted the stance embedded in ambitious instruction that *students could and should take up the role of epistemic agents in classroom science rather than act as passive participants as their teacher determined the science work*. Warren and Rosebery (1995) refer to this stance as "equity in the future tense," in which teachers work to problematize the asymmetric disciplinary 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 of conservative science instruction and larger American society—that competition and individuality are the sole means to achieving scientific success.

As Maria, Karen, and Joseph illustrate, the most productive science practice communities are the result of many individuals working in concert (Hankinson-Nelson, 1990; Longiono, 1990). 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, teachers enacting ambitious instruction shape novel science practice communities. Students in these communities, acting as epistemic agents, learn that their ideas can and should have a bearing on the knowledge and practice develops over time (Addelson, 1983).

CONCLUSION

I hope this study adds to the growing conversation in our field about the possibilities for students to learn science-as-practice 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, the students and teacher actively engaged in science-as-practice, working on explanations of puzzling phenomena in their localized classroom context. I do not advocate for classrooms in which there are no perceived "significant" questions and "appropriate" answers. To some degree, classrooms should reflect how science is actually practiced in the "real world." However, I believe that the cases of Maria, Joseph, and Karen provide an opportunity for our field to confront entrenched ideas about the science practice communities that teachers and students negotiate over time in classrooms.

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