Science Teachers in Research Labs: Expanding Conceptions of Scientific Practices

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Abstract

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Argumentation is a central epistemic process contributing to the generation, evaluation, and application of new scientific knowledge. A key challenge for science educators and researchers is to understand how important social dimensions of argumentation, such as collaborative sense-making discourse, can be implemented in learning environments in ways that are pedagogically appropriate, responsive to the cultural assets that students bring to the classroom, and aligned to professional scientific practices. This dissertation investigates how secondary science educators learned about scientific argumentation and collaborative sense-making through participation in a professional development program at a cancer research center. It examines how their experiences in research laboratories influenced the pedagogical approaches to argumentation they used with their students. Theoretically, this research draws on sociocultural conceptual frameworks to investigate how teachers were motivated to broker key practices to the classroom, and how they positioned themselves, their students, and the discipline of science in new ways.

Methodologically, this research examines the written and discursive reflections of 25 secondary science teachers as they experienced argumentation in scientific research settings and further engaged a subset of 6 teachers in collaborative autoethnography (CAE) during the subsequent school year. It also utilizes design-based research to examine how research experiences for teachers can be architected to promote an understanding of the social dimensions of argumentation and to help teachers take up equitable educational approaches that foster expansive argumentation practices in school settings. Major findings fall into three general areas. First, teachers broadened their ideas of "what counts" as argumentation after using observational scaffolds to examine the culture and discourse of scientists working in professional laboratories. Second, when teachers shifted discourse to better align with practices of professional research, they productively altered power dynamics and the cultural production of authority in the classroom. Finally, teachers grew in their interpretive power (Rosebery, Warren, Tucker-Raymond, 2016) through experiencing the research setting as learners and through the CAE process. A diffractive analysis (Haraway, 1992) revealed the importance of relationships, trust, and vulnerability in promoting rigorous classroom argumentation. Expanding teachers' views of scientific practices not only prepares them to engage students with science in ways that are more authentic to the discipline, but also helps teachers recognize and leverage the creativity and resources that students bring to their science learning. Ultimately, such pedagogical shifts can increase students' access to the social, cultural, and material aspects of science, broaden possibilities for their futures, and promote equity in science education.

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Dedication

I dedicate this work to my children Jade and Sam, to my husband Tim, and to science teachers everywhere.

Chapter 1: Introduction

Overview

The view of science as a set of socially negotiated practices enacted by members of a knowledge-building (i.e. "epistemic") community has deep historical roots in science education research, philosophy of science, and science studies (Kuhn, 1962; Latour & Woolgar, 1986; Pickering, 1995, Rouse,1996). Recently, it has also found traction amongst science teachers and the science education community as a result of the vision put forth by the *Framework for Science Education* (National Resource Council, 2012) and the *Next Generation Science Standards* (NGSS Lead States, 2013). Researchers argue that students need to engage in these interrelated practices as they learn about important concepts and content in science that in order to understand how new scientific knowledge is constructed and evaluated (Duschl, 2008a; Osborne, 2014; Schwarz, Passmore, & Reiser, 2016).

Researchers have noted the central role of argumentation as a scientific practice and the need to represent its importance in science education (Berland & Reiser, 2009; Bricker & Bell, 2008; Driver, Newton, & Osborne, 2000; Duschl, 2008b; Erduran & Jimenez-Aleixandre, 2007; Kuhn 2010). Argumentation is therefore particularly critical to scientific inquiry as it centers on the relationship between constructing new knowledge claims and critiquing them (Ford, 2008; Osborne, 2014). Argumentation can provide students with important insights into how professional scientists make and defend claims and how they wrestle with the uncertainty inherent in scientific inquiry (Manz, 2018). Arguments have characteristic structures that help coordinate claims and evidence (Toulmin, 1958) but are also forged and tested in dialogue with others (McNeill & Knight, 2013). The social dialogic aspects of argumentation in educational settings have been less frequently studied than argument structure (Berland & Reiser, 2009; McNeill & Knight, 2014).

A critical question is how teachers come to value the inclusion of social dialogic argumentation in their classrooms in the first place. While the NGSS standards are a driver for teachers to think about argumentation, what motivates them to shift their classroom practices to not only include argument structures (such as Claim-Evidence-Reasoning frameworks, see McNeill & Krajcik, 2012) but also to broadly conceptualize the practice of argumentation, decenter their own power in classroom talk, and create new opportunities for shared social sense-making among students? Collaborative discourse and argumentation play a key role in helping scientists as well as students make meaning—and develop common knowledge—with their peers. However, the opportunities for such talk is often rare in science classrooms (Bricker & Bell, 2012; Osborne, 2010; Simon, Erduran, & Osborne, 2006; Berland & Reiser, 2009).

This research focuses on a professional development experience for secondary science teachers that is embedded in a cancer research center (the "Center"). What follows is a story of the relationship between the Center and science teachers. What opportunities exist (or can be created) in spaces where scientific research is conducted to support science educators in improving their craft? What kinds of experiences can drive professional change in teachers towards developing structures that reflect professional scientific discourse? How can they create greater opportunities for students in their classrooms to share their experience and perspectives, build their understanding, and learn from one another? These are questions that drive this work and research, not only because I believe that teachers are professionals who deserve respect and support, but because the vision that students have of science is so dependent on their teachers' beliefs and practices.

A thread running through this dissertation is the broader idea of sense-making: by scientists as they work to understand their results, by teachers as they process their experiences in the research setting and consider the implications for the classroom, and by students as they try to make sense of the science that they learn in school as well as observe in the world around them.

In this overview, I first briefly outline the purpose of the research. Then, I describe the problem space in which this work is situated by discussing prior work on teacher professional development in argumentation. I also explore research on teachers' experiences in professional scientific settings. Next, I introduce the conceptual territory that the study is located in, provide context for the overall methodology of the research, and provide details on the site, context, and participants. Afterwards, I explore my positionality relative to the subject matter, participants, and context (Savin-Baden & Major, 2012). Finally, I provide summaries of each empirical chapter.

Purpose and Summary

The overall purpose of my research is to investigate how secondary science educators learn about argumentation and scientific sense-making through participation in scientific research experiences and professional development, and how their experiences influence the pedagogical approaches they take to argumentation with their students. It also explores what role teachers' own views of sense-making in science play in how they structure learning opportunities for their students, and how those ideas might evolve over time through their own reflections and professional development experiences. Theoretically, it uses a sociocultural lens to emphasize teachers' experiences with argumentative practice in scientific and classroom communities. It also extends the research emphasis on the practice of argumentation in science education to encompass the broader role of collaborative argumentation and deliberative sense-making within scientific and classroom communities. Methodologically, it examines the written and discursive reflections of teachers as they experience disparate forms of argumentation in scientific research settings and engages a subset of teachers in collaborative autoethnography (Chang, Ngunjiri, & Hernandez, 2012) when they return to their classrooms. It also utilizes design-based research (Bell, 2004; Brown, 1992; Collins, Joseph, & Bielaczyc, 2004; DBR Collective, 2003) to contribute to an understanding of how research experiences for teachers can be architected to promote a broader understanding of argumentation and help teachers translate their experiences into educational approaches that foster expansive sense-making discourse practices in school settings.

I conducted this research during a 13-day summer professional development workshop, the Teacher-Scientist Partnership (TSP, a pseudonym), and continued through the following 2017-2018 school year. The three empirical chapters that follow this introductory chapter lay out findings from different dimensions of teachers' experiences. I describe these chapters briefly below and then again in more detail at the end of this chapter.

In the first empirical chapter, I broadly describe how TSP teachers thought about argumentation during and after their lab experiences and participation in the workshop. I examine how teachers' views and perspectives about argumentation shifted and the changes they made to their classrooms in the subsequent school year. As this was a design-based research study, I discuss elements of the design that contributed to my findings and also provide design recommendations for the future.

In the second empirical chapter, I focus more specifically on how TSP educators viewed discourse and power dynamics in the lab settings and how they connected those observations to their teaching. When teachers Incorporated student talk that more closely aligned with scientific disciplinary discourse, they decentered their own power and facilitated more equitable participation among students.

In the final empirical chapter, I describe school-year findings related to argumentation, classroom culture, and relationships generated in partnership with a smaller subset of six teachers. The group used a collaborative autoethnographic approach to share professional learning – generating questions of interest to the group, recording responses in written autoethnographic form, and working together to identify themes in the data and to discuss them.

Across the three empirical studies, the opportunity to become immersed in the work of professional science and to process their findings with peers focused the learning experiences of science teachers. Although they varied in their levels of engagement and in the depth of their views about youth argumentation and learning, teachers described how their pedagogy and their ideas about scientific practices, power, and equity shifted as a result of their participation. The studies highlight how the design of professional learning experiences can foster these kinds of shifts in understanding and practice.

Argumentation and Teacher Professional Development

While the practice of argumentation has been extensively studied in science education research (see reviews by Cavagnetto, 2010; Erduran, Ozdem, & Park, 2015; Lee et al. 2009; and Lin et al. 2014), the role of the teacher remains under-examined. Shifting science education to include a focus on practices such as argumentation requires that teachers be prepared to provide appropriate framing contexts that represent those practices (Berland & Hammer 2012). As McNeill and Knight (2013) note, “a focus on argumentation not only requires a shift in the desired student learning goals but also requires teachers to take on new and different roles” (p. 936). Integrating argumentation into classrooms can be challenging for teachers, particularly if they do not have a strong understanding of the practice themselves (Simon, et al., 2006; Zembal-Saul, 2009). However, research has shown the value of providing teachers with professional development focused on argumentation (McNeill & Knight, 2013). Many studies of classroom argumentation have focused on elementary teachers (Zembal-Saul, 2009); socioscientific dimensions of argumentation (Chowning, Griswold, Kovarik, & Collins, 2012; Crippen, 2012; Kilinc, 2017; Sadler 2006), or the effectiveness of particular curriculum or argumentation scaffolds (McNeill, 2009; Kuhn 2010).

This research builds on this earlier work to specifically focus on how secondary science teachers can learn about the collaborative and discursive dimensions of argumentation through professional development in research settings. While accounts of classroom designs that support teachers in promoting argumentation and collaborative debate and discourse in their classrooms exist (e.g. Bell, 2002, 2004), little is known about how professional development can best foster teacher learning about such approaches. McNeill & Knight's (2013) professional development with teachers has explored teacher learning from a perspective grounded in the classroom (promoting lesson development, using records of classroom practice and student work, and supporting reflection) in an attempt to increase teachers' pedagogical content knowledge of argumentation and the ability of teachers to evaluate arguments (and particularly its dialogical dimensions). However, there is a lack of studies exploring teacher learning about scientific practices from a perspective grounded in the professional scientific community. My research contributes to the literature by providing an account of how teachers in a professional scientific setting learned about argumentation practices in a real-world context and how they thought about the enactment of such practices in their classrooms.

Research Experiences and Teacher Professional Development

Science teachers are tasked with helping students understand important scientific practices such as argumentation and to become familiar with their use. However, most science teachers lack direct experience conducting research or using scientific practices themselves (Russell, 2005; Windschitl, Thompson, & Braaten, 2008). Therefore, the vision of science that their students are presented with often reflects a "final form" version of science (Duschl, 1990; Manz, 2015) that represents scientific content devoid of the processes that helped derive and warrant that knowledge. One of the ways that teachers can deepen their understanding of the role that argumentation plays in research settings is through participation in Research Experiences for Teachers (RETs). While teacher professional development in the research settings of scientists has the potential to provide educators with deeper understandings about scientific practices, little is known about how teachers learn, and what they learn, about practices such as argumentation from such experiences.

Research experiences for teachers are predicated on the assumptions that participating in such experiences will enhance teachers' understanding of science as well as enable them to shift their teaching to more authentically reflect scientific practices. As Feldman, Divoll, and Rogan-Klyve (2009) note, "Clearly, if science teachers are to help their students learn the nature of science as inquiry, know how to engage in scientific inquiry, and learn science through inquiry, then they must have the knowledge and skills to make this happen" (p.443). While earlier science education reform documents outlined the importance of inquiry teaching and learning, and ensuring that students understand the central role of inquiry in science, the *Next Generation Science Standards* (NGSS Lead States, 2013) attempt to more explicitly outline and clarify scientific practices, such as argumentation and explanation, that comprise inquiry. Research experiences for educators have long been supported at wide range of scientific institutions through programs such as the National Science Foundation (NSF) RET. Most of these share the same goal: providing teachers with authentic experiences in the hopes that their understanding of science will increase, and that they will be able to in turn impact their students' conceptions.

While few science teachers overall participate in research, there have been numerous studies that investigate teachers who have been able to have research experiences in scientific laboratories (see Brown and Melear, 2006, for a review). A wide range of outcomes have been reported, from frustration on the parts of scientists and teachers (with scientists expressing dismay at the lack of knowledge of the teachers, and the teachers feeling inadequate), to experiences where both scientists and teachers report learning from one another in meaningful ways. Numerous researchers have investigated the impact of RET on teacher's beliefs, attitudes, and values about teaching science as inquiry or on practice (Enderle et al., 2014; Herrington, Bancroft, Edwards, & Schairer, 2016). Researchers have noted how research experiences help teachers see the complexity of scientific processes and develop a more nuanced picture of science process than a series of proscribed, linear, and static procedural steps (Melear et al., 2000). Studies have focused on constructs such as changes in teachers' "functionality" as scientists (Faber et al., 2014) or how RET experiences influenced teachers' beliefs, attitudes, and values about "teaching science as inquiry" (Herrington et al., 2016). Enderle et al. (2014) studied 120 teachers in two RET programs. They found that research experiences that provided teachers with support from master teachers and opportunities for reflection on the teaching of inquiry (both also found in the TSP model) were more successful in shifting teacher's beliefs and impacting their teaching practice than experiences without those supports.

Although teachers in these programs emerge with greater understanding of both science disciplinary content and practices, research indicates that bringing insights from their research experiences into their classrooms remains a struggle (Brown & Melear 2007; Lotter, Harwood, & Bonner, 2007; Lunsford, Melear, Roth, Perkins, & Hickok, 2007). Researchers have attributed this observation to the logistical or systemic difficulties of bringing research practices into classrooms, teachers' views about how the practices of science and teaching differ, or a lack of understanding of how scientists learn to do science (Brown & Melear, 2007; Feldman et al., 2009).

What is missing from the research base is how teachers learn about key scientific practices in such settings. In particular, research on how teachers reflect on instances of sense-making argumentation that happen in the context of deliberative discourse among scientists is lacking. For example, Brown and Melear (2007) define an authentic inquiry-based experience for teachers as one that "centers on investigations of scientific phenomena. The learner observes the phenomena, manipulates/'tinkers with' materials, asks questions, designs investigations, conducts experiments, analyzes data, and reports results." Such a focus misses an important opportunity for teachers in research experiences - the chance to see how scientists interact with one another to put forward claims, critique and challenge one another, and develop shared understandings. Similarly, Sadler, Burgin, McKinney, and Ponjuan (2010) reviewed 53 studies of research apprenticeship programs, including 11 for teachers. While these studies examined a broad range of outcomes, none of them examined the impacts on participants' understanding of argumentation or that explicitly focused teachers in research settings on collaborative and sense-making discourse practices. *This research project aims to fill that gap by drawing teachers' attention explicitly to examples of argumentation in professional science, providing* *opportunities to reflect on scientific practices that they observe and to discuss them with one another, and involving teachers in exploring what the implications of their experiences are as they endeavor to bring them to their classrooms.*

It is unclear what level of expertise science teachers who participate in research experiences need to achieve before they are able to impart a genuine sense of the scientific enterprise to their students. Although longer RET experiences correspond to a larger number of positive outcomes (Sadler et al., 2010), it is unlikely that all teachers can reach the level of a 'Knowledge Producer', unless they participate in extensive research experiences that require time commitments outside of the realm of possibility for most teachers. As Duschl and Osborne (2002) note:

> Very few science teachers have ever become fully-fledged members of the scientific community - a process of socialization which normally requires the opportunity to undertake original research. Thus, not only are science teachers' knowledge of the nature of science limited by the nature of their own education, but they, themselves, have not been exposed to the normative discourse practices of the scientific community. Replicating or modeling discourse practices within the classroom is, therefore, inherently problematic raising serious issues about how such understanding can be developed by both initial and continuing professional development. Not until pedagogical practices and curricula begin a process of transformation and establishing opportunities for students to engage in equity that models authentic practice tracking data to evidence, and evidence to explanations can we expect a transformation in the nature of science classrooms. (p. 64)

My research suggests that brief (but purposeful and targeted) approaches can be effective for broadening science teachers' understanding of practices such as argumentation. Shorter experiences are not only more likely to appeal to a greater number of teachers, but they can also serve to increase teachers' confidence in their abilities (Sadler et al., 2010) and interest teachers in future research opportunities. *Therefore, this research contributes to knowledge of how focused research experiences can deepen teachers' understanding of important scientific* *practices and can shift how teachers structure discourse practices in classrooms with an ultimate goal on centering the sense-making resources of learners.*

Conceptual Territory

Conceptually, this work uses a sociocultural lens to frame and make sense of findings. I am interested in how such a perspective illuminates the social and cultural dimensions of scientific activity, the research experiences of teachers, and science learning of students in the classroom. Becoming a scientist means becoming an increasingly involved participant in the key social activities of the scientific community (Lave & Wenger, 1991), in part through socialization by those individuals with more experience (Wertsch, 1988). Vygotsky, whose thinking was instrumental in the development of sociocultural theory, argued that ways of talking, asking questions, and demonstrating knowledge occur at the social level and become internalized by individuals over time. The roots of individual mental processes lie in those of groups; culture lays the foundation for the internalization of mental processes and behaviors (Vygotsky, 1962; Wertsch, 1988). In describing science through a sociocultural lens, Lemke (2001) notes, "what matters to learning and doing science is primarily the socially learned cultural traditions of what kinds of discourses and representations are useful and how to use them (p. 298)." Sociologists of science have also emphasized the degree to which scientific knowledge is socially contingent; it is both a product of the cultural world that produces it and a shaper of that world (Kelly, Carlsen, & Cunningham, 1993; Cunningham & Helms,1998). Similarly, the field of science studies points to the discipline of science as a set of dynamic and socially constructed practices rather than one unitary body of knowledge and way of knowing (Rouse, 1998).

Learning, in this view, is also a social practice situated within a community rather than simply the acquisition of decontextualized knowledge by isolated individuals. Sociocultural views open up opportunities in this research to acknowledge the complexity of learning; the importance of interactions and relationships with others, cultural and historical factors, context and situation, and the role of mediating tools such as language (DiGiacomo & Gutiérrez, 2017; Greeno, Collins, & Resnick, 1996; Lave, 1996). Many psychological perspectives focus on individual behavior and cognition. In contrast, sociocultural, psychological, and anthropological perspectives emphasize activity and cultural practices as units of analysis (Nasir & Hand, 2006). As Nasir and Hand note, "Sociocultural theories…articulate a role of culture not only as a system of meaning carried across generations, but also as being constantly being created and recreated in local contexts. Sociocultural perspectives examine the roles of social and cultural processes as mediators of human activity and thought…This notion of activity offers a unit of analysis that affords an understanding of the complex intertwining of the individual and the cultural in development…learning is constituted by changing relations in these social relationships and the social world" (2006, p. 458).

The emphasis on learning in practice also acknowledges that learners participate in multiple interrelated "structures of social practice" (Bell et al. 2012, Dreier, 2009) across different communities to which they may belong or identify with. In this view, learning can be seen as increasing participation in the authentic work and practices of a community alongside peers and more knowledgeable individuals (Vygotsky, 1962; Lave & Wenger, 1991). While teachers are not participating in science research experiences in order to become scientists, they are making a "consequential transition" between science and science education worlds (Beach, 1999) and generating new and productive cross-setting understandings. As Wenger (2000) notes, communities are defined by boundaries, but boundaries are also extremely productive sites of creativity, new possibility, and innovation. Prior research that has investigated ways in which practices of scientific communities can be represented in appropriate ways in classrooms (such as the work on Community of Learners, Brown & Campione, 1994 and Productive Disciplinary Engagement, Engle & Conant, 2002) influenced both the study design and the analysis of findings.

In summary, this research applies a sociocultural lens to investigating how teachers broaden their understanding of scientific community practices such as argumentation, to broker elements of practice in ways that are appropriate to the classroom, and to create new possibilities in science learning for their students (Wenger, 2000). This perspective offers a rich way to analyze the experiences of teachers as they participate in scientific and professional development activities, interact with scientists, other teachers, and their students, and think about how disciplinary practices that are central to scientific sense-making and knowledge-building can be represented with students.

Methods

The overall methodology draws on a combination of qualitative methods (participant interviews, focus groups, open-ended survey responses). It also uses a design-based research approach and engages selected participants in collaborative autoethnography. Below, I provide background on both design-based research and collaborative autoethnography. Each empirical chapter provides greater detail about the data sources as well as the methods used to collect and analyze data. In this research, data were analyzed through a combination of open coding and codes derived from theoretical constructs of interest using Dedoose® qualitative analysis software. The study was reviewed and approved by the University of Washington's Institutional Review Board.

Design-Based Research. Design-based research (DBR) offers a productive approach for innovating, testing, and refining learning interventions in real-life learning environments (Brown, 1992; Collins et al., 2004; Sandoval, 2014; Design-Based Research Collaborative, 2003). DBR encompasses the "theoretical and empirical study of complex human interventions as they can be used to promote and sustain innovation in everyday settings" (Bell, 2004, p. 251). A focus on the situated nature of learning provides the impetus for Learning Scientists to study interventions in natural settings (Brown, 1992; Collins et al., 2004; Sandoval, 2004). DBR methods allow for the study of detailed interventions and social interactions in real-world contexts, giving researchers access to complex learning phenomena. Productive innovations result from particular designs being enacted in specific contexts and systems, yet the specifications and theoretical framing of such interventions can provide broader models of learning in complex systems (DBR Collective, 2003).

Design-based research differs from formative assessment and other iterative processes in its focus on building theory through research and its attention to the theoretical aspects of design decisions (DBR Collective, 2003). While there is a broad range to theoretical approaches within DBR (for example, those grounded in developmental psychology, cognitive science, cultural psychology, or anthropology), they are united by their shared emphasis on understanding the conditions that support sustained innovation in education (Bell, 2004). DBR experiments also focus on developing theories of learning that "do real work" (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003, p.10) in educational settings; they not only illuminate learning processes but also inform the enactment of the design in learning contexts. Theoretically, the designed interventions that are tested through DBR methods represent specific "conjectures about learning within educational designs" (Sandoval, 2004, p. 222); these conjectures (and the specific task structures and lesson materials, participation structures, and tools and material support elements they embody) can provide an empirical framework to help advance theoretical understanding. One of the major contributions from DBR studies is the development of "ontological innovations" (diSessa & Cobb, 2004, p. 77), theories that aim to explain observations and new phenomena that arise out of the implementation of designs.

DBR experiments take an engineering and design approach to developing theories and innovating in learning settings. One hallmark of DBR is the responsiveness of the design to issues that arise during testing. DBR experiments are extended and iterate flexibly in order to adjust to circumstances of practice (Brown, 1992; Cobb et al., 2003; Collins et al., 2004). As Cobb et al. (2003) note, "design experiments create the conditions for developing theories yet must place these theories in harm's way. Thus, design experiments always have two faces: prospective and reflective" (p. 10), that together exemplify the iterative process and allow DBR researchers to engineer educational environments as they research them.

DBR methods are appropriate for this study because I am interested in how learning experiences for teachers can be architected to support teachers' growth in learning about scientific practices. In particular, my research seeks to surface design principles that can advance teachers' understanding how practices such as argumentation occur in professional scientific research settings and help them bring productive elements of disciplinary discourse to their classrooms.

Collaborative autoethnography (CAE). Ethnography is well-suited to this research because it provides a way to examine the culturally situated behavior of teachers and how they make meaning from their experiences across settings. In the final empirical chapter, I describe a part of my research that involved selected participants as researchers. The use of participants helps guard against misrepresentation of teacher experience by the researcher (Wolcott, 1988). As noted by Barab, Thomas, Dodge, Squire, and Newell (2004, drawing on Finn, 1994), participant research has the following qualities: 1) It is people-oriented and especially responsive to experience/needs of individuals from traditionally marginalized groups; 2) It is power-focused and able to support individuals in developing critical consciousness/awareness; and 3) It is praxis-centered and committed to improving both theory and practice (p. 257). Finally, Walford (2008) notes that giving high status to participants' own experiential accounts and providing them with the ability to influence both the researcher and the direction of research help to moderate the power of the researcher. Partnering with participants, he notes, allows analytical frameworks to arise from the direct experiences of those studied. Conducting research in partnership with teachers assumes that they are knowledgeable about their worlds and can help us understand them.

Collaborative autoethnography (CAE) is a "qualitative research method in which researchers work in community to collect their autobiographical materials and to analyze and interpret their data collectively to gain a meaningful understanding of sociocultural phenomena reflected in their autobiographical data" (Chang, Ngunjiri, and Hernandez, 2012, p. 23-24). As a method, CAE builds on three interrelated analytical elements: an emphasis on deepening learning and understanding through discourse and engagement with others, a focus on self-reflection, and a commitment to ethnographic methods. In CAE, the researchers (in this case, teachers) are not only visible, but at the center of the research.

CAE draws on the strengths of both collaborative ethnography and autoethnography. Collaborative ethnography “deliberately and explicitly emphasizes collaboration at every point in the ethnographic process, without veiling it - from project conceptualization, to fieldwork, and, especially, through the writing process” (Lassiter, 2005, p. 16). By desettling traditional relationships in the researcher-participant interaction through its commitment to power sharing, it also takes a more critical approach to ethnography and elevates the “emic” or insider point of view (Pike, 1967). Autoethnography provides a framework for applying specific interpretive tools to self-reflection, while collaboration allows a community of researchers to join together to deepen and enrich their understanding. By collectively processing biographical data related to shared experiences, researchers can gain a greater understanding of both the phenomena under study as well as the broader sociocultural context in which those phenomena reside.

Chang et al. (2012) note the transformational potential of this research methodology for professional development, allowing participants to explore their own identity development, become more reflective practitioners, and become empowered to find and share their own voices as they engage in critical dialogue with others. CAE methods have also been used by teachers and teacher educators in diverse ways: for example, to research implementation of science curriculum (Coleman & Leider, 2014), develop and evaluate culturally responsive pedagogy (Han et al., 2014), integrate feminist pedagogy in science teaching (Capobianco, 2007), and teach qualitative methods and writing at the university level (Lapadat, 2009).

Site, context, and participants.

Site. This research project took place at a freestanding cancer research center (the “Center”) in an urban center on the West Coast of the US. The Center has over 3,000 employees working in five divisions: basic research, human biology, clinical research, vaccine and infectious diseases, and public health. Founded in 1975, it was a pioneer in the field of bone marrow transplantation as a treatment for leukemia and related disorders and continues to be the site of cutting-edge research into cancer and other diseases impacting human health.

Context. The Teacher-Scientist Partnership (TSP, a pseudonym) is a professional development program at the Center for secondary school science teachers. Since 1991, TSP has been offering teachers direct experience in state-of-the-art labs, support in developing engaging curricula, and access to valuable teaching tools. Each year, a new cohort of 20-25 teachers participates in the program.

The year-long program includes: 1) An intensive 2-week Summer Session in which teachers work closely with each other, TSP staff, and scientist mentors to gain skills and expertise in molecular biology. This includes 5 days of direct experience working alongside scientists in research laboratories and attending lab meetings; 2) Time and assistance during the session to develop a curriculum project that brings the research experience back to their classrooms; 3) Additional meeting times throughout the school year to prepare teachers for the experience, reflect on its impacts, and bring the larger community of teachers together; and 4) Access to a Kit Loan Program so students have the opportunity to conduct hands-on molecular biology investigations. There are 18 different kinds of kits and 70 total kits available. Kits include all the equipment and supplies necessary for teachers to conduct labs involving methods such as such as gel electrophoresis, bacterial transformation, DNA extraction or column chromatography. Each year, 16,000 students from 1,500 classes use kits from the TSP Kit Loan Program.

The program, which was developed collaboratively by scientists and educators, has a strong focus on valuing teacher experiences and developing lasting relationships with teachers.

Over 550 teachers have participated in the program since its inception, creating a strong community of educators who are a resource for one another. TSP educators have also made a large impact on science education in the state where the Center is located and have used their TSP training and resources to impact over 400,000 students.

The program also involves TSP teachers who have participated in the summer program in prior years and who have returned to help teach some of the content and to serve as trusted intermediaries between new teachers, staff, and scientists. These “Lead Teachers” also visit participants in their lab placements and help participants develop lesson ideas based on the research experience. Lead teachers lend the valuable perspective of teachers who have seen their own practice evolve as a result of TSP. Each year, four past participants serve in this role. In 2017, one Lead Teacher was new in the role and the others had more experience – having participated as Leads for 20, 18, and 8 years.

Partnerships and relationships between teachers and researchers are valued by the TSP professional development program. Participants continue to stay connected to the program after their initial year; some serve as Lead Teachers in subsequent years, others come back for additional research experiences, and many teachers draw on each other and TSP staff for ongoing professional advice and support. Many teachers continue to borrow equipment and supplies throughout their teaching career. The learning and relationships that take place in the program are complex, branching, and multiply over time. For example, in the year that this research was conducted, two of the participating mentor scientists were former students of teachers who had attended the program in prior years, and who were strongly influenced by those teachers. These scientists wanted to give something back to support teachers and their future students. One mentor scientist even attended the same high school as the teacher she worked with and elected to work with her for that reason.

The year-long TSP program includes and Opening Day, a Summer Session, a Reflection Day, and opportunities during the year for special professional development opportunities. Once they have completed the Summer Session, new participants are eligible to borrow equipment and supplies from TSP for their classrooms. Each of these program components, as they occurred in 2017-2018, is described further below.

Opening Day. On Opening Day in May, teachers met one another, the TSP staff, and the Lead Teachers. They learned how to use some of the basic molecular biology equipment (micropipettes, gel electrophoresis boxes) that they would encounter during the program and that they could borrow for their classrooms through the kit loan program once they completed the program. They participated in these experiences as “students” themselves. Teachers received a lab notebook and were asked to follow a reflective writing format that included their professional and personal reflections. At the end of the day, teachers also met the mentor scientists whose labs they would be placed in during the summer. Mentors selected participants they wanted to partner with from the teacher pool, often on the basis of shared interests. Occasionally, a mentor will take two teachers: In the summer that this research was conducted, two mentors selected more than one teacher. The teachers and mentors discussed possible research projects and each mentor provided an article related to their work written at the level of a scientifically engaged layperson. Each teacher brought their class syllabus and shared the context of their teaching. TSP encouraged scientists to visit their teacher’s classroom both before and after the summer experience. The majority of mentors worked at Center, but some worked in neighboring research institutes or biotechnology companies.

There is a separate orientation for mentors before they meet their teachers. This orientation helps prepare mentors for the kinds of research activities that they could plan for their teachers, provides background on where the cultures of science and education overlap and where they diverge from one another, and allows mentors to ask questions and hear from experienced mentors. It also helps set expectations for their participation. We shared the format for reflection in the lab that teachers would be using, so that mentors could be aware of it. We also asked mentors to ensure that they provided an experience where teachers could attend a lab meeting or witness discussions between scientists that included elements of persuasion and sense-making.

Summer Session. During the 13-day July Summer Session teachers worked closely with each other, TSP staff, and scientist mentors. The first three days were similar to Opening Day in content; they gave teachers a chance to get to know one another, experience TSP curricular lessons and resource kits first-hand, and hear about classroom implementation from the Lead Teachers. The next five days consisted of direct experience working alongside scientists in research laboratories. Lead Teachers and TSP staff visited each teacher twice during the lab portion of the program, checking to see that the teacher's relationship with their mentor was going well and that the teacher was keeping up their journaling and reflections in their lab notebook. During the final five days, teachers had time and assistance from Lead Teachers and TSP staff to develop a curriculum project that helped them bring the research experience and the kit resources back to their own classrooms. The following year, the program was extended from 13 to 15 days. A detailed list of all activities specifically related to argumentation is provided in Chapter 2, Table 1: TSP Overview: Argumentation Related Activities.

School Year Meetings. Six teachers volunteered to be part of a smaller group that met four times during the school year to think more deeply about student engagement in argumentation by engaging in collaborative autoethnography. Teachers were co-researchers in this part of the study and we collaboratively designed the direction of the research. Prior to each session (except the first), participants decided on the questions they wanted to reflect on. During the meetings, we identified themes in the autoethnographic writings that each participant contributed to answer the question. We also engaged in discussion on relevant readings. During the school year, there were also four additional day-long professional development workshops open to all past TSP teachers.

Reflection Day. The following May, towards the end of the school year, the entire cohort of teachers reconvened to reflect on the impacts of the TSP program on their classroom work. Teachers shared their experiences enacting their curriculum projects and using kit resources. They also shared their attempts at incorporating what they had learned about the social discursive dimension of argumentation with the TSP staff, Lead Teachers, and their peers.

Participant Recruitment and Selection

Participants were recruited to the overall TSP program in a variety of ways: through their professional colleagues (for example, other teachers at their school), through their districts or pre-service programs, or through marketing at professional development conferences. The program also advertised through print (postcards, brochures) and social media. Emails were sent to schools in remote geographical locations or in under-resourced communities. Participants were all teachers from within the same state as the Center but could be at any stage in their career. The program is designed for secondary science teachers and most participants were high school life science teachers. The full demographics of the cohort are described in Chapter 2.

At the 2017 Orientation Day, I briefly described the research to the 21 TSP participants and 4 Lead Teachers and provided them with written information to take away with them. When they returned for the summer program in July 2017, I provided additional opportunities for questions and asked those who were interested in participating to turn in their consent forms. All teachers (including Lead Teachers) consented to participate in this phase of the research study.

Researcher Positionality

In this section, I describe my positionality relative to the subject matter, participants, and broader context (Savin-Baden & Major, 2012). These elements are deeply interconnected because of my long history with the program. While I now serve as the TSP Director, I was also a TSP participant as a young science teacher over twenty years ago. It was a formative experience for me at the start of my professional career in science education and my interest in biomedical research. I developed relationships with other participants and scientists that continue to this day. After my own TSP experience, I went on to conduct two summers of research in a clinical laboratory at the Center. I am still strongly connected to the researcher with whom I spent my two summers. As a result of that experience, I felt comfortable enough to start a biotechnology class at the high school where I taught. I also partnered with teachers I had met in TSP to create a novel model for a life science fair that provides science mentors for students and that allows entries in a broad range of categories including art, journalism, molecular modeling, etc. While I had been motivated to participate in TSP in order to be able to borrow equipment and supplies for my classroom, the greatest benefit ended up being the connection to scientists and other teachers.

In the next decade, I worked in a science education non-profit organization and led curriculum efforts and professional development for secondary science teachers. Our focus was on social and ethical issues in how science is conducted and how scientific discoveries should be used. I concentrated on helping science teachers engage their students in bioethical decision-making and discussions related to science and society. As I worked with teachers to help them feel confident in leading seminar-style discussions (Parker & Hess, 2001) about texts related to bioethical issues, several things became apparent: (a) that science teachers were more comfortable leading discussions about procedures, data, or results; (b) that such discussions were actually parallel to the kinds of discussions that scientists engage in as they design experiments or analyze data with their peers; (c) that if such discussion structures could be used more frequently in the science classroom, in conjunction with genuine questions about optimal procedures or puzzling results, students would have a deeper understanding of the role that collaborative and critical dialogue plays in science.

Before returning to TSP, I helped lead a non-profit focused on equity in education. This brought me a greater awareness of some of the cultural dimensions of working with students. The students often excelled in supportive and challenging educational environments, but also struggled with difficult personal circumstances, complex trauma, and the biases and racism of those around them. I witnessed many different communicative styles, some individual, but many rooted in cultural expectations or practices. I thought a lot about how students' experiences and their personal assets often remain hidden from teachers – and how those might be resources for learning and discussion in science classrooms. I wondered if more students would identify with science if they were able to feel that their voice and perspective mattered.

During my first year at TSP, I felt I there was a natural opportunity to weave in a focus on the practice of argumentation into the program, particularly given the emphasis on scientific practices in the *Next Generation Science Standards*. In prior years, TSP teachers attended lab meetings with their scientists, but without a specific lens or focus to think about what was happening there. Likewise, when teachers assumed the role of students in learning how to use some of the curricular materials and supplies (for example, when conducting an experiment to insert DNA into bacteria), there was a natural opportunity to have them use their own data to engage in discussions with their peers and to practice discourse strategies that they could use in the classroom. I thought that a subset of teachers might also be interested in thinking about students' resources and the cultural dimensions of argumentation when they went back to their classrooms the following year. I wanted to think with other educators about how to position students as capable and how to draw on their experiences as valuable resources, and I wanted to do it in a way that would privilege the ideas and voices of teachers.

Analytical Concerns

Insider/Outsider Status. I naturally identified with the participants in the program and I wanted them to succeed. I also felt a deep commitment to supporting them both in their classrooms and in their professional growth. However, I was directing the program that I was researching. In addition, I have been out of the classroom for some time and so felt less attuned to the specific problems of practice that teachers were encountering. So, there are some ways that I was more of an "insider" and others where I was an "outsider." In addition, there was a natural power differential between the participants and myself resulting from my position as a director and as a researcher. I occupied a role that conveyed some authority, and that had the potential to influence how participants interacted with me and the degree to which they may have felt comfortable sharing.

Validity. Data triangulation and member checking can both strengthen the internal validity of a study (Merriam & Tisdell, 2016). I triangulated multiple methods and data sources to confirm findings. As a way to member-check my interpretations, I shared emergent themes and ideas with the participating teachers. I also engaged colleagues in my university academic research group as informed experts in order to provide checks on my interpretations.

Etic/Emic approaches. Descriptive accounts can be etic or emic: etic accounts are “based on concepts that come from outside the culture studied” while emic ones “involve descriptions that use categories from within that culture that would be used or recognized by its members” (Emerson, 2001, p. 31). My research utilized both approaches. The research on TSP teachers experiences with argumentation described in Chapters 2 and 3 drew heavily from educational research and theory (an etic approach). However, in the collaborative autoethnography I partnered with teachers to try to understand local meanings from inside the cultures they navigate, which is more of an emic approach. Nevertheless, as Emerson notes, “emic accounts are not literally members’ constructs, but rather second-order renderings of those constructs produced in one fashion or another by the ethnographer” (p. 35). Teachers contributed their accounts, which were reflective of their experiences, and analyzed them collaboratively. Those accounts underwent another layer of analysis as I considered them together holistically. If material from the Chapter 4 is accepted for publication, the teachers will serve as co-authors.

Structure of Dissertation

Chapter 2: Brokering argumentation practices from scientific research settings to science classrooms: *I had not really thought of what scientists do as "scientific argumentation”.* The first empirical chapter focuses broadly on how secondary science teachers made meaning from their observations of scientists enacting argumentative practices in the professional research setting and how they shifted their thinking and their work with students in their classrooms in the subsequent year. I was guided by the following research questions: How do secondary science teachers learn about argumentation and scientific sense-making through participation in research experiences? How do teachers' observations of sense-making in professional research settings influence their conceptions of the role of argumentation in science and in secondary science instruction? From a design-based research perspective, I also examined what kinds of tools/materials, tasks/activities, and discursive practices could help advance the broader goals of expanding teachers' conceptions of argumentation and shift their practices to include more opportunities for productive uncertainty (Manz, 2018), collaborative sense-making, and deliberative discourse in their classrooms (Sandoval, 2014).

I examined the experiences of a cohort of 21 secondary science teachers and 4 Lead Teachers as they participated in the TSP program. The TSP teachers observed and reflected on ways in which argumentative practices were situated and enacted in scientific research settings. They also considered the implications of their observations for their own classrooms. I present major thematic findings from across the whole cohort and then provide vignettes of three teachers who illustrate different ways that teachers took up new ideas about argumentation practices. The chapter describes both the specific design elements of the experience that were structured to support such reflections and the broader design principles that emerged as a result. Data for the analysis came from transcripts of teacher discussions, semi-structured interviews with selected participants, field notes, teacher posters and artifacts, surveys that included open-ended questions, and written reflections from teachers' daily journals.

The TSP program provides a unique experience for teachers; it is brief enough in duration to appeal to a broad group of educators who might shy away from lengthy research commitments, but substantial enough for teachers to have an immersive experience in a lab with a research mentor. It provides teachers, most of whom have not had research experiences in the past, with a chance to see "practices" in the context of a scientific research environment, rather than as an abstraction. My analysis demonstrates how teachers can become motivated to incorporate scientific practices in their classroom in ways that reflect the central role of argumentation and social knowledge-building and sense-making discourse in science. Findings from this analysis have implications for the professional development of science teachers and encourage other research centers or teacher pre-service and in-service programs to include such structured research experiences.

Chapter 3: Science teachers decenter classroom power following experiences in professional research settings: *I took a step back...and it was amazing.* In the second empirical chapter, I describe a set of findings related to power and discourse that emerged from the larger study described in Chapter 2. The chapter details how TSP educators viewed the relationship of discourse and power dynamics in the lab settings and how they connected those observations to their teaching and classroom practices. This study examines the following research questions: How do secondary science teachers learn about power and its connection to argumentation and scientific sense-making discourse through participation in research experiences? How do teachers' observations in professional science research settings help them move away from hierarchical power arrangements and towards collaborative and equitable sense-making discourses in their classroom? It also investigates, from a design perspective, how professional development can be designed to help teachers consider how their pedagogical choices can shift epistemic authority to students and promote equitable student participation. I was also interested in exploring what motivates teachers to include more opportunities for student argumentation, sense-making, and knowledge-building discourse into their classes and to take a step back from positioning themselves as the main arbiter of power and knowledge in the classroom.

Professional development that includes focused research experiences in scientific settings offers a way for teachers to reflect on the ways that power, knowledge-building, and collaborative discourse are related in science. In this chapter, I suggest that such experiences can prompt teachers to consider the implications for their own classrooms and how they manage discourse. They can also help provide what I term "epistemic motivation," or impetus, for teachers to make difficult pedagogical and philosophical shifts that better represent the fundamental role of collaborative discourse and argumentative sense-making of science. This paper examines how teachers recognized and reflected on their power (particularly in managing discourse) after observing scientists' argumentation in research labs and discussing their findings with one another. When teachers created discourse opportunities for students that reflected some of the disciplinary ways of talking that they had observed in the research center, they decentered teacher power, represented the discipline of science in more authentic ways, and facilitated more equitable participation among students.

This chapter explores how discourses (specifically language-in-use) reflect and impact larger Discourses (characteristic ways of "saying, doing, and being", Gee, 2014, p.47) and what the implications of such a theoretical lens are for understanding power in science classrooms. I also examine how individuals come to be positioned in particular roles, with certain responsibilities and expectations (Harré, Moghaddam, Cairnie, Rothbart, & Sabat, 2009). My analysis examines how teachers across the cohort reflected on their own position through their experiences in the research lab and investigates their thinking about the relationship between physical arrangements of space, power and authority, and student contribution. This research suggests that focused professional development in research settings can support the "desettling" of taken-for-granted routines and roles in science teaching to foster more equitable and epistemically authentic science practices in classrooms.

Chapter 4: Strengthening Teachers' Interpretive Power Through Collaborative Autoethnography: Engaging Students' Cultural and Everyday Resources in Argumentation. The final empirical chapter describes findings from a subset of six TSP teachers/researchers during the school year. The teachers met with me four times to discuss their own autoethnographic reflections about how their experience in TSP impacted their classroom practice. The focus of the reflections was on how assets that students bring to argumentation from their own experiences and background can be elevated and serve as resources for argumentation. Before each session, teachers wrote an autoethnographic response to the prompting questions. At the sessions, these were all shared and reviewed by other teachers. Collaboratively, we identified themes in the data and discussed them.

The initial question, which I provided, asked teachers to reflect on their own positionality and history and how those influenced how they structured talk for their students. Subsequent questions were developed by the team and included:

- How do our own relationships with students ("knowing them") impact classroom talk and argumentation? How do we build those relationships? How can we be close, yet professional?
- How do students' relationships with one another ("knowing each other") impact classroom talk and argumentation? What kind of instructional structures support talk and argumentation? What kind of instructional structures support relationship-building?

- What are my own ideas about "learning" and "rigor"? How these ideas relate to argumentation? What classroom moves are integral to my beliefs about learning? How can we combine engagement and "rigor" among diverse students?

At the last session, teachers also shared how their thinking about argumentation and other scientific practices changed as a result of their reflections, readings, and discussions in the argumentation research group.

I used the construct of "diffraction" (Haraway, 1992) to explore how ideas traveled between teachers and changed across the sessions. The analysis shares both the findings and themes surfaced by teachers and my own thoughts on how teachers cultivated their interpretive power (Rosebery, Warren, & Tucker-Raymond, 2016) through this process. Teachers elevated the importance of relationships and safety in the classroom in order to support productive argumentation. They also considered the ways in which the sociocultural resources that students bring to argumentation can be valued and leveraged for learning.

Summary

This research investigates how teachers made meaning from their observations of, and experiences with, scientific practices in research settings. It provides design principles for science teacher professional development to support students in learning about, and engaging in, social argumentative practices in science. Teachers who shifted discourse structures to incorporate evidence-based persuasion, critique, and collaborative sense-making laid the groundwork to elevate the role of student perspective and voice and to disrupt the traditional hierarchical power structures in their classrooms. This dissertation also provides a model of a research partnership with teachers focused on professional reflection. It investigates how the methodology of collaborative autoethnography can help teachers reflect on the unique cultural and historical perspectives of students and the resources that they bring to argumentation. This study examined how teachers could expand their conceptions of argumentation along two dimensions: by elevating the importance of the social and discursive aspects of argumentation in scientific knowledge-building and by emphasizing the diverse contributions students can make to argumentation from their lived experiences.

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Chapter 2: Brokering argumentation practices from scientific research settings to science classrooms: *I had not really thought of what scientists do as "scientific argumentation"*

Abstract

This study investigates how secondary science teachers who participated in professional development at a research center learned about scientific argumentation. As part of their experiences, teachers spent one week with scientific mentors in research labs observing how scientists talk, particularly when they are trying to persuade one another, weigh potential procedural or experimental options, or make sense of their findings. This article explores the experiences of a cohort of 21 teachers and 4 experienced lead teachers as they examined the role of argumentation in science, reflected on its social dimensions, and considered "what counts" as argumentation in their own classrooms. This study uses qualitative methods in coordination with design-based research to foster an expansive view of argumentation with teachers: one that goes beyond students' written conclusions for known-answer activities to highlight the social, discursive, persuasive and meaning-making dimensions of argumentation. Teachers reflected on the shifts in argumentative practices that they employed in their own classrooms after their research laboratory experience and their participation in a professional development workshop. They recounted shifts in pedagogical practices based on a deeper understanding of the importance of argumentation and a desire ("epistemic motivation") to align elements of professional practice with those of the classroom. Across the cohort, teachers demonstrated: (a) a heightened awareness of argumentation as an embedded, ubiquitous feature of scientific activity; (b) expanded ideas about forms and uses of argumentation; and (c) an understanding of how features of argumentation such as collaborative sense-making and critique can help manage uncertainty and build knowledge. Three short vignettes illustrate different ways in which teachers made meaning of their experience and some of the challenges they encountered.

Findings also surfaced design knowledge about how professional development can highlight the role that argumentation plays in science and broaden teachers' views of what counts as argumentation, with implications for secondary science teaching.

Overview

> *I wish that students could sit in on [a professional science lab meeting]…a couple of takeaways that I got were that the presenter doesn't always know the answer, and that's ok…There were a lot of questions being asked and he was very not defensive at all, which I feel like kids get… I thought that the lab meeting was super cool. I also feel like it's important to do those open investigations to make that argumentation work. Otherwise, everyone is doing exactly the same thing and there's no discussion. (Elizabeth, small group discussion)*

It is possible to become a science teacher without ever having had a professional research experience. Students who are successful at science in school may pursue science and science education in college and then go directly back into the classroom as teachers. In the quote above, one such science teacher shares her thoughts from sitting in on a scientific lab meeting - specifically, her insights about the presenting scientist's acknowledgement of not having all the answers, the role of the audience in critiquing ideas, and what kind of investigations and structures would be necessary to make "that argumentation work" in the classroom.

This research study centers on the practice of argumentation, a key process contributing to the generation, evaluation, and application of new knowledge in both disciplinary and everyday contexts (Bricker & Bell, 2008). Argumentative practices underlie scientific activity and are at the root of the social construction of scientific understanding (Berland & Reiser, 2009; Duschl &Osborne, 2002; Ford & Forman, 2006). Scientists engage in argument to persuade one another, but also to puzzle through problems together, speculate, propose solutions, and attempt to make sense of findings. Awareness of the importance of incorporating the practice of argumentation into science classrooms has been growing (Bricker & Bell 2008; Osborne, 2010), particularly as reform initiatives set a vision for student science learning that identifies argumentation as a key practice. The Next Generation Science Standards (NGSS) and corresponding *Framework for K-12 Science Education* (NGSS Lead States, 2013; NRC, 2012) highlight argumentation as one of the key practices of science. For example, the *Framework for K-12 Science Education* (NRC, 2012), states:

> Although there is no universal agreement about teaching the nature of science, there is a strong consensus about characteristics of the scientific enterprise that should be understood by an educated citizen…What engages all scientists…is a process of critique and argumentation. Because they examine each other's ideas and look for flaws, controversy and debate among scientists are normal occurrences, neither exceptional nor extraordinary. (p.78)

Incorporating argumentation in science classrooms has a multitude of benefits for learning, including: providing students access to cognitive/metacognitive reasoning; helping them develop critical thinking and communication skills; engaging them in the language of science; fostering their participation in epistemic aspects of science; and encouraging them to reason with rational criteria (Erduran & Jimenez-Aleixandre, 2007). The inclusion of argumentation within school science provides students with broader insight into how scientific knowledge advances while giving them experience with the social processes that underlie the construction of scientific ideas (Bell & Linn, 2002; Bricker & Bell, 2008). Research suggests that collaborative discourse and critical dialogue focused on student claims and justifications can increase student reasoning abilities and conceptual understanding (Osborne, 2010), and that collaborative classroom debate can help students deepen their understandings of the role of important social processes such as critique in science (Bell & Linn, 2002; Bell, 2004).

Past research indicates that argumentation occurs infrequently in science classrooms, although that may change with the advent of the NGSS and an increased emphasis on scientific practices (NGSS Lead States, 2013). Students and teachers often adhere to views of science as factual information (Lemke, 1990, Driver, Newton, & Osborne, 2000). Additionally, many science teachers lack direct experience conducting research or using scientific practices themselves (Russell, 2005; Windschitl, Thompson, & Braaten, 2008). It is not surprising, then, that studies indicate that opportunities for students to participate in social aspects of argumentation are rare (Osborne, 2010; Berland & Reiser, 2011; Bricker & Bell, 2012). In particular, the role of collaborative and critical discourse for the purposes of shared sense-making is rarely foregrounded (Bricker & Bell, 2012; Manz, 2015).

For most teachers, it is not practical to spend the time learning how to become scientific "knowledge producers" (Feldman, Divoll, & Rogan, 2009) – yet they are expected to understand scientific practices in order to teach about them and engage students in them. While teacher professional development opportunities in research settings have the potential to provide educators with deeper understandings about scientific practices such as argumentation, little is known about what teachers learn about practices in such contexts or how they consider the implications for their work with students. For example, a review of 11 research apprenticeships programs of teachers found none that explicitly focused teachers on collaborative and sense-making discourse practices (Sadler, Burgin, McKinney, and Ponjuan, 2010). This represents a missed opportunity in teacher professional development, as research organizations have deep expertise in science practices. In this paper, I describe a qualitative and design-based research study that addresses this gap by examining how members of a cohort of secondary science teachers made meaning about scientific argumentation from their experiences in labs at a research center and from a professional development workshop.

Purpose

The purpose of this study is to examine how teachers in a professional development program that is embedded in a scientific research center learn about argumentative practices, with a particular emphasis on their observations of how scientists use collaborative discourse to design their investigations and interpret their results. This study investigates the experiences of teachers who visit labs within the research center with the intent of observing how scientists talk with one another, particularly when they are trying to persuade one another, weigh potential procedural or experimental options, or make sense of their findings. It explores the experiences of secondary science teachers as they examine the social dimensions of argumentation among scientists, reflect on the role it plays in science, and consider "what counts" as argumentation in their own classrooms.

This study uses qualitative methods in coordination with design-based research (Brown, 1992; Collins, Joseph, & Bielaczyc, 2004; DBR Collective, 2003) to foster an expansive view of argumentation with teachers: one that goes beyond students' written conclusions for known-answer activities to highlight the social, discursive, persuasive and meaning-making dimensions of argumentation. Teachers reflected on the shifts in argumentative practices they employed in their own classrooms after they engaged in research laboratory experiences and their participation in a professional development workshop. Findings surfaced design knowledge about how professional development can highlight the role that argumentation plays in science and broaden teachers' views of what counts as argumentation, with implications for K-12 science teaching.

In this paper, I first present background on some of the ways that argumentation has been taken up conceptually within science education research in order to explain the broader need for this study. Next, I discuss the socio-cultural theoretical framework which underlies this research. Specifically, I examine the theoretical context of teachers' roles as "brokers" (Wenger, 2000) as they cross the boundaries of various communities of practice (Lave & Wenger, 1991). I then present the qualitative research methods used for this study and discuss my analytical approach. The analysis section examines argumentation as a specific practice being brokered across different communities: teachers described their expanded understanding of argumentation-related practices in professional scientific lab research settings and their reflections on how those practices can be transferred to classroom communities. In the analysis, I consider the impacts on the teacher cohort as a whole before describing three brief illustrative vignettes. Finally, I conclude with a discussion of the broader implications of this research for design of teacher professional development and for science education.

Research Questions

The following research questions guided this study:

- How do secondary science teachers learn about argumentation and scientific sense-making through participation in research experiences?
- How do teachers' observations of sense-making in professional research settings influence their conceptions of the role of argumentation in science and in secondary science instruction?

This study also investigates the following design-centered question:

- How can professional development be designed to promote science teachers' understanding of the role of argumentation in the creation of new scientific knowledge, and support teachers in applying this knowledge to their work with students?

Background

In providing background context for this research, I first clarify the stance that I take relative to argumentation as a practice and the relationship of sensemaking and argumentation. I argue that in order for classroom argumentation to more accurately reflect scientific practices, teachers need to present argument broadly, and not only as a structured form of reasoning with evidence, but also as an embedded, enmeshed dimension of scientific inquiry that is often negotiated discursively through collaborative sense-making and critique. I close this section with brief discussion on how teachers' awareness of, and experience with, scientific practices in context may help them form expanded conceptions of argumentation.

Argumentation: an expansive, interconnected view of practice

In this paper, I will take an expansive, situated, and interconnected view of argumentation, in line with the ways that the practice is actualized in research settings and endeavors. Scientists often make formal arguments, particularly attempting to persuade others in papers or in presentations. However, they also engage in fluid and socially situated arguments as they develop explanations for their findings, build new knowledge, and make sense and meaning with their peers. My position aligns with argumentation researchers who emphasize that argumentation plays a role in collaborative sense-making as well as in persuasion, and that both elements of scientific argument are important to share with students (Bell, 2002; Berland & Reiser, 2009; Berland & Reiser, 2011, McNeill & Krajcik, 2008). Furthermore, emphasizing the social dimensions of argumentation helps students understand how knowledge is created in action with others. As the *Framework* (NRC, 2012) notes, "to engage productively in science...students need to understand how to participate in scientific discussions, how to adopt a critical stance while respecting the contributions of others, and how to ask questions and revise their own opinions" (p. 252).

Sensemaking and argumentation

In this paper, I explore how teachers understand the role of argumentation in discourse, both to persuade others and to make sense and meaning. The constructs of sense-making and argumentation are closely related, although they have distinctive characteristics. Sense-making serves to build knowledge and understanding of phenomena (Berland & McNeill, 2011). It is "about actively trying to figure out the way the world works" in response to scientific questions (Schwarz, Passmore, & Reiser, 2016, p. 6), and developing explanations that justify their positions (Braaten & Windschitl, 2011). Odden and Russ (2018) define sense-making as "a dynamic process of building or revising an explanation in order to "figure something out" - to ascertain the mechanism underlying a phenomenon in order to resolve a gap or inconsistency in one's understanding" (p. 6). They go on to describe how different kinds of knowledge (everyday and formal) are offered up and connected in order to build explanations, and how those ideas are vetted against prior knowledge and other available information. They emphasize that sense-making can be thought about as a stance or epistemological frame, a cognitive process, and a discourse practice. It is this last dimension, sense-making as a collaborative discourse practice, that closely connects to argumentation. They note that students arguing in this sense-making style are "trying to build an explanation together, and while they may critique each other's arguments they are doing so to make their explanations stronger, not to 'win'" (p. 10) (see also Brown and Campione's "guided inquiry" process (1994), Scardamalia and Bereiter's "knowledge building" (1999), and Bransford's work with the Cognition and Technology Group at Vanderbilt on "anchored instruction" (1992) for earlier research in this vein). Lastly, Odden and Russ (2018) emphasize that argumentation also extends *beyond* sense-making as it could be used for purposes such as persuasion or authority - or to express prior knowledge that has already been constructed into an explanation.

Argumentation in Classrooms

Representing argument as a guiding element of inquiry. Teachers need more opportunities to represent argument as an integral and guiding component of inquiry, rather than simply a product of it. Approaches that position argument as a fundamental aspect of inquiry help foreground the context in which scientific argumentation occurs. Manz (2015) describes the need to shift the pedagogical focus on scientific argumentation from *how students develop explanations for existing knowledge* to the *ways in which argumentation is inextricably linked to the development of new knowledge,* explaining:

> To date, most accounts of argumentation emphasize how students support knowledge claims rather than how they contest and develop their means for knowing. Therefore, most studies focus on how students use evidence, rather than how they participate in making it…This approach presents a simplification of argumentation that approximates reconstructions of activity that occur after investigations have been concluded and are made by experts who have internalized the voices of other community members…However, there is growing evidence that another approach might have significant affordances: positioning argumentation as a social process for which students bring in significant resources, then helping them see the scientific enterprise as worth applying those resources to. (Manz, 2015, pp. 22-23)

The argumentative processes that are integral to shaping new understandings and that are a key epistemic practice of science are effectively hidden from view if scaffolds that draw upon established knowledge are over-emphasized (Duschl, 1990). Rather than (re)constructing knowledge claims which are mere "echoes of scientific activity systems" (Manz, 2015, p. 23) and the work scientists have already done, it is important for teachers to be able to emphasize the dynamic social aspects of argumentation in sense-making and knowledge-building with their students.

Over-reliance on argumentation frameworks. Argumentation frameworks, which help students provide evidence for claims and link them with reasoning, provide a clear approach for introducing argumentation and supporting students in developing arguments – particularly written ones. Such scaffolds can be helpful tools within a practice-centered approach if they are used in conjunction with opportunities for students to discuss and compare their arguments and to work with others in their classroom community to make sense of their understandings.

There is also potential for teachers to overly rely on frameworks at the expense of other dimensions of argumentation. Researchers, instructional designers, and educators have placed much emphasis on supporting students in developing arguments using Claims-Evidence-Reasoning ("C-E-R") heuristics (McNeill & Krajcik, 2008), which are based largely on Toulmin's analysis of argumentation structure (Toulmin, 1958/2003). Toulmin's analysis of argumentation provides a theoretical foundation for teaching argument structure and has been widely taken up in science education and other disciplines as the "Toulmin model" or "Toulmin Argument Pattern" (Simon, 2008). Significantly, Toulmin himself did not intend for his framework to be applied rigidly as a "model" (Toulmin, 1958/2003, p. vii). The basic structural elements of the Toulmin model are: (a) a Claim; (b) Data/Evidence; (c) Warrants, which connect the Data and Claim; (d) Qualifiers indicating the strength of the Claim; (e) Rebuttals; and (f) Backings, statements that support the Warrant (Toulmin, 1958/2003, p. 94). Lessons that emphasize argument structure typically proceed by *teaching students a framework or structure first*, and then providing opportunities to apply that structure (for example, C-E-R approaches). These interventions emphasize the explanatory aspects of argumentation and reflect a view of argument as "product of inquiry rather than an enmeshed component of inquiry" (Cavagnetto, 2010, p. 352). In contrast, lessons that emphasize the situated nature of argument present the practice as an essential and embedded aspect of investigative activity and consider all the parts of the scientific process that one could argue about, from the design of studies to the inclusion or exclusion of ideas in models.

Argumentation can be part of a wide variety of teaching approaches. However, reification of argumentation frameworks into a single simple formula such as C-E-R communicates a limited view of argumentation and its role in science to students, particularly if they are used as ends in and of themselves. Such scaffolds pull selected, isolated elements of the broader practice of argumentation from larger activity systems, effectively decontextualizing them (Manz, 2015). There is a risk that teachers will continue to use argumentation within traditional teaching approaches rather than thinking about how the practice can be enacted in ways that align with the new vision for science education outlined in NGSS (Henderson, McNeill, Gonzalez-Howard, Close & Evans, 2017).

There are several additional problems that can arise from over-reliance on C-E-R frameworks. First, the claims students make using such scaffolds are ordinarily targeted to phenomena that are already well understood by the scientific community, through investigative processes that remain largely invisible to students (Manz, 2015). C-E-R frameworks, if used with instructional models that privilege the transmission of content over exploration and investigation, can imply that there is a single "correct claim" that students should be making that will yield a "correct explanation"—which is at odds with the way knowledge work happens in the sciences. If teachers can create opportunities for students to wrestle with multiple plausible claims, they can foster an expansive view of what "counts" as an appropriate claim and represent the disciplinary work of professional science more authentically. Second, while these scaffolds are intended to be faded from use as students become more experienced in coordinating claims and evidence, they can become fixed and used by teachers in formulaic ways that represent a simplified endpoint of the argumentation process (Berland & Hammer, 2012; McDonald & Kelly, 2012, Manz, 2015; Pea, 2004).

Expanding classroom argumentation beyond "pseudoargumentation." In order for students to develop epistemically authentic representations of the functions and forms of argumentation in science, they need to experience how argumentation can be applied to creating new ideas and knowledge through collaborative and critical discourse. Observational studies have shown that instances of these kinds of argumentation practices (particularly of using collaborative discourse to build knowledge through classroom interactions) are rare in classrooms (Bell, 2004; Bricker & Bell, 2008; Berland & Reiser, 2011). A key challenge for science educators and researchers is to discover ways in which argumentative practices that are embedded in collaborative sense-making discourse can be implemented in learning environments in ways that are pedagogically sound, as aligned to professional science as possible, and responsive to student sense-making assets and resources (Manz, 2015). Scientific research environments provide an opportunity for educators to observe such practices in context and to consider their role and value.

Berland and Hammer (2012) argue that the ways in which teachers "frame" the work of the classroom influences students' participation in scientific argumentation. They introduce the term "pseudoargumentation" (p. 88) to note how overemphasizing argument structure can result in argumentation being viewed as part of the "classroom game" (Lemke, 1990, p. 11) by students. Berland and Hammer argue that "introducing argumentation through explicit instruction in how to argue might undermine framings that are more consistent with scientific argumentation and therefore inhibit student engagement in this practice" (p. 88). In particular, they note that science education researchers have come to recognize that promoting argumentation requires designing situations that make "the point of argument clear" (p. 85), which necessitates a decreasing focus on teaching "argumentative skills and an increasing focus on creating situations in which students see the need to engage in these argumentative behaviors" (p. 83).

Teachers' limited experience with scientific practices in context. Finding ways to create more opportunities for sense-making argumentation in science classes relies in large part on the motivation, abilities, and confidence of teachers. However, teachers rarely have opportunities to build their understanding of the types of social processes and discourses that help warrant new knowledge in professional science (Windschitl & Stroupe, 2017; Windschitl, Thompson, & Braaten, 2008). Henderson and colleagues (2017) point out a wide range of reasons why teachers might be challenged to incorporate argumentation in their classrooms. For example, traditional classrooms are much more geared to "focus students on why right answers are right, with much less emphasis placed on why wrong answers are wrong" (p. 7, see also Ford, 2008). They go on to note the difficulty of compelling teachers, who in most cases have not learned science through argumentation themselves, to then represent that practice in their classroom. Even teachers who have research experience may not see the applicability of those experiences to their classrooms or be able to translate their understanding into instructional materials and teaching strategies (Brown & Melear, 2007; Windschitl et al., 2008). Teachers may also struggle with how to reconcile their images of scientific argumentation with their perceptions of the resources and competencies that students bring to school, or how to shift discourse and power structures in necessary ways (Cazden, 1988; Hudicourt-Barnes, 2003; Henderson et al, 2017). Additionally, they may view argumentation negatively because of the popular association of the term with conflict or social dispute (Bricker & Bell, 2008). Strategies are needed to help expand teachers' conceptions of argumentation and bring that broadened perspective to their classrooms; this study investigates how professional development can address that need.

Conceptual Framework

Sociocultural Learning Theory and Communities of Practice

Theoretically, this research is situated in sociocultural learning theory, which emphasizes that learning happens through participation in activities and practices of communities and is socially, culturally, and historically situated (Lemke, 2001; Vygotsky, 1962). Sociocultural theory helps to address the complexity of teachers' learning experiences as they move through various contexts (science lab, teacher workshop, and classroom), interact with scientists, other teachers, and students, use various tools and resources, and reflect on discursive practices such as argumentation. Drawing on the work of sociologists and historians of science, Lemke notes that a sociocultural perspective also "means seeing the scientific study of the world as itself inseparable from the social organization of scientists' activities" (Lemke, 2001, p.296, see also Latour, 1987; Lynch & Woolgar, 1990). This perspective also illuminates why a focus on social and discursive practices in science, such as argumentation, is important - as it acknowledges the situative nature of how people learn about science or the broader world (Bell, 1997; Bell & Linn, 2000; Bell, Tzou, Bricker, & Baines, 2012). This research also draws on the conceptual framework of communities of practice and social learning systems (Wenger, 2000). Scientific research groups are communities of practice, but also serve as epistemic communities (Knorr-Cetina, 1999). Feldman et al. (2009) make a distinction between the goals of communities of practice (where the goals are improvement of practice, or competence), and epistemic communities (where the goals are focused on creating new knowledge and warranting it). This research explores what teachers take away from observing both practice-based and epistemic dimensions of argumentation in a professional scientific community.

Boundaries as Sites for Learning

The boundary of a community of practice is implied by its own existence distinct from others. There is a robust literature exploring the idea of boundaries as productive sites for learning (Engeström, Engeström, & Kärkkäinen, 1995; Akkerman & Bakker, 2011; Wenger, 2000). Boundaries both connect different communities and present opportunities for learning that differ from those inside a community. Educators in the professional development workshop described in this paper (the Teacher-Scientist Partnership, or TSP, a pseudonym) experienced the boundaries between their own TSP community, the research scientists they interned with, and their classroom communities where they teach students. There is theoretical potential for teachers to feel thwarted in their learning, and experience a lack of belonging, if the discrepancy between their own experience and the dimensions of competence they are encountering in scientific settings is too great. There is, however, also a great potential for learning if competence and experience can be brought together in productive ways at that boundary. Generative boundary crossing processes are essential to the functioning of social learning systems such as those generated through the TSP experience.

Boundary encounters (Wenger, 2000, p.236) are a particularly relevant dimension of the TSP experience. Teachers "visit" and are exposed to a variety of community practices within the research center such as lab meetings. Wenger also notes that the ability of visitors to process the implications and meanings of their observations collectively allows them to more readily bring the learning back to their own communities. In the case of TSP, teachers are not considered apprentices on their way to becoming full-fledged members of the research scientist community (although there are instances of that happening). The intent is that educators generate productive learning at the boundary between the communities in order to develop their understanding and be able to share those insights with their students. Of particular theoretical relevance are the constructs of “brokering” (Wenger, 2000) and “consequential transitions” (Beach, 1999). Brokers such as teachers can use their membership in, or understanding of, multiple communities - to “transfer some element of practice into another” (Wenger, 2000, p. 109). For example, teachers in this study worked to broker scientific discursive practices across communities of professional research and the classroom. While Wenger focuses on the transfer of practices, Beach (1999) focuses on transfer as a change of relations between individuals and practices they engage in across settings (what he terms consequential transitions). These relations are recursive, with individuals influencing practices and settings and in turn being influenced by them. Changes of relations are developmental processes that involve the “continuity and/or transformation of knowledge, skill, and identity embodied in the relation” and are consequential “when they are consciously reflected on, often struggled with, and the eventual outcome changes one's sense of self and social positioning” (Beach 1999, p. 114). Rather than applying something learned elsewhere to a new situation, consequential transitions (such as teachers’ transitions between the research lab, TSP community, and classroom) involve social and material transfer and transformational change.

School Science Communities of Practice

The greater the alignment between the discourses of science learning environments with those of science practitioners is, the greater the correspondence between students’ vision of science and what transpires in scientific “communities of practice” (Lave & Wenger, 1991). However, the process of aligning these discourses is fraught with difficulty; not only is science terminology and language-in-use related to science challenging, but students rarely experience opportunities to engage with scientific practices such as developing conceptual models through argumentation with others or appropriating scientific discourse to make sense of observations (Rosebery, Warren & Conant, 1992; Bell 2004), although this is central to the vision for K-12 science education represented in recent educational standards documents. Within formal classroom settings, students can become adept at navigating the demands of a particular representation of science in schools; often, the demands of being a "good science student" are at odds (and may even directly conflict) with those required of a science practitioner. Teachers' own perceptions of scientific practices and their views of how new scientific knowledge is generated can also influence learning environments (Windschitl, 2004). In order for students to grow in their science learning, it is important for teachers to appreciate the role of argumentation in science and to be able to create learning environments that support students in constructing knowledge through scientific practices (Duschl, Schweingruber, & Shouse/NRC, 2007).

Sociocultural learning theory provides an overarching lens for analyzing the ways that teachers understood their experiences as they engaged in related communities of practice; the professional scientific community of the lab, the community of science teacher peers in TSP, and the communities of their schools and classrooms. There are opportunities for generative learning at the boundaries of communities of practice, and sociocultural theory provides a useful way to consider how teachers made meaning as they traversed boundaries and engaged in consequential transitions. With its attention to the importance of contextualized social practices, sociocultural theory is particularly well suited to studying how teachers notice, reflect on, and enact social dimensions of the practice of argumentation.

Methods

Research Design

My research questions lend themselves to qualitative methods because I seek to understand how teachers interpret and assign meaning to their experiences in the professional development program (particularly their time in research labs) as well as their reflections about their classrooms in the following year. This analysis takes place within design-based research project seeking to contribute to understanding of how research experiences for teachers can be architected to promote a broader understanding of argumentation and help teachers translate their experiences into educational approaches that foster expansive sense-making discourse practices in school settings. In this section, I describe the research setting, participants, and data sources and types. I also briefly describe the design-based research context of the study.

Design-Based Research

Design-based research (DBR) offers a productive approach for innovating, testing, and refining learning interventions in real-life learning environments (Brown, 1992; Collins, Joseph, & Bielaczyc, 2004). The interventions that are tested through DBR methods represent specific "conjectures about learning within educational designs" (Sandoval, 2004, p. 222); these conjectures (and the specific task structures and lesson materials, participation structures, and tools and material support elements they embody) can provide an empirical framework to help test designs and advance theoretical understanding.

Design Conjectures. The design involved several intentional elements related to noticing, sharing, and developing shared understandings of argumentation in the lab in relation to classroom practice. The design conjecture map for this research (Sandoval, 2014) is presented in Appendix B: Conjecture Map. The following are high level conjectures for the research:

- Broadening teachers' abilities to enact productive instances of argumentation with students is facilitated by experiencing the central role of argumentation in science and strategies for transforming student discourse in classrooms

- Scientific argumentation as a practice involves the coordination of claims with evidence through reasoning, but also involves sense-making through collaborative and discursive processes of critique and deliberation

These conjectures are embodied through tools/materials, task/activities, and discursive practices that are summarized in Appendix B.

There were four main mediating processes in the design: (1) A vision of contextualized, epistemic argumentation practices developed through evidence that teachers have gathered through their participation in scientific practices and processed with their peers; (2) Experiencing discourse strategies modeled in the workshop from the perspective of a learner; (3) Opportunities to create/modify lessons to include elements of productive disciplinary discourse and uncertainty; and (4) Collaborating and reflecting with a community of peers and Lead Teachers. The outcomes that the design aimed to achieve were both epistemic and pedagogical: That teachers would have a broader understanding of "what counts" as argumentation and the epistemic role argumentation plays in science, and that teachers would emphasize knowledge-building through argumentation by creating opportunities for productive uncertainty, collaborative sense-making, and deliberative discourse in their classrooms.

Table 1: TSP Overview: Argumentation Related Activities provides a summary of the chronology of the workshop that centered on argumentation, including main curriculum elements, delivery format, materials and conceptual resources, and the main ideas and relevance of the activities (Crippen, 2012). Additional details can be found in Appendix C: Argumentation Work in the TSP Professional Development Workshop.

Table 1: TSP Overview: Argumentation Related Activities

Name	Element	Format	Materials	Main Ideas/Relevance
Initial argumentation reflection	Reflection and Discussion	Individual followed by small group	Journal, Guiding questions	Surface initial ideas

DNA Lab	Lab Activity	Lab activity followed by conclusion-writing	Slide presentation including Argumentation Toolkit (Learning Design Group, Lawrence Hall of Science & Boston College, 2015)	Introduce Claims, Evidence, and Reasoning structures, discussion about what else might be needed for argumentation
Overview Argumentation and Scientific Practices, Norms	Presentation	Slideshow	Framework (National Resource Council, 2012) Argumentation Toolkit, Accountable talk resources (Michaels, O'Connor, & Resnick, 2008)	Contrast "scientific method" and scientific practices. Lay groundwork for group norms: respect, accountability to science and classmates, and commitment to equity.
Generating ideas for Questions	Small group/Large Group Discussion	"Carousel" style: small groups circulate and comment on post-its, with debrief	Question Stems, Ambitious Science Teaching (Windschitl, Thompson, & Braaten, 2018)	Model how to generate types of question stems with students
DNA Lab Conclusions	Small Group Discussion	Paired discussion	Idea Coaching (Wingert, 2017) and STEM Teaching Tools (Wingert, 2016)	Model scaffolded pair discussion
Argument in Action	Video	Video of viewing of lab meeting with transcript followed by small and large group discussion, also noted classroom video	Lab Meeting video with transcript Argumentation Toolkit Video (Learning Design Group, Lawrence Hall of Science & Boston College, 2015)	Focus on argument and discourse elements in lab setting, preparation for viewing lab meeting in lab placements
Bacterial Transformation Lab Results	Large group discussion	Seminar-style lab discussion of data	See Griswold, Shaw, & Munn, 2017	Model seminar discussion of ambiguous lab results
Results of Experiments Designed by Groups	Large group discussion	Small groups assumed audience "roles" in questioning presenters	See Herrenkohl & Guerra, 1998	Model structure for students to ask questions of presenters
Lab Research Experience	Embedded in research lab environment (5 days)	Individuals or pairs, mentored by scientists	Journal Reflection Guiding Questions (See Brice Heath, 2012), including requirement to identify argumentation exemplar to share	Guide teachers' observations of argumentative and sense-making discourse practices in research labs
Lab Research Debrief	Reflection and Discussion	Individual followed by small group	Journal, Guiding questions	Reflect on practices in lab settings
Curricular Planning	Presentation followed by teacher work session (3 days)	Individuals or pairs, mentored by Lead Teachers	Guidelines for incorporating argumentation and sensemaking into teacher projects	Guide teachers' incorporation of ideas into activities for classroom enactment
Final argumentation reflection	Reflection and Discussion	Individual followed by small group and large group	Journal, Guiding questions	Surface and process ideas after workshop
Post-school year argumentation reflection	Reflection and Discussion	Individual followed by small group and large group	Journal, Guiding questions	Surface and process ideas after school year

The list of reflective prompts for teachers to respond to in their daily journals was a key tool that scaffolded their observations in the research labs and anchored later discussions. Some of these questions were based in part on Heath's (2012) conception of functional elements of relational, referential, or extensional language in discussion. Questions included:

- Pay attention to argumentation and sense-making talk, and when it happens.
        - What is the purpose of the argumentation or sense-making talk?
        - Notice the many different forms argumentation can take. Were participants trying to provide feedback about a procedure or research design?
        - Were they trying to understand data?
        - Were they providing a competing hypothesis/claim?
    - Did you hear people trying to persuade each other? Or come to a shared understanding?
    - Did they give each other feedback or critique?
    - Did they bring in specific kinds of evidence (such as specific expertise/knowledge, or reference to another person's or group's work)?
- Science research labs are communities that do shared work, as are science classrooms. What aspects of argumentation and sense-making are important for the work that these communities do?
- Record any thoughts you have about how the argumentation and sense-making practices in the lab are similar to/different from what happens in your classroom or in schools generally.
- How is argumentation different when the answer is known vs. unknown?

Teachers were also asked to select one exemplar of argumentation and to provide context, description, and an analysis to share with others.

Setting

The Teacher-Scientist Partnership is a unique professional development program for secondary school science teachers embedded in a scientific research institute of over 3,000 people. Since 1991, TSP has provided over 550 teachers with direct experience in research labs, curricular support, and access to molecular biology equipment and supplies. The 2017-2018 program included: 1) An intensive 13-day Summer Session in which teachers worked closely with each other, TSP staff, and scientist mentors to gain skills and expertise in molecular biology. This included 5 days of direct experience working alongside scientists in research laboratories and attending lab meetings ("lab placements"); 2) Time and assistance during the session to develop a curriculum project related to the program that was designed to be used in their classrooms; 3) Access to an extensive kit equipment loan program so students could conduct hands-on molecular biology investigations; and 4) Additional meeting times throughout the school year to prepare teachers for the experience, reflect on its impacts, and bring the larger community of teachers together. The additional meetings times included a full day orientation, a follow-up reflection day at the end of the school year, a kit-sign up day, and four topical one-day workshops. The program also included "Lead teachers"- TSP teachers who participated in the summer program in prior years and who returned to help teach some of the content and to serve as trusted intermediaries between new teachers, staff, and scientists. Lead teachers also visited participants in their lab placements and helped participants develop lesson ideas based on the research experience. The program provides support to over 16,000 students annually.

Participants

Demographic Information. There were 25 total participants: in addition to all 21 TSP cohort 2017-2018 teachers, all four lead teachers also agreed to participate in this study. The cohort was overwhelmingly white and female: only three teachers identified as non-white (all Asian) and only one identified as male (although two lead teachers were also male). While 13 teachers had some prior research experience (often at the undergraduate level), 8 teachers had no prior scientific research experience. The majority of teachers were high school educators and taught in public schools: three taught middle school and two taught in independent schools. Appendix A: Figure 2, TSP 2017-2018 Cohort Years Teaching, shows a fairly even distribution of teaching experience in the cohort, with 11 teachers having more than five years of experience and 10 teachers less than five. Appendix A: Figure 3 and Figure 4 illustrate demographic characteristics of the students of participating teachers. Appendix A: Figure 3, Estimated percentage of students of 2017 TSP teachers who qualified as an underrepresented minority in STEM, eight teachers reported that over 50% of their students are underrepresented. Similarly, Appendix A: Figure 4, Estimated percentage of students of 2017 TSP teachers who receive free or reduced lunch, shows that nine teachers report that over 50% of their students receive free or reduced lunch (often used to indicate low socio-economic status).

Data Sources and Methods

I collected data to try to understand teachers' initial conceptions of argumentation, note changes in their conceptions over time, and assess how those conceptions influenced their thinking about their classroom practices. I captured teachers' written reflections in their lab notebooks, their discussion about those reflections, as well as interview and survey data. Small hand-held audio recorders were used to record the discussions, which were later transcribed. I also wrote field notes/analytical memos (Brice Heath, 2008) throughout the research process, which became part of the data corpus. The overall strategy for collecting and analyzing data is presented in Appendix D: Research Questions and Data Collection. An overview of elements of the professional development that addressed argumentation, as well as the specific prompts that were used to generate data, are provided in Appendix C: Argumentation Work in the TSP Professional Development Workshop. I analyzed transcripts from over 17 hours of discussions and interviews using Dedoose® analysis software. I also reviewed over 1,550 pages of writing in lab notebooks.

Participant self-documentation and artifacts. Teachers had multiple opportunities to record and reflect on their experiences in the laboratory setting. The workshop incorporated a "micro-ethnographic" approach, asking teachers to observe discourse with an eye toward the culture of science and to identify examples of argumentation and sense-making in their journals. Afterwards, teachers shared these examples with one another and discussed why they selected them for discussion. In their accounts, they wove together their reporting of what they observed with ideas for how to bring argumentation and related practices back to their classroom communities. These written reflections provided information about how participants were making sense of their experiences and provided information about what aspects of the professional development were most impactful (Barab, Thomas, Dodge, Squire, & Newell, 2004). Teachers wrote answers to the same prompting questions used in focus group discussions in their journals before participating in the semi-structured conversations at the beginning and end of the workshop. Posters made by teachers during the workshop also served as data.

Discussions. Teachers participated in both small and large group discussions (Merriam & Tisdell, 2016). The small focus/discussion groups of 4-5 people met three times during the course of the program: before and after their summer laboratory experience and at a follow-up Reflection Day near the end of the following school year (May 2018). Discussions allowed teachers not only to share their experiences, but to process them with others. Lead teachers used a structured protocol to facilitate the discussions and ensure the participation of all group members: each teacher had 4-5 minutes to share their reflections, and once everyone had shared the discussion was open. I also recorded smaller discussions and conversations that were conducted as part of the TSP program (for example, between teachers who were developing lessons and their lead teachers) and large-group discussions (including a culminating debrief at the end of the summer). My field notes/analytical memos (Brice Heath, 2008) related to the discussions also served as data. Small hand-held audio recorders were used to record the discussions.

Interviews. Semi-structured interviews (Merriam & Tisdell, 2016) with selected participants helped clarify comments and member-check assertions. Originally, I had not planned to conduct individual interviews, but decided to talk further with two selected teachers based primarily on their clearly evolving understandings of argumentation during the workshop: Melissa and Anna worked on a project that directly reflected a change in their understanding of the potential for using argumentation and discourse practices in their classrooms and their ideas exemplified the thematic findings that were emerging across the cohort. Melissa, who is featured in a case study/vignette later in this chapter, was also interviewed the following spring.

Surveys. Teachers completed surveys at the end of the summer professional development and at the Reflection Day the following May. In addition to demographic information, teachers provided feedback and reflections on their experience to triangulate the focus group and interview data. The surveys included both program evaluation questions and questions focused on this research. They included Likert-scale and open-ended questions. Data from the open-ended questions were included alongside text and discussion data for analysis.

Data Analysis

To inductively code participants' written data and audio transcripts of interest, I used a modified grounded theory approach (Glaser & Strauss, 1967). In addition to looking for data related to my research questions and theoretical perspective, I also used open coding to flag units of potentially relevant data (Merriam & Tisdell, 2016). I later used axial coding to relate categories to one another to refine category schemes (Corbin & Strauss 2015). My initial analysis of the data corpus focused on looking teachers' views on argumentation, specifically argumentation in the lab, general definitions, and ideas about incorporating it into the classroom. I also looked at data related to teacher's views on communication and the role of discourse in science overall and in the labs in particular. A large group of codes reflected teachers' considerations related to aligning elements of their workshop experience with their classroom pedagogy (for example, their intent to change classroom discussion, the current state of their classroom teaching, or specific ideas for changes they wanted to make). Another large group of codes looked at teachers' own professional growth, including ideas about science, ways that they thought about their students, their experience as learners, and the barriers to change they noted.

From the preliminary analysis, I identified several themes related to how teachers were making meaning in the research setting. One theme was the teachers' observations of how common argumentation is in research settings, which was closely connected to the epistemic role of argumentation in scientific knowledge-building. Another theme related to ideas of the kinds of scientific activities that involve argumentation. Teachers saw argumentation not only in conclusions, but also in discussions about procedures and analysis of data. Interesting themes also emerged relative to teachers' observations of power dynamics in research settings and what the implications were for discourse in their classrooms (explored in Chapter 3). It became evident to teachers that the task/activity structure for students had to have certain characteristics to yield productive argumentation. Using these emergent themes as well as others, I went back and selectively re-coded the data to find additional examples, look for disconfirming evidence, and try to establish relationships between themes (Merriam & Tisdell, 2016). I also discussed emerging themes with teachers. These emergent themes eventually developed into the "argument elements" presented in the Analysis as Table 2: Themes About Argumentation Across the Cohort.

Position. I have a deep connection to TSP, having served as a participant over 20 years ago as a beginning science teacher. However, I now serve as the Director of the TSP and the designer of this study, so there is a danger of disproportionately elevating data related to positive outcomes in the research. I tried to counter this by looking for trends in surveys across the whole cohort as well as in discursive and written interactions, and by actively seeking disconfirming evidence (Erickson, 1986). I serve as program director and select people for participation in the program (although participation is also contingent on being selected by a scientific mentor), so there is a natural power differential between the participants and myself. They may have also experienced the desire to provide information that would align with my interests and hopes. While participants did receive stipends, these were not tied to assessments or evaluations of the teachers' performance. I tried to be transparent in addressing such issues from the onset and was committed to being open and responsive to concerns.

Validity. I triangulated multiple methods and data sources to confirm my findings and shared my analysis with the participating teachers to member-check my interpretations (Merriam

& Tisdell, 2016). This happened through discussions with individual teachers (particularly ones featured in the vignettes) and lead teachers, and in a whole-group discussion in the final Reflection Day. I also engaged colleagues in my university academic research group as informed experts in order to provide checks on my interpretations.

Findings and Analysis

Argumentation Practice Themes Across the Cohort

Three broad themes encompass the shifts teachers described during and after their TSP experience (Table 2: Themes About Argumentation Across the Cohort). First, teachers shifted in their thinking about the epistemic role of argumentation and its central connection to scientific activity. Second, teachers broadened their ideas about what counts as argumentation, both in terms of the form and development of arguments as well as the aspects of inquiry involved. Finally, teachers considered the social dimensions of knowledge-building through argumentation and reflected on the importance of the structure of tasks and activities in facilitating students' discourse and understanding. This represented a movement away from positivistic views and towards post-positivistic framings of knowledge work. The data reflect the nuanced and complex ways that teachers were thinking about argumentation; teachers often surfaced multiple themes within the same quote and also transitioned seamlessly between their observations and their thoughts about implications for the classroom. The ability to discuss and reflect on their experiences with other teachers played a major role in helping teachers in their own sense-making around their observations.

Table 2: Themes About Argumentation Across the Cohort

	Argument element	Initial focus	Emergent patterns
Epistemic Role of Argumentation			

	Role in scientific activity	Argument structures (such as Claims-Evidence-Reasoning) mostly separate from activity	Ubiquity of argumentation as an epistemic and embedded feature of scientific activity
What Counts as Argumentation			
	Form and development of arguments	Arguments mostly written and developed by individuals	Arguments also verbal and developed through processing with others in a community
	What aspects of scientific investigative process are involved	Arguments mostly focused on conclusions	Arguments can be made for other aspects of scientific activity (for example, procedures or analysis)
Knowledge-Building Through Argumentation			
	Dimension of argumentation stressed	Persuasive elements of argumentation	Importance of collective sense-making and knowledge-building elements
	Feedback and Critique	Feedback/Critique for corrective purposes, comes primarily from teacher	Feedback/Critique for sense-making and knowledge-building, comes from many others
	Tasks and Activities	Using known-answer experiments to highlight concept	Developing productive uncertainty through the choice of tasks/activities

The findings and analysis section consist of two major subsections. In the first subsection, I explore the major themes that emerged in the study from across the teacher cohort. In the second, I use three brief vignettes to illustrate a range of trajectories of teachers' experiences.

The central, epistemic role of argumentation across scientific activity.

Scientific argumentation - it's so important! It's how science happens! (Elizabeth, lab notebook)

After the workshop, teachers had a heightened awareness of the central importance of argumentation and collaborative discourse in generating knowledge in science. Teachers noted that they had been thinking of argumentation as an "external concept" - as a discrete activity, separate from other parts of science, but that their experience helped them understand its integral role. Raven discussed how her conception of scientific argumentation had evolved. Surprisingly, she hadn’t previously thought of scientists’ activities as scientific argumentation. She had heard about the term “scientific argumentation” from the National Science Teachers Association (NSTA) and other science education groups, but she had not connected the term to what scientists themselves do. Raven’s comment illustrates how scientific practices can be abstracted and absorbed conceptually by practices of school.

> **I think that I had not really thought of what scientists do as "scientific argumentation" (though I’ve heard about that from the NSTA and other scientific education groups)** (emphasis added). I had always thought it was about using evidence to make a point, and that it was all part of the process of science. I had not realized how important this type of communication was (and how scientists seem to talk like this often, without always realizing they were doing it consciously). I don't think I would have noticed it without the preparation I got with having to notice it. I saw it often in the lab as well as the lab meeting where the two mentors (and others in the lab) we were working with asked questions of the data, or talked about what it might mean, especially when there were anomalies in the data. (Raven, end of year survey)

After her experience, she placed a special emphasis on how common and how important argumentative discourses are among scientists, and how argumentation can help in understanding and making meaning from findings.

Other participants also noticed how pervasive argumentative discourse was in professional scientific settings. Cara observed that it was “really at the heart of scientific exploration and progress.” Anna was struck by how much talking the researchers did as part of their everyday work, and how the actual experimental research was actually part of a mechanism to drive more questions and talk. In a discussion with other teachers, she noted that the time researchers spent communicating with one another and interrogating each other was critical to the scientific process in the lab. Elaborating, she described how pervasive this style of talk was: “...one of the things that I found in the lab was that these individuals would communicate with each other constantly, and about things that seemed pretty flippant, like maybe I wouldn't have picked it out as an argumentation piece. It's constant and it doesn't stop and it's pretty endless.”

Teachers such as Anna expressed surprise at the frequency and patterns of argumentative talk they observed. They expressed that such talk is fundamental to how scientists interact, a key dimension of the research cultures they observed, and a foundational practice of science. Rather than seeing argumentation in the abstract, as a disconnected idea relevant only for science education purposes, they saw how ubiquitous it was in scientific activity. Such insights help teachers view argument as central practice of scientific communities (Wenger, 2000) as well as an essential guiding element of inquiry (Manz, 2015).

"What counts" as argumentation.

Social dimensions of argumentation. Another way that teachers expanded their conceptions about argumentation was in considering "what counts" as argumentation. Teachers noted that arguments develop through discussion, that multiple individuals contribute to the development and evaluation of scientific claims, and that social sense-making has an important role in science. Rhea wrote: "I have refined my definition of argumentation. I would say now that it seeks to share what is known through the input of many scientists. When a presenter doesn't know the answer, they seek insight from peers. Using a lab meeting format leads to more authentic argumentation discussions and a better idea of what is meant by 'peer reviewed'.

Argumentation across scientific activity. Teachers also noted that arguments can be used for many different aspects of scientific activities. Many teachers, including members of the study cohort, incorporate argumentation in their classroom by asking students to write conclusions to laboratory exercises using Claim-Evidence-Reasoning frameworks. TSP Teachers observed that argumentation in lab settings can be used for more purposes than conclusion writing. Teachers specifically noticed when argumentative talk centered on determining the most appropriate procedure (or troubleshooting a procedure that wasn't working as expected) or trying to make sense of results. For example, Michelle jokingly referenced a postdoctoral student whose primarily role appeared to be talking to others about data analysis and protocols rather than doing lab work itself. She said that her experience “was really interesting because a lot of the only times people talked to each other in the lab...was looking at results; “I got this weird thing, what do you think it means?” Significantly, she noted that this kind of interchange was representative of “how every conversation in the lab went.” Louise noted how scientists used argumentation to choose techniques, make sense of findings, and select between different kinds of analytical methods by considering trade-offs: “There was so much argumentation, and a lot of it had to do with things like, ‘I tried this different gating technique and I'm not sure which technique is better. Look at my results, what do you think? Which one should I use?’” Similarly, Victoria noticed the prevalence of argumentation in developing procedures and designs in the earlier stages of problem solving. After her lab experience, she reflected on and expanded her ideas of what argumentation looks like in science beyond the C-E-R framework ordinarily used to justify a conclusion, or “claim at the end.” Victoria noted that much of the argumentation talk she observed was at the beginning of a problem, and this was different from argumentation “at the end.”

> I wrote in my original [reflection] that scientific argumentation is often like your C-E-R. This is my claim at the end, this is my evidence that I've gotten, and this is why. A lot of what the talk I heard in my lab was they're at the beginning of the problem. They don't have a claim yet. They have ideas but it's more discussion on problem solving or like, “Oh my control produced a product, it shouldn't have. Why might that be happening? Everything worked but this tube and I can get everything to go but this one. What's going on?” (Victoria, end of summer whole group discussion)

In discussing their observations and insights, teachers such as Victoria demonstrated expanded conceptions about argumentation; they noticed that scientists used argumentation in research settings in discussion and problem-solving with others, and throughout different phases of scientific activity. Using tools such as reflective journaling in response to specific prompts, teachers were able to reflect on how their transitions to the lab expanded their ideas of scientific activity and the role of argumentation within it. These tasks and objects helped facilitate productive boundary encounters for teachers and allowed them to coordinate their experiences and understanding with one another in subsequent peer discussions (Wenger, 1998).

Knowledge-building and sense-making through argumentation.

Argumentation is used for more purposes than persuasion.

> I used to think of argumentation as choosing a position and providing data as to why you are correct. [I want] my students to understand that the position or idea is not the end point but it is the start of a discussion in which both sides need to participate. (Mollie, end of year survey)

Another way that teachers broadened their conceptions of argumentation was in the way that they thought about the purpose of argumentation. Persuasion is a core use of argumentation, but it can support other key scientific knowledge-building actions (such as decision-making, interpreting, or clarifying). Rather than focus solely on persuasion, teachers expanded their conception of argumentation to include ideas about social sense-making and knowledge-building and considered how this would impact their classrooms. For example, Mollie connected the ideas of the central role of argumentative talk in scientific activity with the idea that claims can be developed by multiple people. In her lab notebook, she talked about her shifts away from ideas of argumentation as persuasion towards a recognition of the social elements that can help in many scientific activities: “When I first reflected on scientific argumentation, I focused a lot on persuasion for a variety of purposes. I now see that argumentation is also the daily discourse a scientist may do to answer a question or further a theory. This still cannot be just a claim. Evidence and reasoning must follow up the claim, but it can be a "living" thought that multiples can contribute to…”

Mollie's experiences in the research setting had shown her not only the everyday, integral aspects of the practice to scientific research, but also that scientists use argumentation to figure things out ("answer a question") or build knowledge ("further a theory"). Notably, she referenced how claims still need to be followed up with evidence and reasoning in this kind of argumentation, but that it is a dynamic "living" thought that others can help to build and collectively contribute to. Thus, arguments are not only developed by individuals, but also through the interaction of many scientists. Bridging to the classroom, she noted that:

> I think so much of what kind of has been drilled into me in my school is that we want to have students have all kinds of thoughts and write their own words and not necessarily plagiarize each other…but when you're in a lab and you're watching a claim be filled in with evidence and reasoning by 6 other people in a room, I'd forgotten that it doesn't have to be a singular person and that there's a lot of value to having that student-to-student discourse and that I shouldn't be diminishing that. I should be encouraging that. (Mollie, end of summer whole group discussion)

In discussing her thoughts with others, Mollie contrasted school and the lab in terms of the emphasis school places on individual work (the push for students to "write their own words") with group sense-making and collaborative development of justifications in lab settings. She noted that having students to work together to build claims would be a worthwhile practice to transfer to the classroom community. Mollie simultaneously reconceptualized her ideas of how scientific work progresses and what that means for her classroom and "student-to-student discourse".

Teachers understood that incorporating more student opportunities for collaborative sense-making represented a significant cultural shift within their classroom. For example, Michelle considered how she could bring the kinds of talk she heard in the lab to her classroom: "My biggest thoughts were: How does that [discursive] culture develop, is it like that in every lab or just the lab I was in... How can I get my students to talk to each other like this?" Similarly, Anna suggested that the scientists from across "all walks of life" used discourse in common ways – allowing them to share in a community of practice. In making a connection to the classroom, she highlighted how, after the workshop, structured talk influenced students' ways of thinking, which in turn influenced her classroom culture. She even extended the impact beyond the classroom, noting that she hoped students would develop analytical ways of thinking and take their experiences and develop a "lens of communication" to see and understand the world outside of the classroom.

Teachers expanded their conception of the function of argumentation beyond persuasion to the collective sense-making and knowledge-building dimensions of the practice (Berland & Hammer, 2012; Manz, 2015). Furthermore, teachers wondered how they might get their students to talk to each other in ways that they had observed scientists doing. In doing so, they considered how they could "broker" the social argumentative practices they had observed in labs back to the classroom to help establish a discursive culture reflective of scientific communities (Wenger, 1998).

Critique: Feedback and questioning comes from many others.

> As far as argumentation I found that I've come to a better appreciation of how it works in science. What seems like a hostile exchange (or what may be perceived so in another context, or people with other perspectives) is just a way to improve work and come forward on science. (Raven, end of year survey)

Another theme among teacher responses to the impact of observing the lab meeting and the activities in the research lab was the idea of supporting students in questioning and critiquing one another. Teachers aimed to have students not be threatened by critique or alternate interpretations. For example, Tamara reflected that students needed opportunities to interact with one another's ideas:

> When watching scientists' discourse, I noticed that they constructively question and rebut others' ideas in order to come to better conclusions and ideas. Rather than having students express their thoughts and supporting them with evidence, they need to work deeper and

> address other students' ideas and thoughts and either support them with evidence or use evidence to question what they're thinking. (Tamara, end of year Reflection Day survey)

Teachers also shared their experiences with critique in the classroom at the end of the school year. They also noted how important it was for feedback and critique to come from other students, not just the teacher. On his end of year survey, David reflected on how he worked with his students to have them be resources for each other in interpreting, defending, and questioning experimental results and to become more open to critique and other views: "Students are realizing that they can listen to other students' ideas and not be threatened by alternative interpretations." He also thought about stepping back and not being the sole person to offer feedback to students: "This experience on argumentation was very helpful in getting me to see how important argumentation is for my students. Prior to TSP, I was the main input students had in developing their thinking in science. Now it is all my students…" In another example, Michelle noted that one of the big ideas she shared with students is that others can serve as resources to help in one's own thinking. Significantly, she talked to her students constantly about the importance of critique and how important that was for knowledge-building: "We talked explicitly about how challenging each other's ideas is how we have come to a place that we are in science. If you are not challenging each other and learning from each other, then you are not going to get anywhere."

Some teachers raised issues related to power in group discourse. They considered the role the PI had in setting the tone and fostering a culture that was conducive to constructive critique. Teachers concluded that much of the success of a discussion depends on who has the power and who is setting the tone for discourse within a group. They also discussed the challenge of appropriately balancing safety and comfort with the ability to include critique. Clearly, discursive interactions such as critique happen in contexts of power. Issues of teachers' awareness of power in discourse are discussed in more detail in Chapter 4.

Teachers noted the important role of critique and having one's ideas challenged by peers, and how such discursive practices take shape within the specific culture of a community of practice. Because of their insights into the role of critique in scientific settings, teachers had a heightened awareness of how important it was for students to constructively challenge one another's ideas and be open to working together towards greater scientific understanding. Many researchers have highlighted the kinds of shifts that foster the development of knowledge-building communities among students (Brown & Campion, 1994; Scardamalia & Bereiter, 2006), elevate the role of student critique (Ford, 2008), and create cultural norms for sense-making (Engle & Conant, 2002). Yet despite this history of thought in the educational research community, teachers in the TSP program were encountering and enacting these ideas for the first time – highlighting the need to develop strategies in professional development that support teachers in creating and sustaining such classroom communities.

Making argumentation work: Generating productive uncertainty through activity.

[Students] need open investigation for argumentation to work. (Rhea, lab notebook)

Significantly, teachers recognized that certain kinds of activity structures provide the kinds of ambiguity necessary to foster productive opportunities for argumentation. In the quote above, Rhea makes an important point – open investigations with a level of productive uncertainty (Manz, 2018) are needed for "argumentation to work" and lead to meaningful discussions. If students are pursuing a known-answer question using a predetermined strategy, opportunities for collaborative discussion and sense-making are thwarted. A classroom investigation with some ambiguity in terms of how students could craft a procedure or in terms of expected results yields a more fruitful and productive opportunity for discussion and argumentation. In the quote that opened this paper, Elizabeth shared a similar thought with other teachers when she debriefed her experience: “I also feel like it's important to do those open investigations to make that argumentation work. Otherwise, everyone is doing exactly the same thing and there's no discussion.”

Investigations in science classrooms are often directed towards getting the “right answer” or illustrating a point, which frames science as a “rhetoric of conclusions” (Schwab, 1958). By focusing on the centrality of argumentative discourse in science during the workshop, teachers came to realize that some of the activities they used were not necessarily conducive to promoting collaborative sense-making. Randi and Louise reflected on the scripted and pre-determined nature of the experiments that they conducted with students in the past, such as labs that emphasized particular results or right answers. They considered the need to allow students more responsibility in the labs they conduct, and to place more emphasis on opportunities to figure things out. Randi noted that “I...guide them all to do it the same way so that we all kind of get the same results and almost as though the results are the most important. What I really need to do is step back and make my labs a lot more inquiry based and let it be messier because they need more responsibility.” Louise had a similar sentiment about the existing curriculum at her school: “I feel like the hardest thing right now is that our curriculum at our school is what we've always been doing, so a lot of the labs we do are a means to an end. There's a right answer at the end....”

Victoria shared her desire to break away from “classical” (known-answer) experiments and provide more opportunities for student agency in choosing a question or designing an experiment. She also related that rather than helping the group arrive at the right answer so that they could write up their conclusions, she wanted to try incorporating more opportunities for seminar-style discussion (similar to what was modeled in the workshop with teachers' own results).

> I want to structure it like [the example seminar]...Maybe forcing them to use scaffolds in the beginning and letting them flounder and letting it be silent and letting kids take risks and really emphasizing that science only exists to figure out things that we don't know. There are all these people with PhDs and all this education and they're literally working on stuff every day where they're just like, I have no idea what's happening. Every single day. Just like re-emphasizing that over and over and over and just hammering that in. (Victoria, summer small group discussion)

Michelle responded to Victoria, picked up on her idea, and extended it. Michelle reflected that students are engaging in an authentic practice, just at a different level: "You're just at the beginning part of that journey. That person (scientist) did that and now they're just doing it at this level." Collaborative sense-making discourse opportunities allow students to learn about a community of practice, as they are participating in similar approaches as scientists, but at a level that reflects the "beginning part" of a journey to becoming a scientist or gaining a greater awareness.

One of the ways that teachers expanded their thinking about argumentation was in recognizing the kinds of contexts that provide engaging opportunities for argumentation. While Victoria recognized that ambiguity in results to known-answer experiments offered some opportunities for argumentative discourse, Louise was able to imagine specific ways of intentionally bringing argumentative talk into classrooms. Writing in her notebook, she called out two productive areas that she had observed in the research lab: making sense of data and the development of experimental procedures: "I think…these examples could be modeled in a high school science classroom. If someone wants to use a new technique (say for measuring movement of pill bugs) they should discuss why they think their method is better or if we should keep the original method, or if you should do both and then compare results...students could (also) go through argumentation to decide how to calculate data/results, what data to exclude and why, etc."

This final theme illustrates how teachers acknowledged the limitations of confirmatory lab activities (National Research Council, 2006) and developed a heightened recognition of how important certain types of task and laboratory activity structures are for making argumentation work in the classroom. In doing so, they considered how argumentation can be useful and relevant in different phases of an investigation, as well as how scientists (and students) can use argumentation to work through uncertainties and make choices to maintain epistemic alignment throughout an investigation (Rouse, 1996). Specifically, teachers expanded their ideas of what characteristics of a lab would help problematize instructional content (Engle & Conant 2002), foster elements of productive uncertainty (Manz, 2018), and yield opportunities for rich and engaging argumentation.

Teacher Trajectories from Workshop to Classroom. Overall, teachers were optimistic about their expanded understandings and carried that through the school year. In the survey provided at the end of the summer (n=21), 81% agreed that their observations of argumentation in their research labs would impact their classroom (the rest were unsure). The vast majority of teachers (86%) also agreed that other facets of the professional development experience (for example, modeling a seminar discussion of data from an experiment) would also impact their classrooms, with 9.5% unsure and one teacher noting that she already used a lot of similar strategies.

Across the cohort, teachers believed that the TSP experience impacted their thinking about communication and argumentation in science. Even though the over half of the teachers in the cohort had some level of prior research experience (62%, n=21), creating a specific focus on argumentative discourse practices appears to have made a broad impact. Teachers reconvened in May of the following year to reflect on their school year experiences and the impacts of their summer workshop. *All 19 teachers responding to the year-end survey agreed that their thinking about communication in science and argumentation as a scientific practice changed since they started TSP*, with the majority (68%) answering “Yes, definitely” and the remainder “Somewhat”. Those teachers who indicated that their thinking was somewhat changed (32%) also noted that they had either been practicing scientists prior to teaching or had extensive specialized teacher professional development from other sources. (n=19, 2 participants did not complete the survey due to maternity leave).

Teachers also noted the influence of observing scientists’ talk on how they structured talk opportunities for their students, affirming the value of providing focused, embedded experiences in professional scientific settings for teachers. In response to the question, “Did observing how scientists talk to one another in lab meetings and during the course of their work influence how you structured opportunities for talk in your science classroom?”, the vast majority (79%) answered affirmatively (42% yes, and 37% somewhat, n=19). Of those that answered, ‘not really’, one teacher noted that she did not see a lab meeting, and another indicated she responded so because of her extensive prior lab experience.

Many teachers referenced their attempts to build in more opportunities for student to student discussion in their classrooms for the purposes of sense-making. They noted how students grew in their ability to develop their own ideas and communicate them. Some teachers made explicit connections to the ways they had shifted talk in their classrooms to help students build their understanding collectively. Teachers also noted that pulling away from leading discussions and providing more opportunities for students to talk with one another increased the ability of students to search for evidence and to see each other as resources.

Vignettes. The following short vignettes illustrate three different trajectories teachers took in thinking about argumentation as a practice and describes their implementation of new efforts in the classroom. They help illustrate some of the factors that influenced how teachers thought about argumentation and what their ideas meant for their work with students. In the first vignette, Melissa provides an example of a teacher who, although initially skeptical, heartily took up ideas about argumentation and its social dimensions after witnessing a lab meeting. She was motivated to create a curriculum project that was practice-focused and to implement that with students during the following year. In the second vignette, Jan illustrates how teachers can recognize the value of new approaches and practices, have strongly stated intent to incorporate them into their classrooms, yet still struggle when it comes to making actual change. Nevertheless, Jan was able to finally take a risk to try a "lab meeting" with her students when the opportunity presented itself. Finally, Louise's vignette represents the concerns of teachers who worry about how to reconcile opportunities for argumentation with the known-answer experiments that populate much of the biology curriculum. It also illuminates the worries that teachers may have about students not having enough content knowledge to argue effectively and meaningfully.

Melissa: "I need to let students go and do their own thing." Melissa made pronounced shifts in her thinking during and after the workshop. Her story provides an account of how a teacher can come to better understand the important role of epistemic practices in science and in the NGSS vision. She not only came to a greater appreciation of the social role of argumentation in science, but also figured out a way to enact related practices in her classroom. Her success with students was due in part to her planning for a practice-focused multi-day series of lessons during the workshop.

Melissa's teaching background and initial views. Melissa teaches 10th grade biology in a large suburban public school. She has extensive teaching experience (17 years) and has conducted no research in the past, although she has participated in several intensive professional development workshops (including one led by the author that focused on teaching ethical issues in science). In her initial definition of argumentation, Melissa focused on persuasion. She wrote, "Scientific argumentation would be using facts and evidence about the natural world to convincingly persuade another person(s)..." She provided a fairly standard post-positivist view of the benefits of peer review, and demonstrated an understanding of the importance of professional collaboration and peer feedback: "Presenting evidence to peers and receiving feedback helps strengthen one's understanding, uncover mistakes/misconceptions" The classroom examples that she provided focused on socio-scientific argumentation and included having students argue for or against the reintroduction of wolves to Yellowstone National Park or persuading peers to "fund" a public health policy proposal to fight emerging diseases.

Melissa's workshop reflections: The "watershed" moment at the seminar. As with other teachers, Melissa demonstrated a disconnect between her description of the importance of argumentation in science and its inclusion in science education. In her lab notebook, she seemed perplexed as to why the workshop was asking questions and sharing information about argumentation. After the first day, she wrote:

> Scientific argumentation tasks and discussion baffled me a bit. Where is this coming from? What is it replacing or fulfilling or what void in science ed is it filling? How does it fit in our current and future instruction re: student learning? What evidence is there that is better than what we are currently teaching? Is it driven by NGSS?

On the second day, teachers participated in an activity that modeled how questions for discussions might be generated by students. This helped Melissa understand how scaffolding could support student discussions:

> Today the argumentation aspect became more clear to me. It was very helpful to see the handouts (on scaffolding student discourse) and do the group work on the posters to come up with examples of types of questions or sentence starters that students could ask to help move peer's explanations forward. Ideas for encouraging students to participate in discussion were also helpful. Here are the questions we analyzed: Asking for a probing question; Asking for clarification; Adding onto an idea; Respectfully disagreeing with an idea; Asking for evidence/reasoning.

Later that first week, teachers participated in a seminar discussion to try to interpret the results from one of the molecular biology classroom labs (bacterial transformation) that they completed. This experience was designed to model how such a “lab meeting” discussion could be facilitated and for teachers to experience it as students would. Later, she referenced the seminar as a watershed moment – which helped her think about letting students “go and do their own thing” in discussion, implying a step back from her own role in leading discussions: “This is fertile ground for me because I haven't ever done the scientific seminar, and that experience was kind of watershed for me because it's like, ok, it's time Melissa. I need to let students go and do their own thing”.

Melissa’s lab experience reflections: sense-making with input from others. However, it was her experience in the lab in the second week that really helped her make rich connections between her professional scientific practice and the classroom. After she had observed a lab meeting, she wrote in her lab notebook:

> I am thinking now, after seeing the lab meeting in action, vs. our first day discussion at TSP, that the term "argumentation" in science is not at all related to the generic or legal meaning of the word "argument" where "to win" the argument is the goal. I am thinking of it now as a method to surface potentially relevant info…to advance the research....I need to improve in this to do a more effective job planting ideas for students to think about. This communication step is where the deepest collaborative learning and potential for pushing knowledge forward might occur. Even if a finding (or discovery) is made by

> an individual, it's importance is better understood when shared with others for their response, input, insights. "Sense-making" is more accurate when constructed with input from others. I need to build ways in the classroom for students to have more peer communication. WORK ON THIS!

In her reflection, Melissa broadened her conceptions of goals for argumentation beyond “winning” to sense-making and surfacing ideas which advance research. She framed the role a teacher plays in a classroom as similar to one of Principal Investigator in the lab in terms not only of challenging others, but of soliciting ideas and questions from others in the community and facilitating the argumentation and discussion to a productive end. She also expressed a desire to grow in her ability to provide ideas “for students to think about.” Significantly, she noted that communication amongst members within the classroom learning community provides the opportunity for deep collaborative learning and understanding.

Melissa’s curriculum project: “The NGSS has actually helped me think about it.” In the final week, teachers worked on curriculum projects that were applicable to their own contexts. In the following exchange, Melissa discussed how to take selected elements of the experience of the lab back to the classroom with Anna, another TSP teacher. Anna had partnered with Melissa to create a collaborative project. They were joined by Rachel, Melissa’s Lead Teacher, whose role was to help guide the development of their project. Melissa had just mentioned that she was glad she could focus on argumentation in her project.

> Anna: I've been asking a lot about what was the purpose of our time in lab aside from it just being a really wonderful opportunity to get to learn, to get to establish connections, to communicate, to see a little bit more about this, but it seems as though this is the gap, right? This is the gap we're trying to bridge as science teachers, to give kids a way to talk about it. There is a way we communicate and a way they ask questions and make meaning and the way from our perspective as we act as a PI. How are those preventing or encouraging communication and interactions? How are we getting at points that we want? How are we asking the students to make meaning from this? All of these things are so, so prevalent in science beyond our classroom. How do we put that in our curriculum now to make it effective?

> Rachel: I would say the same thing…so if you can hold that thought, that could be what your project is and I think I really like what you just said; that's the bridge we've been looking for…
>
> Melissa: I'm glad I waited 17 years to have this…

Anna echoed Melissa's sentiment and added that she saw the lab experience as an opportunity to view the "gap" that they are "trying to bridge as science teachers, to give kids a way to "talk about" science and make meaning through communication and interactions. Melissa sarcastically and playfully mentioned that her insights have come 17 years into her teaching career.

The curriculum project that they chose to create was a reconceptualization of a traditional DNA extraction lab, where students would decide on their own protocol, provide evidence for their reasoning about the best procedure, and then discuss the results with the class to collaboratively determine a redesign of the optimal method for all to try in a second attempt. In thinking about their plan, Melissa referenced a comment made by a visiting scientist about the difference between reading about the history of art versus drawing something, making a parallel to confirmatory science versus an opportunity to provide students agency in experimental design. Melissa also called out how much of a growth area this was for her, and how shifts were necessary not only to support teachers, but also to provide new curricular opportunities. The conversation picks up again when Melissa and Anna are starting to plan their project with Rachel.

> Melissa: Like [the visiting Nobel prize-winning scientist] said yesterday, you can just copy what's already known. It's like…reading about the history of art versus drawing something…That was a really helpful analogy for me…We don't have nearly enough of these kinds of experiences, in my view. I, as a teacher, am deficit in this area but also our curriculum doesn't really lend itself to this kind of thing. It's very exciting.

Importantly, Melissa saw this opportunity as a way to see the value of the NGSS, and was able to see that her project exemplified ideas of "3-dimensional learning" as it "hit all 3"; disciplinary core ideas, practices, and cross-cutting concepts:

> Melissa: There's the content, like the biology idea, but then I saw the practices is carrying out an investigation, constructing your explanation, engaging your argument. Then there was the crosscutting concept which for this one was structure and function. It hit all three...But I had not thought about it at all, and dare I say that looking at the NGSS has actually helped me think about it...as I pulled out the (NGSS summary) and started wading through all that language, I began to see it in a different way and realized how I mostly operate in this domain; the content domain.
>
> Rachel: I think we know that that's where teachers are operating.
>
> Melissa: But, secondarily, this is also going on; it's just not overt in how I think about my day or my lesson or my unit. Our project is not here. Our project is in the practices.

Melissa recognized that she operated mostly in the content domain, and the Rachel affirmed that is commonly where teachers operate. Melissa indicated that she ordinarily didn't think about practices, but that in her particular project she had elevated the role of practices and centered her project on them.

Melissa after the workshop. At the end of the workshop, Melissa reflected back on her initial definition of argumentation in her notebook. She wrote that her thinking about argumentation had broadened beyond persuading others of a position on a controversial issue. Melissa also called out the importance of using an activity structure with either inherent uncertainty or variable results in order to foster discussion (Engle & Conant, 2002; Manz, 2018).

> Argument doesn't have to center on a controversy - a lab experience can work too! It generates evidence that is worth of discussion but only (best?) if the outcome is not known - or has variable results (as in our transformation lab - a very robust discussion ensued from the different results each lab group got).

During the school year, Melissa piloted her curriculum with her classes. When teachers came back to reconvene at the end of the school year for Reflection Day, Melissa talked about her experiences and considered how she had shifted her classroom practices. In response to the question, "Has your thinking about communication in science and argumentation as a scientific practice changed since you started TSP?", she noted:

> Due to my increased awareness of promoting student communication as a scientific practice I have been more conscientious about building opportunities for student discussion into lessons. My TSP project is the best example….[My] students prepared for and conducted their own mock "lab meeting." I provided guidelines but students ran their own meeting. The students sat in a circle and shared their lab results, asking questions of each other that focused on evidence…[M]any students were very engaged…I think that my heightened awareness of argumentation helped keep me mindful of incorporating more opportunities for students to discuss their ideas and to push them to cite their evidence when making claims. And in pointing out when they are making assumptions or drawing conclusions that don't align with their evidence.

Students “ran their own meeting” after being provided with guidelines, and Melissa noted student engagement in the process. Melissa also reflected that her own increased awareness of argumentation helped her create more chances for students to put forth and discuss evidence-based claims and also for her to help students evaluate those claims. In response to the question, “Did observing how scientists talk to one another in lab meetings and during the course of their work influence how you structured opportunities for talk in your science classroom?”, Melissa noted that the lab meeting was pivotal, particularly in helping her consider the conditions in the classroom that help foster critique.

> Attending my scientist's lab meeting was a critical turning point for me in appreciating how scientists talk. I more purposely this year I tried to create a classroom atmosphere where it is OK, even welcomed, to challenge another person's idea or to ask for evidence. Again I think this worked best in my TSP project.

Melissa’s curriculum project was also taken up by other teachers. The workshop staff incorporated the project into the repertoire of activities for the members of the following summer’s cohort, and several other teachers tried this lesson with their students in the subsequent year. Melissa and Anna also collaborated with the TSP staff team to co-author a description of the lesson for a popular practitioner journal, illustrating how empowering and supporting professional educators has the potential for widespread impact (Chowning et al., 2019).

Melissa’s experiences highlight a number of the emergent ideas expressed by other teachers through the program and discussed earlier; while she initially focused on persuasion in argumentation, she broadened her ideas to *include social sense-making after noticing the importance of such practices in the research setting*. She was able to use her experiences in a lab and resources from the workshop to create an open-ended educational experience that helped foster productive discussion and that included student critique. Students created a shared rationale for their group's experimental approach, but afterwards focused on making sense of the results and creating an optimal procedure collaboratively across the class community. Part of her success in enacting changes in her classroom, aside from her strong motivation, was the fact that she had carefully planned a series of lessons designed to foster argumentative discourse as her summer curriculum project. That project arose in part because of the lens through which she was able to look at her research experience (enabled by the scaffolds and prompts to observe argumentative discourse) and through the processing and collaboration she was able to do with her peers (Anna) and lead teacher (Edwards, 2011; Goodwin, 1994). Leveraging these supports, Melissa was able to successfully broker argumentative practices she had observed in the scientific community to her classroom (Wenger, 2000) and change the relations between herself, her students, and the discourse practices enacted in her classroom in consequential ways (Beach, 1999).

Kelly, Crawford, and Green (2001) describe several elements of epistemic practice that can be enacted in classrooms: the varied cultural elements that interact with individuals to provide a vision of scientific activity – "what members of a particular community acknowledge as experiments, texts, objects, valid interpretations, theoretical frameworks" (p. 137); the ways teachers and students interact and talk when engaged in science; and the need for student's agency in classroom interaction and in sorting out information and multiple perspectives. In these interactions "facts are constructed; membership is inscribed; social relationships are established and challenged; a way of talking is established; and discourse practices are developed and displayed…Thus, as people engage with science, they are engaged in a [sic] complex and multifaceted social processes embedded in cultural practices of relevant groups” (p. 138). Michelle designed her classroom experiences for students to reflect some of these elements of scientific practice. For example, she created cultural opportunities for learning that used tools such as written and discursive scaffolds to reinforce the role of evidence-based claims in argumentation. For example, students initially discussed ideas for protocols in small groups and created charts to record their planned use of particular reagents (in terms of the order of their use and the amounts), and provided their justifications for their choices. She also elevated collaborative student discourse in sense-making as students designed methods and discussed results. Finally, she provided students with agency in creating their own procedural designs and deciding which elements of class procedures to incorporate in the collective redesign.

Jan: the “epic fail.” Jan also expanded her views on argumentation. However, in contrast to Melissa, Jan’s trajectory illustrates how teachers can be challenged in implementing their ideas in the classroom despite their stated intent to do so. Although full of enthusiasm to change student discourse in her classroom and try “lab meetings” after the summer workshop, Jan did not actually try a such a sense-making discussion until faced with an unexpected “failure” in a culminating lab activity with her biotechnology class.

Jan’s teaching background, initial views, and lab experience. Jan teaches at an urban parochial school and has 33 years of teaching experience. In addition, she has spent multiple summers conducting scientific research. To illustrate her initial view of argumentation, she wrote the following in her lab notebook: “Scientific argumentation is the process that scientists use to rigorously test ideas and assumptions. It is often impossible to design a ‘conclusive’ experiment.

Argumentation provides input from other scientists that can help identify experimental design flaws and/or point to new/alternate research pathways." She noted that she hadn't used argumentation in her classroom often but did have students present posters of their lab work for feedback. She had an unusual mentoring experience in TSP, working with a collaborating scientist who helps run an outreach program rather than working in a lab. However, she often referenced her past research experience. For example, she noted that she had experienced lab meetings at the university where she did her research and knew that they could "range from formal/very stressful to more casual."

Jan's curriculum project. Jan's TSP curriculum project focused on developing the scope and sequence for a new biotechnology course using the scientific materials and resources from TSP. She also considered how to incorporate some of her learnings about student sense-making and collaborative argumentation into the course and stated her intention to incorporate lab discussion of results. Debriefing with the whole group, she shared her plans for incorporating lab discussions and elevating student voice in leading discussions:

> [S]ome questions that I would have them focus on: What went well about this lab? What didn't go well and why do you think it didn't go well? Were there unexpected results and why were they unexpected? What did you expect and why do you think you got the results you got? Trying to allow them to be the leaders of the lab discussion.

However, as is sometimes the case with teachers' intentions following a summer workshop, Jan found it difficult to actually carry out her plans during the school year. At the Reflection Day meeting, she shared how she intended to hold lab meetings but that she had actually not done so for most of the school year, partly from being overwhelmed with teaching a completely new course that required a lot of preparation and in part because she was not being comfortable conducting such a discussion. A chance "epic fail" in the capstone lab for the course provided the opening for her and her students to try to figure out what happened. That lab meeting went "super-duper well" and her foray into trying such a discussion cemented her intent to try again the following year. As she shared with a small group at Reflection Day:

> So, [the DNA lab] was the epic fail. We got no (DNA) bands…Then I thought…we're going to make this into a learning experience. We rearranged the seats and I said, "Okay, we're going to have a lab meeting…Let's talk about it." We went around and each group talked about what they did for the lab and we designed a way to test [various elements of the protocol].

Jan went on to describe how she called a scientist at the company that made the DNA extraction kits they used, and how this person talked to each class, sharing her professional expertise with the class. With additional information, the students developed a new protocol, which was successful in producing results. She shared her enthusiasm with her peers:

> Jan: I was really, really pleased with the way that whole thing went. It made me realize that I ...can make the time to do it and just maybe not quite do as many labs but it is just so worth it…I never would have done it if we hadn't had this because I just was chicken…The biotech class is new to me and I'm doing all these new kits and I'm just overwhelmed and I can't do that too. I made all kinds of excuses not to do it. Then it just happened at the end of the year...I'm glad we failed…It sort of was perfect for me because old dog, new tricks. It's really hard for me sometimes to do stuff that is out of my comfort zone, and that really was.
>
> Louise: Even new dogs, new tricks. I'm always afraid to get in there sometimes because I just haven't done it enough.
>
> Jan: It's hard to try something new and know that it could blow up in your face. You could end up with dead silence for like 15 minutes or chaos.

Jan and Louise both shared one major barrier to teachers enacting strategies that reflect expanded views of argumentation: fear. Jan acknowledged that opening up her class to lab meeting discussions was "outside of her comfort zone." Whether a veteran teacher (as Jan was) or relatively new to the profession (as Louise was), both talked about the risk of trying something new that could potentially wind up with either student silence or classroom unmanageability.

Part of what Jan highlighted was the opportunity for students to "take ownership" of the discussion, and that they, rather than the teacher, were engaged in collaborative argumentation to figure out what happened. To Jan this was a "powerful" outcome. In the second school year after the workshop, Jan mentioned to us that it had become a fixture of her practice - she had already conducted three lab meetings in the fall semester. She noted their impact on students' abilities to communicate and their confidence in a follow-up survey: "I am having my students conduct regular lab meetings to share their results...they have been so fruitful! What's more, my students seem to be more confident and able to express themselves and their thinking as a result."

Jan's experience illustrates that even a teacher with extensive research experience can have a difficult time incorporating scientific practices into their classroom. Jan had more experience in research labs than many of her peers and had a solid understanding of the fundamental role argumentation plays across scientific activities. She also implemented many biotechnology lessons that yielded ambiguous results and that provided ample opportunities for argumentation. She clearly understood the value of social dimensions of argumentation and the importance of collaborative sense-making as she emphasized her intentions to implement such discussions after the workshop. Furthermore, contextual factors were working in her favor: Jan is in a parochial school where she is not beholden to pressure from national standards, and she was teaching a course where she had a great deal of freedom to innovate within her curriculum.

Nevertheless, Jan had difficulty enacting her intention to incorporate "lab meetings". Pressures such as feeling overwhelmed or being afraid can prevent teachers from taking the final step to implement new ideas in their classroom even when external conditions support change. However, when an ideal opportunity (the "epic fail") presented itself, Jan took a risk and tried something new that she had been intending to do all along. The seeds had been planted earlier - when the right time presented itself, Jan was ready. Significantly, the failure she described reflected a common occurrence in research settings – protocols not yielding expected results.

Such failure was something that many teachers referenced as a potent take-away from their research experiences. Jan's success with her first lab meeting at the end of the school year emboldened her to continue to add even more lab meetings to her classes the second year after the workshop, illustrating how new elements in teacher classroom practice can take time to implement even if teachers have deep knowledge and experience with research and are strongly committed to change.

Jan's vignette highlights how teachers need time to make classroom shifts that align with their expanded views of argumentation. She provides an example of a teacher who understood the scientific community well and had a solid understanding of the practice that she intended to broker to her classroom, but had difficulty with implementation (or, as she put it, "getting the ball over the finish line"). This was in part due to fear of how students would react to more agency and opportunity for discourse and critique with one another. Jan's story demonstrates the complexity of representing social dimensions of scientific argumentation in classrooms, the difficulty of making changes to well-established discursive patterns of classroom social and cultural communities (Cazden, 1988; Meehan, 1979), and teachers' fears of loss of power and control (Hudicourt-Barnes, 2003, also examined further in Chapter 3). It took an unexpected disruption to a culminating project for Jan to shift her stance, transform the "failure" into an incomplete object of focus that was "open, question-generating, and complex" (Schatzki, Knorr-Cetina, & Savigny, 2001, p.190) and shift the classroom activity system (Engeström, 1999) to allow greater opportunities for epistemic agency and authority in her students.

Louise: Tensions in Translation. Louise, whose trajectory is described in the final vignette, illustrates some of the tensions that teachers struggle with as they try to reconcile the typical known-answer experiments with the desire to provide students with meaningful opportunities to argue. Her story also illustrates how, for some teachers, taking up C-E-R structures in their classes is a major shift towards incorporating more argumentation in their classroom.

Louise had been teaching for 9 years and was completing her National Board certification. She worked in a large, suburban public school and had no prior research experience. Her initial definition of scientific argumentation and its purpose was “supporting an idea with observations, facts, evidence...When analyzing the claim, all known evidence/observations should be in line with the claim. If not, we need to adjust our thinking/understanding of the topic.” Her initial classroom argumentation example detailed a lab which provided disconfirming evidence for students’ initial conceptions about cellular respiration in plants. Louise was helping students to think about the role of evidence in supporting claims, yet her example focused on a lab activity where students knew that they were trying to get the right answer.

Louise struggled with how to incorporate sense-making discussions in relation to known-answer experiments. She called out a fundamental tension and challenge for teachers: that scientific and school science systems are different activity systems that historically have had different end goals – production of new knowledge versus transmission of existing knowledge. Louise noted that when things “didn’t go right” in scientific lab activity it could be that whatever model or theory the researchers were developing was not in line with the evidence. She contrasted this to school activity, where the end goal is most often to illuminate or confirm the model or theory. She then provided an example familiar to many biology teachers:

> This is one of the things that I'm kind of struggling with because we talked a lot about when things failed in our labs and how when something failed, the scientists didn't throw out their theory because the evidence didn't support it. They collected more evidence. They redesigned their experiments and they went back to the drawing board. I'm trying to

> figure out how that process fits into my classroom because when something doesn't go right in a lab that we do, I don't want my students to throw out the theory and think that plants don't do cellular respiration because we didn't see plants do cellular respiration. At the same time, *I have been known to run around and put vinegar in my bromothymol blue so that they see the right thing* (laughter of others) because when they see the wrong thing, they get so many more misconceptions that we then have to break down. This idea of when is it ok for an experiment not to work and when is it important to go back and redesign our experiment and how do we have time for that. Also, a lot of the things that we do, I need them to see the correct result, because I'm trying to break down some misconceptions they already have about how the world - I don't know. I'm in this crazy swirling head space (emphasis added).

Louisa expressed how difficult it was for her to resolve conflicts when confirmatory experiments don't work as expected. In such cases, teachers often steer students back to what was supposed to happen – a known-answer result that serves to illustrate a point. Constraints such as limited time prevent teachers from being able to repeat experiments or collect more data. Louise even admitted that she had doctored lab results so that students could be sure to "see" what they were supposed to and would not draw erroneous conclusions that would create even more confusion.

In her Reflection Day survey, she responded to the question, "Has your thinking about communication in science and argumentation as a scientific practice changed since you started TSP?" by sharing how she had implemented the use of argument structures. Louise was excited about implementing the C-E-R framework in the year after the workshop:

> I have been using claim, evidence, reasoning in my classroom for the first time this year. I had always worked with students to explain their answers and to write conclusions, but it wasn't until this year that I used C-E-R. It worked particularly well with the evolution unit where I wanted to students to be able to make a claim as to if evolution had occurred, provide evidence to support their claim, and the reason through how the evolution would have occurred.

Finally, rather than viewing argumentation as a constructive learning process, Louise questioned whether her students had sufficient content knowledge to argue effectively. When asked whether observing how scientists talk to one another in lab meetings and during the course of their work influenced how she structured opportunities for talk in your science classroom, she responded that her students didn't have the depth of knowledge to be able to engage with one another to engage with each other like scientists do: "The scientists in the lab all knew the content really well. They were able to ask questions and provide feedback due to their depth of knowledge. My students don't have a depth of knowledge. This is something I am still working on."

Louise's experience pointed to the need within teacher professional development programs to more thoroughly address the issue of how to reconcile the prevalence of known-answer lab experiments with the desire for more open-ended activities. Teachers need a vision of, and models for, how they can integrate activities that demonstrate or support disciplinary content ideas with those that engage students in scientific practices. These models can serve as supports as teachers consider how to broker aspects of their experience to help support conceptual change in students. Her vignette also revealed that some teachers may hold back from engaging students in collaborative sense-making discussions because of a belief that students do not have the necessary level of content knowledge needed to engage in such talk. Teachers may not see the opportunities to broker argumentative practices if they feel that the gap between the practices of the professional research community and those of the classroom is too great to surmount.

Louise's story represents a long-standing question in education around how to best engage secondary students in science learning and scientific practices. It reflects the ongoing tension between ensuring that well-established scientific content knowledge is shared and engaging students in the processes that warrant such knowledge (Rudolph, 2005). In the past few decades, studies in scientific communities of practice have highlighted the highly situated and contextualized work of scientists and the role that social sense-making plays in knowledge-building processes (Latour & Woolgar, 1986), which has led to a new emphasis to try to represent these practices in schools in ways that help students understand what counts as science (Duschl, 2008; NGSS, 2013). However, the historical weight of how science has been taught in the past is challenging to bring into alignment with the new vision for science education. Louisa's concerns represent challenges that teachers face as they try to enact new ways of thinking about science and science education in their classrooms, and highlights the importance of scaffolds, resources, and models that can support teachers to introduce elements of scientific practice to students.

Despite a unanimous response from teachers that TSP had changed their thinking about communication in science and argumentation as a scientific practice in some ways, not all teachers experienced large shifts in their thinking, as noted on the year-end survey (n=19). Two teachers noted that their original ideas about argumentation were sound, but that they nevertheless felt more equipped to talk about its significance with students. For example, Marisa noted: "I do not believe my ideas around argumentation have changed but I do feel like I am prepared to better explain to my students why it is important." Four teachers primarily focused on how they wanted to change classroom practice (for example, wanting to align more claims with evidence, add more questioning, and make science talk more transparent to kids). Jessica noted that her initial ideas were "really good" but she now had more ways to incorporate argumentation into the classroom. The remaining 13 teachers all noted a broadening or refining of their ideas and a better appreciation of the role of argumentation in science, including its role in in sense-making and knowledge-building.

Teachers were excited about the implications of their observations for classroom practice, but they also directly acknowledged the challenges of barriers they faced in their discussions.

These included fears of managing open-ended discussions, possible waste of materials with greater student choices, inability to believe that students are capable of more, the belief that a certain amount of content is necessary before students can design experiments, and the pressures of covering content in limited time. Some teachers also referenced a kind of curricular inertia, where the "curriculum at our school is what we've always been doing". Another challenge that teachers noted was creating a context that would allow students to talk to one another despite the social barriers that might exist between them or despite their fears of vulnerability. Unsurprisingly, teachers were also concerned about time constraints, which were often imposed by institutional or external structures (such as 50-minute periods, amount of content they felt they needed to cover, and curricular standards).

Discussion

The focus of this study was to examine how science teachers learn about argumentation and scientific sense-making through participation in research experiences, and to discern how teachers' observations of sense-making in research settings influences their conceptions of the role of argumentation both in professional science contexts and within science classrooms. When reflecting on the specific practice of argumentation in research labs, teachers highlighted the ubiquity of argumentation as a form of basic discursive communication among scientists, and also noted its foundational role in making meaning across scientific activities - from developing procedures, to analyzing data, to drawing conclusions. Significantly, they recognized that in order to incorporate a broader vision of argumentation in their classrooms (one that includes the social and discursive dimensions), they would also need to make certain kinds of pedagogical and curricular shifts, including providing more opportunities for activity structures that allow for productive uncertainty and engaging opportunities for discussion.

Implications for teacher professional preparation and growth

What motivates teachers to incorporate science practices into their classrooms? Teachers, administrators, and professional developers across the United States are considering how to respond to reform movements that elevate scientific and engineering practices such as argumentation. Some teachers may view the need to incorporate practices as something that should be done because of new standards (NGSS) or resources shared by professional organizations. *Within this study, teachers talked about how they had viewed scientific argumentation as something separate from argumentation in science education.* It is reasonable to imagine that teachers, particularly given the enormous pressures they face, would search for approaches and strategies that fit in readily with what they have done in the past (for example, using argument structures in conclusion-writing for known-answer lab activities). Much less familiar to teachers are ways to implement social dimensions of practices such as argumentation. As this research suggests, even teachers with research experience and strong intent and desire to incorporate more collaborative sense-making and knowledge-building talk struggle with inertia or fears of what might happen in their classrooms as a result.

Manz (2015) argues that making activity structures of science visible to teachers could help foster expansive views of argumentation. This research study suggests that professional development in scientific research settings can be used to that effect and can help broaden teachers' conceptions of argumentation and its role in science. Furthermore, this study reports on a relatively short professional development experience which is more broadly accessible to teachers than full summer-long or multi-year Research Experiences for Teacher programs are. The study shows how professional development focused on argumentation (that includes a micro-ethnographic approach focusing teachers on observing argumentation structures 'in the wild' and reflecting on their observations with others) can help educators incorporate more engaging and epistemically authentic visions of practice while shifting discourse and activity structures in their classrooms.

Epistemic Motivation

Across the data corpus, the vision of the centrality of argumentation in research labs was a powerful motivator for teachers, particularly when combined with resources and pedagogical scaffolds. In addition, the opportunity for reflection and processing with others provided many different "windows" into how argumentation looks in research settings as well as ideas for classroom enactments. Incorporating such elements into professional development opportunities can provide a driving force, or what I term the "epistemic motivation" to help teachers appreciate the need for including social dimensions of argumentation in their classrooms and to frame argumentation in meaningful ways for students. I argue that there are several factors that foster epistemic motivation in teachers. Teachers need to be able to: (1) Recognize the importance of the practice within the professional scientific culture and community; (2) Recognize the similarity or disparity in how practices are enacted between that community and their classroom; (3) Aspire to broker elements of practice to the classroom in service of reflecting practices more authentically. For example, Melissa emphasized that focusing on the discussion in a research lab meeting was a "critical turning point" for her in "appreciating how scientists talk" and directly connected that to her desire to foster a culture of argumentation in her classroom. Similarly, Tamara had linked her observations of scientists' discourse to her belief that students "need to work deeper and address other students' ideas and thoughts and either support them with evidence or use evidence to question what they're thinking".

In order to provide students with experiences that more authentically reflect the discursive practices of professional science, it is also necessary to ensure that teachers have the understanding and support to create such environments. Wenger (2000), notes that, "if school practices become self-contained then they cease to point anywhere beyond themselves. School learning is just learning school" (p. 267). A greater emphasis on scientific practices could help teachers break out of the "self-contained" ways of thinking about, and teaching about, science that are commonplace in schools. For example, an emphasis on the social dimensions of argumentation can provide students with an understanding of how uncertainty is managed in science (Manz, 2018) and how groups of individuals can contribute to developing procedures, interpreting findings, or examining claims. In discussing the nature of knowledge, Wenger (2000) describes how our beliefs of what knowledge is influences pedagogy. A belief that knowledge consists of units of information that reside in the brain leads naturally to the more didactic approaches that are commonplace not only in schools but in other learning settings. However, a belief that knowledge is not only stored explicitly but that "knowing involves active participation in social communities" can lead to "inventive ways of engaging students in meaningful practices, of providing access to resources that enhance their participation, of opening the horizons they can identify with, and of involving them in the actions, discussions, and reflections that make a difference to the communities that they value" (Wenger 2000, p. 10-11). Teachers who recognize the value and central role of community-based practices (such as the discourse that shapes and underlies professional research efforts) are in a position to help students achieve a deeper, contextualized understanding of the social dimensions of science.

Teachers as reflective professionals working across boundaries of communities of practice

Teachers in this study not only reflected on their learning in their journals, but they had many opportunities to make meaning of their experiences collectively and build their "relational agency." Edwards (2011) defines relational agency as "a capacity for working with others to expand the "object of activity" or task being worked on...and aligning one's own responses to the newly enhanced interpretation with the responses being made by the other professionals while acting on the expanded object" (p. 34). In this context of this study, the "object of activity" that teachers were expanding was the concept of argumentation, specifically argumentative discourse. Edwards argues that relational agency is mediated by the development of common knowledge (shared ideas of what is important about the object and how the ability to use it) at the boundaries of practices and settings. Providing opportunities for teachers to traverse into scientific settings to observe, gather specific information, reflect on their findings, and process them with peers, helped them to build their relational agency and expertise. For example, teachers were able to compare their lab meeting observations and experiences against those of their colleagues to build a broader picture of what scientific argumentation and discourse looks like in professional settings. Furthermore, Edwards argues that the emphasis throughout professional development must be on a search for meaning: "Professional learning is therefore not simply a matter of induction, though induction into values and key skills is important. Professional learning needs to include a capacity for interpreting and approaching problems, for contesting interpretations, for reading the environment, for drawing on the resources there, for being a resource for others, for focusing on the core object of the professions…" (Edwards, 2005, online, page not available). Throughout the workshop, teachers were provided chances to make meaning of their experiences related to argumentation together to develop “common knowledge” about its importance and to consider the relevance for their experiences for their work with students.

This study also extends our understanding of possibilities for participation across communities of practice. Davidson and Hughes (2018) have conceptualized the role of teachers engaged in research experiences in laboratory settings as “spectator novices.” While they intended for the term to illustrate how teachers move towards legitimacy in a community of science practice with a goal of observing the culture and translating it to their students, the term is misleading in several ways. The role of teachers in such settings is actually considerably more nuanced. First, teachers are not participating in research in order to become scientists, and therefore they are not “novices” trying to become “experts” or more central participants of scientific communities. Their movement between labs, classrooms, and the TSP community is more akin to “consequential transitions” (Beach, 1999), as teachers reflect on and transform their understanding, skills, and the ways they think about their own roles. Second, they are playing a more active role than “spectators.” Although they are observers, they are not passive. They bring their professional expertise to the fore in deciding what elements of practice are relevant to transfer or broker to their classroom communities. As many of the discussion excerpts show, teachers moved seamlessly between their observations of scientific settings and their ideas for working with students (although implementing their ideas in actual classroom settings was sometimes challenging). Finally, teachers noted that they were themselves changed through their engagement across scientific, professional, and classroom communities.

The shifts that teachers made were connected the original design conjectures and the ways those were embodied and mediated through the design: The high level conjectures were that (1) Broadening teachers’ abilities to enact productive instances of argumentation with students is facilitated by experiencing the central role of argumentation in science and strategies for transforming student discourse in classrooms and (2) that scientific argumentation as a practice involves the coordination of claims with evidence through reasoning, but also involves sense-making through collaborative and discursive processes of critique and deliberation. Central to the design was the immersive lab research experience that allowed teachers to engage in and observe scientific practices, including sense-making argumentative discourse, in research settings. This experience was scaffolded thorough resources that structured the observation and reflection, and opportunities for processing with peers and Lead Teachers. The design also aimed to prepare teachers for enacting social dimensions of argumentation in their classrooms by modeling setting norms, generating question stems, and facilitating seminar-style discussions. In order for teachers to bring their understandings to their classrooms in ways that fit their unique circumstances and settings, teachers worked on curriculum materials where they were encouraged and supported in integrating more opportunities for student sense-making discourse.

In future years, the TSP program intends to focus more on this last element of the design – the development of lessons and activities and foster social dimensions of argumentation. As Windschitl and Stroupe note, instructional training for teachers tends to focus more on "managing both material activities and students themselves and less on designing opportunities for students to reason about ideas" (2017, p. 256). Teachers such as Melissa who had created materials specifically to engage students in making and defending claims based on evidence, structures to support the questioning and critiquing of others, and ways to reinforce the importance of building collaboration and community also reported the largest classroom changes. In particular, we plan to engage teachers in thinking about curricular approaches and activities that foster productive disciplinary engagement, provide the appropriate level of uncertainty, scaffold progressive discourse, and that open rich possibilities for meaningful argumentation (Bereiter, 1994; Engle & Conant, 2002; Manz, 2018).

Implications for the Classroom: Science as Progressive Discourse

There is a balance between finding ways to incorporate knowledge that has been developed over the course of scientific activity and opportunities for authentic engagement in scientific practices. In most cases, teachers do not intend to reproduce the total activity of scientific research in their classrooms (barring specially designed research courses). This study suggests that one method for opening up scientific practices to students is through developing their understanding of science as progressive discourse (Bereiter, 1994). Thus students learn to take part in a type of discourse that scientists do. Bereiter argues that "typical hands-on experience has very little impact on students' understanding...what has been missing...is the discourse into which experimental findings need to be brought and critically analyzed if they are to contribute to progressive understanding" (p. 8). Students can learn, in authentic ways, the progressive discourse of professional science, with its commitments to critique, open-mindedness, empirical testability, and knowledge-building. This is what Michelle referred to when she noted that, students engaged in productive discourse are "just at the beginning part of that journey...they're just doing it at this level". As Bereiter goes on to say, "classroom discussions may be thought of as part of the larger ongoing discourse, not as preparation for it or as after-the-fact examination of the results of the larger discourse. The fact that classroom discourse is unlikely to come up with ideas the larger discourse in no way disqualifies it...The important thing is that the local discourses be progressive in the sense that understanding are being generated that are new to the local participants and that the participants recognize as superior to their previous understanding (p. 9).” Thus, even at introductory levels, students can learn how engage in authentic ways with argumentative science talk.

Ultimately, elevating the role of the social, discursive elements of argumentation in science classrooms has the potential to create discourse environments that value student voice. Because activities that generate productive opportunities for meaningful discourse are more open-ended, they also have the potential to elevate student agency if students are given more control over design or interpretation. Regardless of whether or not they implemented “lab meetings” with students, most teachers reported an increased focus on student-to-student discourse and a corresponding step away from their own role as the primary arbiter of knowledge. On a broader level, despite decades of educational research validating such shifts, teachers still saw this as a novel perspective. This finding demonstrates the degree to which the discourse patterns associated with the traditional classroom game are reified in education (Cazden, 1988; Lemke, 1990; Mehan, 1979), pointing to the need for new structures for science teacher learning that are capable of countering the deeply held routines of school. It also draws attention to the necessity of political and institutional support for such shifts.

Caveats and Limitations

This research focused on designing professional development that could leverage the resources of a large scientific research institute and provide educators, and by extension their students, with a more practice-based view of professional science. However, my focus on western scientific approaches that are the norm in this research institution is not intended to disparage the value of other epistemological views such as indigenous ones. Similarly, this work does not mean to imply that science educators should try to mold all students to be identical to professional scientific researchers. Instead, educators should draw on professional scientific practices alongside students' everyday experiences, interests, and cultural backgrounds (discussed further in Chapter 4) to help students understand and celebrate the wonder of the natural world as well as the many ways in which argumentation takes place elsewhere beyond the classroom. (Bang, Brown, Calabrese Barton, Rosebery, & Warren, 2016; Bricker & Bell, 2008; Lemke, 2001).

This study focused primarily on the experience teachers had as they went through a three-week summer workshop with a brief research exposure and follow-up at the end of the next school year. One of the limitations of this work is that it does not extend to observations of the direct classroom experiences of students and teachers. Additionally, the cohort examined was unusual in that only one male teacher participated; although data from his contributions aligned with those of the women, it is possible that a more gender-balanced cohort would yield different results. Similarly, the group was overwhelmingly white; the findings may have also varied had a more ethnically and racially diverse group of teachers participated.

Design Principles

This design-based research effort explored how particular program elements offered opportunities for expanding science teachers' views of argumentation. Several design principles emerged from the findings that could aid others involved in teacher pre-service or in-service professional development, particularly those involving a research experience. Overall, these principles aim to foster sense-making about collaborative argumentative science discourse in teachers. Allen and Penuel (2015) demonstrated how sensemaking theory could help teachers move towards NGSS-based approaches through professional development. These recommendations align with their approach, which argued that professional development should introduce ambiguity for teachers (for example, in terms of their roles in the classroom and their pedagogical goals) in order to provide impetus for teachers to consider what changes to make to reconcile their previous position with their new understandings.

1) Use scaffolds to help frame the research experience and sharpen teachers' "professional vision" around scientific practices (to help them "know where to look and what to look for"). Teachers received a journaling guide with a number of questions for them to reflect on and respond to daily during their lab experience. This scaffold focused teachers on attending to scientific knowledge-building through talk and asked them to select an example of argumentation to share with others. The TSP program had included a research experience for teachers for over twenty years, but it was not until we asked teachers to specifically attend a lab meeting and bring an exemplar of argumentation back to discuss with other teachers that they became attuned to how argumentation, sense-making, and knowledge-building discourse are foundational scientific practices. Framing the experience included previewing a video of a lab meeting to encourage teachers to move beyond trying to understand the content of the scientific discussion and to focus on how researchers were talking with one other. Such efforts, combined with structured opportunities to discuss and process their findings with others, sharpened the "professional vision" (Goodwin, 1994, p. 607) for teachers and tuned their attention to key discursive practices. As Goodwin notes, 'the ability to see a meaningful event is not a transparent, psychological process, but is a socially situated activity accomplished through the deployment of a range of historically constituted discursive practices" (Goodwin, 1994, p. 607). Teachers such as Raven noted that she would not have noticed how common argumentative discourse was among scientists "without the preparation I got with having to notice it." Increasing the "transparency of practice" (Little, 2003, p. 918) for teachers in scientific settings helped give them a window into important ways of making meaning in science. Future studies might investigate different representations and formats (for example, scaffolded viewing of lab meetings on video) in order to determine if they are effective in promoting understanding.

2) Model pedagogical and curricular discourse structures that can be used in classrooms. The workshop modeled strategies and provided resources for teachers to use to help them increase collaborative argumentation in their classrooms, using a cognitive apprenticeship model (Collins, Brown, & Hollum, 1991). Teachers participated in a lab activity that generated enough authentic uncertainty to afford a productive discussion of results. Afterwards, we held a seminar "lab meeting" to discuss results and establish a shared understanding of them, as well as to highlight important pedagogical concerns. Teachers set norms for discussions and also generated question stems and practiced "idea coaching" (Wingert, 2017) with one another. Teachers learned about C-E-R argument structures as an argument pattern but also learned how such structures can limiting (Manz, 2015; Windschitl, Thompson, & Braaten, 2018). Many teachers commented on how learning like a student in the lab, in the workshop, and in creating a final product, was a powerful takeaway and helped increase their empathy for the kinds of activities that are meaningful and engaging.

3) Provide examples of tasks/activity structures with a productive level of uncertainty. Teachers were also provided with models of tasks and activities that would lend themselves to productive discourse and opportunities for knowledge-building (Michaels, O'Connor, & Resnick, 2008; Windschitl, Thompson, & Braaten, 2018; Wingert, 2017). As Louise's vignette illustrates, some teachers are concerned about how the traditional goals of teaching content knowledge through known-answer labs square with the goals of incorporating opportunities for collaborative argumentative discourse. Researchers have noted that "even in classrooms utilizing reform-based pedagogies, students are typically allowed to construct knowledge only insofar as they construct expected knowledge" (Russ and Berland, 2018, p. 1). Similarly, Danielsson and Warwick (2016) showed how teachers can worry that knowledge obtained through inquiry could conflict with knowledge they hope their students come away with - the "final form" (Duschl, 1990) knowledge. Louise's story also illustrates how teachers worry about their students not having enough subject matter knowledge to argue effectively. To help resolve these tensions, teachers need support to create and use activities which capitalize on unexpected results (an "epic fail") or which give students agency in designing and interpreting experiments whose outcomes have a productive level of uncertainty (Engle and Conant, 2002; Manz & Suarez, 2018; Manz, 2018). For example, Manz and Suarez have found that strategies such as "beginning with complex phenomena, iterating on investigations, and leveraging variability in students' ways of conducting investigations" (2018, p. 771) are strategies for helping students to engage with scientific uncertainty while still maintaining a level of uncertainty that teachers find manageable in terms of pedagogical control.

4) Provide opportunities for "relational agency," reflection with peers, and time to create customized resources. Teachers need opportunities to process observations and reflections from research experience with other teachers, including "lead teachers" with more experience. As one teacher noted, "I loved working in the lab but what really helped me was the camaraderie with other teachers…" Teaching can be an isolating profession, with opportunities for reflection and discussion with peers often limited. Collaborative reflection and meaning-making was one of the most important elements of the workshop for many teachers. For example, teachers could compare notes on the differences in the lab meetings they observed to form a more robust picture of the range of discourse practices in such settings and the stances that PIs and other members took in discussions, building relational agency and expertise with other teachers at the boundaries of scientific and educational practices (Edwards, 2011). Educators also know their own situated teaching and learning context, so providing them with time to create tailored materials that they could use in their classroom helped make it easier for them to shift their practices in the following school year to include more opportunities for student discourse.

Science is still often presented as a fait accompli, appearing in schools in a way that does not reflect the processes in which scientific practices are deeply embedded. At the heart of scientific endeavors lie complex social practices such as argumentation, which need to be represented in learning environments in order to provide young people with a more epistemically authentic and broadly accessible image of science. Overall, this study indicates that expanding teachers' conceptions of argumentation and related discourse practices, and providing them with models and support to do so, has the potential to shift how educators structure talk in their classrooms to further student understanding of scientific practices. Ultimately, providing students with an expansive view of science may have impacts beyond simply increasing their scientific literacy: it may allow youth broader access to the social, cultural, and material aspects of science and foster deeper and more meaningful engagement with its practices.

References – Chapter 2

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Chapter 3: Science teachers decenter classroom power following experiences in professional research settings: *I took a step back...and it was amazing*

Abstract

This study examines how secondary science teachers in a professional development program at a research center learned about scientific argumentation as it is embedded in deeper contexts of social power relations. I investigated two questions about how teachers come to think about power and discourse in their classroom following their experiences. First, I asked how secondary science teachers learn about power and its connection to argumentation and scientific sense-making discourse through their participation in research experiences. Second, I considered how teachers' observations in professional science research settings help them move away from hierarchical power arrangements and towards collaborative and equitable sense-making discourse in their classroom. I also considered how professional development could be designed to help teachers consider how their pedagogical choices can shift epistemic authority to students, create environments where argumentation can happen, and promote equitable student participation. This study used qualitative methods to follow a cohort of 21 teachers and 4 lead teachers through a summer program and the subsequent school year and to investigate how teachers made meaning from their experiences. Major findings from this study include an accounting of how teachers desettled traditional school power structures. First, teachers desettled traditional classroom talk patterns away from teachers primarily asking known-answer questions and students responding. Second, teachers scaled back their epistemic authority, providing students with more agency and ownership of ideas. Third, teachers recognized the value of establishing a culture of community and collaboration, desettling ideas of uniform, independent mastery and emphasizing the sociocultural nature of learning and sense-making. Finally, teachers desettled the traditional project of school and its focus on mechanisms of sorting and ranking

students by their ability to reproduce correct answers. These findings describe the possibilities afforded by a professional development program that included opportunities for teachers to reflect on the pervasiveness of collaborative argumentation and sense-making discourse in professional scientific activity. The professional development also allowed them to experience research settings both as teachers and students themselves. Such design elements, coupled with opportunities to learn specific classroom discourse strategies, provided powerful motivation for teachers to shift to a more practice-based pedagogical focus. Ultimately, engaging students in science in ways that value their intellectual contributions and sense-making repertoires can help foreground for students the fundamental practices that constitute scientific activity, promote more equitable participation among science students, and alter the cultural production of authority in secondary science classrooms.

Overview

If we conceptualize science inquiry as involving a set of practices that are mediated through dialogue and cultural tools, it leads us naturally to consider how science can be represented in classrooms in intellectually honest and equitable ways that reflect those commitments (Bruner, 1960; Cornelius & Herrenkohl, 2004; Driver, Newton, & Osborne, 2000; Manz, 2015; Van Horne & Bell, 2017; Windschitl, Thompson, & Braaten, 2008). What motivates teachers to include more opportunities for student argumentation, sense-making, and knowledge-building discourse into their classes and to take a step back from positioning themselves as the main arbiter of power and knowledge in the classroom? In this paper, I describe a set of findings related to power and discourse that are part of a larger qualitative and design-based research study focused on how members of a cohort of secondary science teachers made meaning about scientific argumentation from their experiences in research labs and from a professional development workshop. The study also examined teachers' reflections about pedagogical shifts they made in their classroom the subsequent year.

Professional development that includes focused research experiences in scientific settings offers a way for teachers to reflect on the ways that social power, knowledge-building, and collaborative discourse are related in science. I argue that such experiences can prompt teachers to consider the implications for their own classrooms and can help provide what I term "epistemic motivation" to shift their pedagogy. Epistemic aspects of science are processes by which scientific knowledge is acquired, constructed, and evaluated. Teachers in this study were motivated to change discourse and learning opportunities in their classrooms as a result of observing epistemic practices in research labs and recognizing the disconnect between how science in practiced in professional settings and in their classrooms. Epistemic motivation provided the impetus for teachers to make difficult pedagogical and philosophical shifts in order to better represent the fundamental epistemic role of collaborative discourse and argumentative sense-making of science in their classrooms.

This paper describes how teachers recognized and reflected on their power (particularly in managing discourse and activities in the classroom) after observing scientists' argumentation in research labs and discussing their findings with one another. By opening up discourse opportunities in their classrooms to reflect the productive instances of collaborative sense-making talk they saw in professional science settings, and by scaffolding learning and talk with appropriate tools and resources, teachers noted that power shifted in their classroom in important ways.

Teaching as Political

Teaching is a political endeavor that reflects issues of power at the local and broader societal levels; power dynamics factor into everyday classroom interactions as well as the broader institutional and societal political contexts in which instruction is situated (Foucault, 1975; Freire, 1970/2002; Gutierrez & Rogoff, 2003; Nasir, Warren, Rosebery, & Lee, 2014). The selection of specific texts and topics, decisions about curriculum and activities, and even the arrangement of students in classrooms reflect an underlying broader vision of what education should be (Bang, Warren, Rosebery, & Medin, 2012; Dewey, 1902). Teachers exert control and power through classroom rules, guidelines, and expectations that communicate to students what an exemplary student looks and acts like ("celebrated subject positions", see Carlone, Scott, and Lowder, 2014 and Holland, Lachiotte, Skinner, & Cain, 1998). These choices may also reflect historical purposes of school that are rooted in dominant culture and often reflect what Freire (2002) termed a "banking model" of education. In such a model, teaching is viewed as a transactional relationship and students as passive vessels to be filled with knowledge, as banks are filled with deposits of money (Freire, 2002). Freire made a connection between authoritarian political systems and the banking model: "the more students work at storing the deposits entrusted to them, the less they develop the critical consciousness which would result from their intervention in the world as transformers of that world (2002, p. 73)." Educational systems thus serve as critical elements of social control (Foucault, 1975). Even teachers who are intent on taking a critical approach to their own instruction are constrained from bringing change to their classrooms, as they are caught up in a larger culture and system of power with institutional norms, cultural/historical precedence, and accountability structures such as high-stakes testing and data-driven evaluation (Carlone, Haun-Frank, & Kimmel, 2010). Despite the influence of restrictive institutional structures, most teachers do have at least some degree of agency and decision-making power in organizing the activities and participation structures of their classrooms.

The Need: Teacher Learning about Scientific Practices

The *Next Generation Science Standards (NGSS)*, which are based off of the *Framework for K-12 Science Education*, integrate disciplinary core ideas with cross-cutting concepts and science/engineering practices (NRC, 2012, NGSS Lead States, 2013). This elevation of the role of science practices (such as argumentation) in classrooms represents a challenge for teachers, particularly for those who adhere to a rigid view of a single, inflexible “scientific method.” Our understanding of how to develop teachers’ fluency with practices, or support educators in taking them up, is limited. For most teachers, it is not practical to spend the time learning how to become scientific “knowledge producers” (Feldman, Divoll, & Rogan-Klyve, 2009) or practicing scientists. Nevertheless, they are expected to understand how scientific practices contribute to knowledge production in science and to engage students in those practices. Windschitl (2004) found that teachers in his study who had significant research experiences and content knowledge were more likely than their peers to use model-based inquiry approaches. While teacher professional development opportunities in research settings have the potential to provide educators with deeper understandings about scientific practices such as argumentation, little is known about what teachers learn about practices in such contexts or how they consider the implications for their work with students. For example, a review of research apprenticeships programs (including 11 for teachers) found none that explicitly focused teachers on argumentation and collaborative sense-making discourse practices (Sadler, Burgin, McKinney, and Ponjuan, 2010). This represents a missed opportunity in teacher professional development, as research organizations have deep expertise in science practices. There is a need to understand how research experiences can be leveraged to help teachers incorporate key dimensions of science in their classrooms and make practice-focused shifts in their pedagogy. Teachers also need to consider how power is distributed in the classroom in order to make such shifts (Donnelly, McGarr, & O'Reilly, 2014).

Argumentation and Sense-making in Classrooms

Research indicates that argumentation occurs infrequently in science classrooms; students and teachers often adhere to views of science as factual information (Lemke, 1990, Driver, Newton, & Osborne, 2000) that represents a "settled" view of science (Bang et al., 2012). Additionally, many science teachers lack direct experience conducting research or using scientific practices themselves (Russell, 2005; Windschitl, Thompson, & Braaten, 2008). It is not surprising, then, that studies indicate that opportunities for students to participate in social aspects of argumentation are rare (Osborne, 2010; Berland & Reiser, 2011; Bricker & Bell, 2012). In particular, the role of collaborative and critical discourse for the purposes of shared sense-making is rarely foregrounded (Berland & Hammer; 2012; Bricker & Bell, 2012; Manz, 2015). While the recent uptake of the NGSS in many states may change this, the research and practitioner communities need accounts of how teachers shift the learning cultures of their classrooms to focus on epistemic practices such as argumentation."

I take an expansive view of argumentation that encompasses the formulation of claims based on evidence and reasoning and also the collaborative and sense-making dimensions of argumentation (Bell, 2002; Berland & McNeill, 2011; Manz, 2015). Sense-making serves to build knowledge and understanding of phenomena (Berland & McNeill, 2011) and is "about actively trying to figure out the way the world works" (in response to scientific questions)

(Schwarz, Passmore, & Reiser, 2016, p. 6). Odden and Russ (2018) emphasize that sense-making can be thought about as a stance or epistemological frame, a cognitive process, and a discourse practice. It is this last dimension, sense-making as a collaborative discourse practice, that closely connects to argumentation. In contrasting sense-making with persuasion, Odden and Russ note that students arguing in this style are “trying to build an explanation together, and while they may critique each other’s arguments they are doing so to make their explanations stronger, not to ‘win’” (2018, p. 10). This is an important point - the goal of sense-making is expanded understanding, not winning per se; arguing, critiquing, and persuading may still be dialogic parts of a scientific sense-making discussion (Bell, 2002).

Of course, argumentation and collaborative sense-making talk are not unique to science. However, these discursive practices play a special role in how new scientific understandings are developed through peer review and other mechanisms of community dialogue - that is, they are absolutely key in warranting new scientific knowledge and the development of theoretical understandings. As Lemke noted, talking about scientific ideas involves “doing science through the medium of language” (1990, p. ix), which includes arguing and discussing in the service of making sense. In arguing for a central role for these practices in science education, Duschl & Osborne note that revealing the criteria by which scientific ideas are evaluated and discussing the justifications for those criteria “can only be done if argumentation occupies a central rather than peripheral position in the values of the science educator” (p. 45, 2002).

Discourse and Power in Classrooms

Discourse plays a key role in power relations in the classroom (Cornelius & Herrenkohl, 2004; Donnelly et al. 2014). For example, Donnelly and colleagues found that discourse in the classroom “constructs and maintains power relations that either stifle or facilitate inquiry-based approaches" (2014, p. 2029). Messages about power are communicated in many ways, including through teachers' authoritative narratives or scripts (Gutiérrez, Rymes, & Larson, 1995), expectations about the ways in which teachers should pose questions and students should respond (Heath, 1982), and control over speaking rights (Cazden, 1988). Thus, discourse both reflects and perpetuates particular power structures that have instructional implications.

Teachers traditionally position themselves as the primary speaker and questioner when they consider what counts as appropriate classroom science talk (Cazden, 1988; Gutiérrez, Rymes, & Larson, 1995). Learning, however, involves participation in practices of a community, including the special ways people talk within a community (Lave & Wenger, 1991). Research has indicated the benefits of collaborative work and associated discourse in serving intellectual goals (conceptual learning, creative problem-solving, learning practices associated with a particular discipline), social goals, and promoting effective classroom management (Cohen & Lotan, 2014). Significantly, studies have also shown how collaborative approaches where students can draw on their assets and act as resources for one another can promote equity among students in heterogeneous classrooms (Cohen & Lotan, 2014; Rosebery, Ogonowski, DiSchino, & Warren, 2010)

When teachers shift some of the epistemic authority for talk onto students, they can disrupt the conventional/traditional ways that power in the classroom is dynamically constructed through patterns of discourse. Moreover, it is not simply giving students voice by increasing the amount of time students talk with one another that matters. Rather, students need opportunities to build knowledge actively, engage in talk that reflects the progressive discourse of science, and to express, test, and refine their own ideas (Bell, 2002; Collins, Berland & Hammer, 2012; Bereiter, Scardamalia, Cassells, & Hewitt, 1997; Scardamalia & Bereiter 2006). Such opportunities are afforded in part by certain kinds of scaffolds, intellectual tools, and activity structures that offer opportunities for productive uncertainty (Cornelius & Herrenkohl, 2004; Manz, 2018; Manz & Suarez, 2018), particularly within a classroom culture where expertise is distributed and students engage in argumentative sense-making dialogue with one another (Brown & Campione, 1990).

The ways in which teachers create opportunities for talk sends a message to students not only about appropriate discourse in the classroom but also about what science is and who gets to participate in it. In this way, both knowledge and power are dynamically situated within classrooms and directly connected with one another. As Gutiérrez and colleagues point out, "power is locally constituted through the various configurations of talk and interaction in the classroom" (1995, p. 446). They note that for traditional modes of classroom talk, the "teacher's epistemic stance, revealed through the monologic script, helps define what counts as valued knowledge in this classroom and thus determines whose knowledge is constructed" (p. 450). The "monologic script" of traditional science teaching is centered on fixed patterns of teacher initiation of questions, student responses, and teacher evaluation of those responses (Cazden, 1988; Mehan, 1979; Nassaji & Wells, 2000), thus limiting opportunities for dialogue. This script reflects dominant school culture and is deeply embedded in practice but can appear natural and neutral to teachers who have themselves experienced this pattern when they were students. Gutiérrez and colleagues describe how the "power arrangements of the classroom, then, influence classroom practices; that is, what is learned and who gets to learn particular forms of knowledge" (1995, p. 450). Such power relationships serve the define and maintain the positions that are available in the classroom (Harré, Moghaddam, Cairnie, Rothbart, & Sabat, 2009). They are learned, develop, and become part of identity through participation in the practices of communities (Foucault, 1975, Gutierrez et al. 1995, Lave & Wenger, 1991).

Study Purpose

The purpose of this study is to examine how secondary science teachers in a professional development program offered through a science research center learn about scientific argumentation as an epistemic practice embedded in deeper contexts of social power relations. It investigates how secondary science teachers who are placed in professional science research labs for a week and experience professional development focused on scientific discourse practices come to think about dimensions of power: Where does authority and knowledge reside? Who is allowed to speak? What factors promote or constrain participation and collaborative knowledge work? It also examines how teachers make shifts within their classrooms that center on sense-making discourse and reflect expansive thinking about their own position, authority, and instructional choices.

This study is part of a larger one (see Chapter 2) that uses qualitative methods in coordination with design-based research (Brown, 1992; Collins, Joseph, & Bielaczyc, 2004; DBR Collective, 2003) to foster an expansive view of argumentation with teachers: one that goes beyond students' written conclusions for known-answer activities to highlight the social, discursive, persuasive and meaning-making dimensions of argumentation. Teachers considered how power and position play a role in discourse in both scientific and classroom settings and also reflected on the shifts in argumentative practices they employed in their own classrooms after the workshop.

I begin with introducing "positioning" - how individuals come to be placed in particular roles, with certain responsibilities and expectations (Harré et al., 2009). I also explore how discourses (specifically language-in-use) reflect larger Discourses (characteristic ways of "saying, doing, and being", Gee, 2014. p.47) and what the implications of such a theoretical lens are for understanding power in science classrooms. I then present the qualitative research methods used for this study and discuss my analytical approach. My analysis examines how teachers reflected on their own position through their experiences in the research lab and investigates their thinking about the relationship between physical arrangements of space, power and authority, and student contribution. Finally, I examine how professional development can support the “desettling” of taken-for-granted routines and roles in science teaching to foster more equitable and epistemically authentic science practices in classrooms.

Research Questions

This study examines the following research questions:

- How do secondary science teachers learn about social power and its connection to argumentation and scientific sense-making discourse through participation in research experiences?
- How do teachers’ observations in professional science research settings help them move away from hierarchical power arrangements and towards collaborative and equitable sense-making discourses in their classroom?

This study also investigates the following design-centered question:

- How can professional development be designed to help teachers consider how their pedagogical choices can shift epistemic authority to students and promote equitable student participation?

Conceptual Frameworks

Positions and Power

Social positions reflect being a particular type of person in a given location or situation and represent a dimension of the range of possibilities within the larger context of social practices (Harré et al. 2009; Bell, Tzou, Bricker, & Baines, 2012). Dreier (2009) notes that "persons are participants involved in personal trajectories in relation to structural arrangements of social practice" (p. 193) and conceptualizes individuals as agents in positioning themselves actively within, and also acting on, that structural "nexus" of practice. The ways in which youth are positioned by others (and how they position themselves) within learning contexts can have profound implications for identification with a practice. Bricker and Bell's (2012) case study of a youth interested in design and building who was positioned differently by his family and his teacher illustrated how "significant learning and hence identification with a practice – or the failure to learn and productively identify with a desired practice – can be viewed as a product of extended positioning processes" (p. 1677). Teachers are in roles that have the power to socially position their students (as well as themselves) in significant ways.

Shifting power through attention to D/discourses

Language carries many meanings within it, but it is also part of a larger set of symbols and interactions that communicate power and position. Gee's influential construct of "Discourses" (with a capital "D") encompass language-in-use ("little d discourse") as well as the "ways of combining and integrating language, actions, interactions, ways of thinking, believing, valuing, and using various symbols, tools, and objects to enact a particular sort of socially recognizable identity" (Gee, 2014, p. 222). Language-in-use "gains its meaning from the 'game' or practice it is part of and enacts" (Gee, 2014, p. 11) - such as the "game" of school or the practices followed in scientific research settings - and the broader Discourses that help someone to be recognized as a science student, a teacher, or a practicing professional scientist. Larger Discourses about school, which are shaped by social, cultural, and historical forces, provide the frames in which teachers can make certain types of positions available.

Discourses allow individuals to “enact and recognize different identities and activities, give the material world certain meanings, distribute social goods in a certain way, make certain sorts of meaningful connections in our experience, and privilege certain symbol systems and ways of knowing over others” (Gee 1999, p. 13). As such, Discourses are created, sustained, and reproduced through the cumulative actions of individuals in particular places and times - which allows them to be transformed through the agency of those who participate in them. However, Discourses are also structurally and institutionally embedded and reflect their broader economic, political, and historical purposes and legacies.

Language-in-use is reflexively related to larger contexts; it both reflects the world in which it is situated but also helps construct that world (Gee, 2014). In the culturally produced “figured world” (Holland, Lachiotte, Skinner, & Cain, 1998) of the science classroom, the types of discourse that happen between students and teachers, who gets to speak, and what is spoken about help define “school science.” Moreover, language helps build multiple dimensions of “reality” - what Gee (2014, p. 32) refers to as “building tasks”. For example, one such task is “significance”: The language and discourse structures that teachers use and that they encourage their students to use points to what should be considered significant in the classroom. Another building task is “politics” (the distribution of social goods): Language is also always “political” in the sense that it reflects how to “distribute social goods in a society: who gets what in terms of...status, power, and acceptance…”(Gee, 2014, p. 8). As such, language plays a key role in the power dynamics within a classroom.

Discourses help shape what defines, and is expected of, science teachers, including what the appropriate structure of argumentation and related practices should be. Because Discourses are so intertwined with teachers’ conceptions of teaching and classroom work, teachers may not be aware of how they are impacted by or reproduce particular elements (Carlone et al., 2010). These powerful global Discourses help frame what counts as a "good science teacher" or "good science teaching," and define the available social identities and positions for students (Carlone, et al., 2014). As Carlone and colleagues note: "We are all familiar with traditional practices of schooling, which perpetuate the teacher as authority, students as recipients of knowledge, and science as a body of knowledge. In this view, schooling is conceptualized as a form of exchange of knowledge (from teachers, to students) for control (of students, by teachers)" (2010, p. 943). Texts can also take on an authoritative role in science classrooms, reinforcing the idea that established science content knowledge should be the primary outcome of science classes, and dictating what is learned in taught in science classes. These familiar and deeply ingrained features of school represent what Tyack and Cuban term the "persistent grammar of schooling" (1995, p. 85). Calabrese Barton and Tan (2009) also highlight the challenges that students (particularly those from non-dominant groups) have in gaining access and entry into participation in school science because of content as well as the exclusive nature of the Discourses of school science. Disrupting these hierarchies has important implications for equitable learning and for making science more accessible across a broad range of students.

How can traditional school Discourses be altered to provide more opportunities for heterogenous student sense-making and intellectually honest representations of scientific work (Bruner, 1960; Rosebery, Ogonowski, DiSchino, & Warren, 2010)? In particular, how can scientific Discourses be represented in schools to reflect the social, cultural, material (and sometimes messy) ways in which professionals researchers engage in their work (Goodwin, 1994; Ochs, Gonzales, & Jacoby, 1996)? In this research study, I focus on how teachers make meaning from their observations of discourse in science labs and how that meaning is reflected in the ways that they think about their role in the classroom. These meanings are cultural productions that are developed, contextualized, and reproduced within larger institutions and systems (Eisenhart, 2001). Carlone et al. (2010) note, “cultural productions allow us to study how sociohistorical legacies (for instance, the meaning of teacher as ‘authority’) are reproduced in local practice and how groups (for example, the teachers in our study), in their everyday practice, confront, reproduce, contest, and or transform these legacies” (p. 943). Building off the work of Carlone and colleagues (2010), who see schools as active sites of struggle, I take up the idea of the cultural production of teacher authority and explore the ways in which its deeply embedded legacy can be interrogated and decentered by teachers themselves. I argue that teacher experiences in professional research labs can be productive catalysts for pedagogical reflection and refinement related to d/Discourse and power in the classroom, providing motivation to make important shifts in support of student learning.

Methods

Research Design

My research questions lend themselves to qualitative methods because I seek to understand how teachers interpret and assign meaning to their experiences in the professional development program (particularly their time in research labs) as well as their reflections about their classroom instruction in the following year. This analysis takes place within the context of a larger design-based research project (see Chapter 2) seeking to contribute to understanding of how research experiences for teachers can be architected to promote a broader understanding of argumentation and help teachers translate their experiences into educational approaches that foster expansive sense-making discourse practices in school settings. In this section, I describe the research setting, participants, and data sources and types. I also briefly describe the design-based research context of the study.

Design-Based Research

Design-based research (DBR) offers a productive approach for innovating, testing, and refining learning interventions in real-life learning environments (Brown, 1992; Collins, Joseph, & Bielaczyc, 2004; DBR Collective, 2003). The interventions that are tested through DBR methods represent specific "conjectures about learning within educational designs" (Sandoval, 2004, p. 222); these conjectures (and the specific task structures and lesson materials, participation structures, and tools and material support elements they embody) can provide an empirical framework to help test designs and advance theoretical understanding.

Design Conjectures. A design conjecture map (Appendix B: Conjecture Map) for this research (Sandoval, 2014), in tandem with the findings from the sources of evidence detailed below, helped derive the design principles detailed in Chapter 2. The following are high level conjectures for the larger research project:

- Broadening teachers' abilities to enact productive instances of argumentation with students is facilitated by experiencing the central role of argumentation in science and strategies for transforming student discourse in classrooms
- Scientific argumentation as a practice involves the coordination of claims with evidence through reasoning, but also involves sense-making through collaborative and discursive processes of critique and deliberation

These conjectures are embodied through tools/materials, task/activities, and discursive practices that are summarized in Appendix B and detailed in Appendix C: Argumentation Work in the TSP Professional Development Workshop. The list of reflective prompts for teachers to respond to in their daily journals was a key tool that scaffolded their observations and anchored later discussions. These questions included two specifically focused on power and equity:

- How does power/position influence who is talking or whose comments are being considered?
- What would a classroom that focused on including and valuing student argumentation and sense-making look like? How can conversation in classrooms be more equitable?

Teachers were also asked to select one exemplar of argumentation (and provide context, description, and an analysis) to share with others. There were four main mediating processes in the design: (a) A vision of contextualized, epistemic argumentation practices developed through evidence that teachers have gathered through their participation in scientific practices and processed with their peers; (b) Experiencing discourse strategies modeled in the workshop from the perspective of a learner; (c) Opportunities to create/modify lessons to include elements of productive disciplinary discourse and uncertainty; and (d) Collaborating and reflecting with a community of peers and Lead Teachers. The outcomes that the design aimed to achieve were both epistemic and pedagogical: That teachers would have a broader understanding of "what counts" as argumentation and the epistemic role argumentation plays in science, and that teachers would emphasize knowledge-building through argumentation by creating opportunities for productive uncertainty, collaborative sense-making, and deliberative discourse in their classrooms. An additional outcome related to decentering teacher power emerged during the course of the research: Teachers consider how teacher moves, authorized speaking rights, and classroom structures influence opportunities for student voice and argumentation.

Setting

The Teacher-Scientist Partnership (TSP, a pseudonym) is a professional development program for secondary school science teachers embedded in a scientific research institute of over 3,000 people. Since 1991, the TSP has been offering teachers direct experience in research labs, curricular support, and access to molecular biology equipment and supplies. The program has developed an active community of over 550 participants. The 2017-2018 program included: (1) An intensive 13-day Summer Session in which teachers worked closely with each other, TSP staff, and scientist mentors to gain skills and expertise in molecular biology and to discuss scientific argumentation. This included 5 days of direct experience embedded in a research lab with a mentor and attending lab meetings ("lab placements"). The placements were determined by the mentor scientists, who selected teachers to work with from the applicant pool; (2) Time and assistance during the session to develop a curriculum project related to the program that was designed to be used in their classrooms; (3) Access to an extensive kit equipment loan program so students could conduct hands-on molecular biology investigations; and (4) Additional meeting times throughout the school year to prepare teachers for the experience, reflect on its impacts, and bring the larger community of teachers together. The additional meeting times included a full day orientation, a follow-up reflection day at the end of the school year, a kit-sign up day, and four topical one-day workshops. The program also included "Lead teachers" - TSP teachers who participated in the summer program in prior years and who returned to help teach some of the content and to serve as trusted intermediaries between new teachers, staff, and scientists. Lead teachers also visited participants in their lab placements to ensure that they were having productive and positive experiences and helped participants develop lesson ideas based on the research experience.

Participants

All 21 TSP cohort 2017-2018 teachers and all four lead teachers agreed to be included in this study. The cohort was overwhelmingly white and female (as is the general teacher population in the area this study was conducted). Only three teachers identified as non-white (all

Asian) and only one identified as male (although two lead teachers were also male). While 13 TSP cohort teachers had some prior research experience (often at the undergraduate level), 8 teachers had no prior scientific research experience. The majority of teachers were high school educators and taught in public schools: three taught middle school and two taught in independent schools. Figure 2, TSP 2017-2018 Cohort Years Teaching, shows a fairly even distribution of teaching experience in the cohort, with 11 teachers having more than five years of experience and 10 teachers less than five. Figure 3 and Figure 4 illustrate demographic characteristics of the students of participating teachers. Figure 3, Estimated percentage of students of 2017 TSP teachers who qualified as an underrepresented minority in STEM, eight teachers reported that over 50% of their students are underrepresented. Similarly, Figure 4, Estimated percentage of students of 2017 TSP teachers who receive free or reduced lunch, shows that nine teachers report that over 50% of their students receive free or reduced lunch (often used to indicate low socio-economic status).

Data Sources and Methods

I collected data to try to understand teachers' initial conceptions of argumentation, note changes in their conceptions over time, and assess how those conceptions influenced their thinking about their classroom practices. I captured teachers' written reflections in their lab notebooks, their discussion about those reflections, as well as interview and survey data. Small hand-held audio recorders were used to record the discussions, which were later transcribed. I also wrote field notes/analytical memos (Heath, 2008) throughout the research process, which became part of the data corpus. The overall strategy for collecting and analyzing data is presented in Appendix D: Research Questions and Data Collection. An overview of elements of the professional development that addressed argumentation, as well as the specific prompts that were used to generate data, are provided in Appendix C: Argumentation Work in the TSP Professional Development Workshop. I analyzed transcripts from over 17 hours of discussions and interviews using Dedoose® analysis software and reviewed over 1,550 pages of writing in lab notebooks.

Participant self-documentation and artifacts. Teachers had multiple opportunities to record and reflect on their experiences in the laboratory setting. The workshop incorporated a "micro-ethnographic" approach, asking teachers to observe discourse with an eye toward the culture of science and to identify examples of argumentation and sense-making in their journals. They were also asked to make observations about power. (See Appendix C for a complete list of questions).

The journals served as one type of material scaffold to mediate discourse among teachers. After their lab experiences, teachers shared these examples with one another and discussed why they selected them for discussion. In their accounts, they wove together their reporting of what they observed with ideas for how to bring argumentation and related practices back to their classroom communities. These written reflections provided information about how participants were making sense of their experiences and provided information about what aspects of the professional development were most impactful (Barab, Thomas, Dodge, Squire, & Newell, 2004). Teachers wrote answers to the same prompting questions used in focus group discussions in their journals before participating in the semi-structured conversations at the beginning and end of the workshop. Posters made by teachers during the workshop also served as data.

Reflective discussions. Teachers participated in both small and large group discussions (Merriam & Tisdell, 2016). The small focus/discussion groups of 4-5 people met three times during the course of the program: before and after their summer laboratory experience and at a follow-up Reflection Day near the end of the following school year (May 2018). Discussions allowed teachers not only to share their experiences, but to process them with others. Lead teachers used a structured protocol to facilitate the discussions and ensure the participation of all group members: each teacher had 4-5 minutes to share their reflections, and once everyone had shared the discussion was open. I also recorded smaller discussions and conversations that were conducted as part of the TSP program (for example, between teachers who were developing lessons and their lead teachers) and large-group discussions (including a culminating debrief at the end of the summer). My field notes/analytical memos (Brice Heath, 2008) related to the discussions also served as data.

Interviews. Semi-structured interviews (Merriam & Tisdell, 2016) with selected participants helped clarify comments and member-check assertions. Originally, I had not planned to conduct individual interviews, but decided to talk further with two selected teachers based primarily on their clearly evolving understandings of argumentation during the workshop: Melissa and Anna worked on a project that directly reflected a change in their understanding of the potential for using argumentation and discourse practices in their classrooms and their ideas exemplified the thematic findings that were emerging across the cohort. Melissa was also interviewed the following spring after she had the chance to enact her lesson in her classroom.

Surveys. Teachers completed surveys at the end of the summer professional development and at the Reflection Day the following May. In addition to demographic information, teachers provided feedback and reflections on their experience to triangulate the focus group and interview data. The surveys included both program evaluation questions and questions focused on this research. They included Likert-scale and open-ended questions. Data from the open-ended questions was included alongside text and discussion data for analysis.

Data Analysis

To inductively code participants' written data and audio transcripts of interest, I used a modified grounded theory approach (Glaser & Strauss, 1967). I used open coding to flag units of potentially relevant data (Merriam & Tisdell, 2016). My research questions and theoretical perspectives (which evolved over time as I found myself deeper in the analysis) also guided my approaches to making sense of the data. I later used axial coding to relate categories to one another to refine category schemes (Corbin & Strauss 2015). My initial analysis of the data corpus focused on looking at teachers' views on argumentation, specifically argumentation in the lab, general definitions, and ideas about incorporating it into the classroom. I also looked at data related to teacher's views on communication and the role of discourse in science overall and in the labs in particular. A large group of inductively generated codes reflected teachers' considerations related to aligning elements of their workshop experience with their classroom pedagogy (for example, their intent to change classroom discussion, the current state of their classroom teaching, or specific ideas for changes they wanted to make). Another large group of codes looked at teachers' own professional growth, including ideas about science, ways that they thought about their students, their experience as learners, and the barriers to change they noted. These results of this analysis are explored further in Chapter 2.

I realized that there was an interesting subset of data related to social power in the context of sense-making and learning. My initial codes related to power focused broadly on "power dynamics in the lab" and "power in the classroom." These often co-occurred alongside other codes such as "feeling like a student" or "social sense-making" in excerpts. I developed a memo to process the excerpts related to power, and began to categorize findings into the following groups: "Observing power dynamics/How the PI influences culture of discourse"; "Teacher feeling like student helps teacher think about power and how difficult it can be for students to speak up"; "Teacher taking themselves out of the conversation more: 'stepping back'"; Elevating student voice and students as a resource for each other's learning"; Increasing equity in student talk (no one knows the 'right answer'); and "Even though the PI has power, everyone on the team is expected to contribute: Collaborative dimension of science influences classroom structure." After discussing the memo with professional colleagues, I subsequently focused on four aspects of power: (a) Positions and power; (b) Power Reflected in Arrangements of Physical Space, (c) Shifting Epistemic Authority; (d) Engaging students' equitable contributions to sense-making. I then went back through all the power-related data again to confirm that these aspects were reflected in the corpus to look for disconfirming evidence, and to select representative findings to highlight. These four aspects of power became the original outline for the analysis portion of this chapter, which I later modified to combine the closely related ideas of shifting epistemic authority to students and engaging their equitable contributions to sense-making.

Researcher Positionality. I have a deep connection to TSP, having served as a participant over 20 years ago as a beginning science teacher. However, I am now serving as the Director of the TSP and the designer of this study, so there is a danger of disproportionately painting the TSP in a positive light. I tried to counter this by looking for trends in surveys across the whole cohort as well as in discursive and written interactions, and by actively seeking disconfirming evidence (Erickson, 1986). I serve as program director and select people for participation in the program (although participation is also contingent on being selected by a scientific mentor), so there is a natural power differential between the participants and myself. They may have also experienced the desire to provide information that would align with my interests and hopes. While participants did receive a stipend, they were not tied to assessments or evaluations of the teachers' performance. I tried to be transparent in addressing such issues from the onset and was committed to being open and responsive to concerns.

Validity. I triangulated multiple methods and data sources to confirm my interpretation of the findings and shared my analysis with the participating teachers to member-check my interpretations (Merriam & Tisdell, 2016). This happened through discussions with individual teachers and lead teachers, and in a whole-group discussion in the final Reflection Day. I also engaged colleagues in my university academic research group as informed experts in order to provide checks on my interpretations.

Findings and Analysis

In my analysis below, I first examine how teachers reflected on their own position and power through their experiences in the research lab. I discuss how teachers identified both with the Principal Investigator (PI) / Lab Director as research group leader and with their students (as a participant in a specialized and often overwhelming setting). They also reflected on what bearing their experiences had on power relationships in their classrooms. I then focus on their reflections about how physical arrangements of speakers can influence power dynamics. In order to more closely examine teachers' conceptions of power and student discourse in school settings, I also investigate how teachers thought about the connection between their own authority and student contribution in the classroom. In analyzing authority, I examine teachers' reflections on how they control, convey, and manage what counts as knowledge in science ("epistemic authority"). In analyzing student contribution, I focus on how teachers think about their role in managing student participation and voice, particularly how they aim to provide more opportunities for equitable sense-making contributions from students. In analyzing the findings, I draw on several strands of prior research to operationalize the concepts of D/discourse and positioning, including the conceptions of power highlighted in the work of Cornelius and

Herrenkohl (2004), first principles of learning in Fostering a Community of Learners (Brown & Campione, 1994), and Productive Disciplinary Engagement (Engle & Conant, 2002).

The analysis follows the cohort of teachers as they reflected on their research experiences during the summer session, and then met up again at the end of the following school year at a Reflection Day. As part of their experience, teachers were asked to observe instances of argumentation in research settings and note how power and position influence who is talking or whose comments are being considered (see Appendix C: Argumentation Work in the TSP Professional Development Workshop). Teachers viewed their experiences in research settings through the lens of their professional expertise and their knowledge of student learning, and they switched seamlessly back and forth between talking about the research labs and their classrooms.

Results from a survey at the end of the school year revealed that the majority of TSP teachers believed they had made shifts in both their classroom discourse structures and in their thinking about their own role. This was true even for teachers who had some level of prior research experience. Even though over half of teachers (62%) had conducted research previously, creating a specific focus on argumentative discourse practices within the workshop appears to have made a broad impact. Across the cohort, nearly 80% (15/19 survey respondents) of teachers noted that their observations of argumentation in their research labs impacted discourse in their classroom and 94% (16/17 survey respondents) agreed that time in the lab influenced how they thought about their role as a science teacher in the classroom. Teachers elaborated on the specific changes they made during discussions on Reflection Day and in open-ended responses to the end-of-year survey.

Social Positions and Power

Teachers reflected on the importance of power and position throughout their experiences in research labs and in the professional development summer workshop. This was manifested in several ways, including the ideas of the teacher as analogous to a lab PI and the teacher as analogous to a student in their own lab experiences.

Teachers in positions of power as "Principal Investigators". Some teachers saw their role as similar to that of a laboratory PI and connected that role to a responsibility for fostering productive sense-making dialogue through argumentation. This idea was something teachers highlighted themselves as a result of their observations; it was not presented to them directly in the workshop. For example, Mollie wrote on her end-of-year survey that she wanted to serve more as an overall guide and give students more autonomy in experimentation: "I kept thinking of a principal scientists' role within the lab. I may guide where the research goes but leave it to the other researchers to run experiments. I wanted to emulate this more." Melissa made a direct analogy between the roles of PI and teacher in her lab notebook:

> The PI challenges the research, as a teacher challenges the student to clarify his/her explanation including relevant and specific details. I chose this example because it has a direct connection to the classroom: teacher (PI) with more knowledge questioning and making suggestions to others in the learning community (lab). Teacher /PI soliciting ideas from others (students). (Melissa, lab notebook)

For Melissa, both the PI and the teacher are responsible for the overall group and are more (generally) knowledgeable than their team or class. As such, they play a role in challenging, questioning, and making suggestions to their lab members or students. Melissa also called out how, in both roles, the importance of soliciting ideas is key in moving the work forward and went on to note the connection to sense-making: "Even if a finding (or discovery) is made by an individual, its importance is better understood when shared with others for their response, input, insights. 'Sense-making' is more accurate when constructed with input from others. I need to build ways in the classroom for students to have more peer communication." Melissa acknowledged her intent and ability (as a person with power in the classroom) to "build ways" to enable productive and collaborative talk in her classroom. She connected her role as Teacher/PI to the importance of establishing ideas for students to think about and talk about, noting how important peer communication and input from others is in sense-making. This idea of being more of a guide/PI in the classroom and less of an expert and disseminator of information represented a positional shift in how Melissa thought about her role in the power dynamics of her classroom (Harré et al., 2009), and one that was closely associated with discourse shifts.

Anna also emphasized the analogous role of the PI and teacher, and wrote the equation "PI=Teacher" in her notebook, followed by the following jottings:

> Consider how the teacher sits with/stands in class and interacts with students as a driver of communication. Power cards - holding communication keys - how to disseminate to students, why when, how. Why give them away, what purpose will it serve, who will benefit, who will lose. How to distribute: evenly, over time, abruptly, give/take? When? Slow release? Certain tasks, high risk vs. low risks? When to give away control of the conversation? (Anna, lab notebook)

In her jottings, Anna's covered a broad set of ideas related to power and classroom talk. She noted that teachers can drive communication, in part through their physical positioning and in part through ceding control of discourse ("disseminating power cards" or "communication keys") to students. Anna also reflected that her pedagogical choices related to student discourse and communication would have varied impacts on her students, benefiting some and perhaps constraining others. As such, she considered her power to influence equitable discourse practices in her classroom and what the implications might be for privileging certain voices over others or trying to provide equal opportunities for communication. She considered the choices she might need to make related to the timing of providing discourse opportunities, the type of task, or the level of associated "risk". Her concerns reflect an understanding of the broader implications of her power to shift language-in-use in the practices of the classroom. Thus, the opportunity for teachers such as Melissa and Anna to observe PIs in the socially constructed situation of the lab experiences instigated reflections on their own positions of power in the classroom.

Teachers in positions of less power as "students". While teachers identified with the role of the PI in the lab, the experience of being in a new environment as learners also helped them identify with their students. Putting teachers in a student role to experience lessons and activities is a common teacher professional development strategy. However, spending a week in a completely unfamiliar environment surrounded by professional scientists, immersed in learning challenging scientific concepts, and using new equipment and techniques accentuated feelings of being a student. These experiences as the individuals with less power and control in a learning environment made a deep impression on teachers and caused them to consider how they might change their own classrooms to better support learners (for example, by providing more classroom opportunities for processing information). Some teachers explicitly referenced feeling overwhelmed in the lab setting – much like their students might be in class – and reflected on their own anxiety about speaking up with questions and keeping up with complex information. They also noted how discursive meaning-making with other teachers had helped them, leading them to consider the value of having students do likewise. For example, Melissa shared:

> I was definitely in the role of feeling like I was the student who was the one barely hanging on by their fingernails. That was a very valuable experience for me. It definitely gives me empathy for those kids whom I'm inclined to be most concerned about in my classroom...I had a real personal experience of what that's like...if you were an adolescent, would you feel comfortable asking a power figure a question? It was hard for me and I just thought, you know, kids are going through this every day. (Melissa, summer small group discussion)

Melissa also shared how important it was for her to be able to talk and process what was happening with Raven (another teacher who was also placed in the same lab), whom she called her "hash-it-out partner":

> I don't know how I would have gotten through this week w/o Raven…What has been clearly demonstrated (internalized) for me is the critical role of dialogue...I find myself getting lost in the details of the materials, measuring, tools, techniques and scrambling to "keep up." In the process I lose the connection to the purpose/objective. I know this happens for kids too!" (Melissa, lab notebook)

Melissa's experiences pointed to the difficulties that students have in asking questions of "power figures" and the social risks of doing so in in front of others, as well as to the value of allowing students opportunities to build understanding through dialogue with "hash-it-out" partners. As she described, students can easily lose the purpose and objective of the work without opportunities for sense-making with others.

Randi also related her insights of feeling like a student though her lab experience, and how important it was to create time for students to be able to process new information. After the lab experience, Randi mentioned how easy it was for things to make sense when they were explained by her mentor but how later she realized she hadn't really understood or retained it. She made a connection to how her own students must feel:

> We've all had that experience I think this past week. It all makes sense when your mentor is explaining it to you...and you think, "Oh ya I've got this" and then you try to re-create it later and it's gone. How often do we do that to our students because we've explained it so clearly and they're like, "Oh ya I get it, I get it, I get it."? But if it stops there, it doesn't become theirs…(Randi, summer discussion group)

Weaving between what she observed in the lab, her own experience as a learner, and her experiences as a teacher, Randi went on to note the importance of having students reflect on, process, and use information in order for it to become meaningful. Even though she had been a professional research scientist prior to teaching, Randi still felt like a student in her new lab setting, which gave her some empathy for the classroom experience of her students.

The lab experience provided teachers with opportunities to both relate to those in power and in charge of managing a group (the PIs) as well as those who are new to an intellectual community (their students). This perspective allowed teachers to have a view into their own position, role, and influence as well as consider how they position others (Harré et al., 2009). In thinking about their role as similar to those of PIs, teachers realized the power they have in determining the structure of discussions and in creating the broader discursive culture in their classrooms. They also noted their ability to encourage peer communication and sense-making through specific discourse moves (such as soliciting ideas, questioning, or offering suggestions). In thinking about their experience as students, teachers gained empathy for how overwhelmed students might feel by an onslaught of information, how difficult it can be to ask a person in power a question, and how processing with others is key to building deeper understanding. In considering these positions and their implications, teachers made connections between language and its influence on the broader Discourse of the social and cultural world of the classroom.

Power Reflected in Arrangements of Physical Space

Teachers also noted that how the distribution of power was reflected and communicated through the spatial arrangements of participants in discussions. Jolene contrasted two conversations she witnessed among scientists and noted how the different physical arrangements created by leaders influenced the group dynamics and the ways in which power was distributed among the group. In the first group, the PI was sitting in the back of the room eating his breakfast with feet kicked up and was not paying much attention ("He was asked a question at one point and was like, 'Oh you're talking to me?' So that dynamic was very interesting…)." The scientist presenting was facing three people at a table who were exclusively involved in discussing the scientists' work, while there was a "whole group of backseat people who didn't speak a word." Jolene contrasted this with another group meeting where everyone was seated at a table "very equally distributed," including outsiders such as herself. She reflected that:

> ...The leader at the top has such a profound effect on the group dynamics. I was reflecting on that as a teacher how we all are at the front of our room leading and how the

> personality of the teacher just has that effect throughout. (Agreement from others, "Yes, yes!") There were still people who didn't talk who were sitting around the table, but it felt very different than the people who were in the back of the room not talking at the other meeting. It was also just a very different style of meeting like, let's all read this, try to make some sense of it. (Jolene, summer workshop discussion)

Jolene established a parallel between leaders in the lab and in the classroom, and described how in each case the cultural aspects, particularly the leader's personality and the way they choose to arrange space, has profound implications for "effect throughout." In particular, she noted the suitability of an equitable arrangement (such as everyone seated around a table) for sense-making discussions. Another teacher in Jolene's discussion group (Debbie) built on Jolene's ideas, noting: "Where you are standing in your classroom, how you have your students arranged, and how you lead that discussion…is going to make an enormous difference. Sometimes you forget that. At least I know I do."

When Mike, a lead teacher, asked about how Jolene incorporates those different types of physical layouts into her classroom, she noted that both types are appropriate for different times. There are times when teachers might want students to feel that they are on an "equal playing field" - where power is more levelly distributed - and that a teacher's physical position can help communicate that students' contributions are important.

Melissa also shared her thinking about the physical structure of the classroom, the location of the teacher, and the resulting impacts on students. She noted that her mentor scientist was also experimenting with different formats to increase participation in meetings.

> I really began thinking about the effect of an informal versus a formal format and how teaching, so much of the time we're in front of the room or we're circulating, but we're not sitting in a circle very often. It's laborious to set up your classroom and have 32 people in the circle like we did with the [modeled practice] science seminar. This idea of, "How do you get everyone contributing?" really was provocative for me in watching this dynamic in the meeting, because [the scientists] were even playing around with, "How can we get more people to feel comfortable participating?" (Melissa, summer workshop discussion)

Gore (1995) highlights “distribution” as one dimension of how power is enacted in classrooms. This includes the ways students are organized (the ways students are separated, grouped, or arranged in certain spatial patterns). The physical distribution of students and teachers makes visible and reinforces messages about power and authority. Melissa noted how the predominant mode for teachers is “in front of the room or circulating” and recognized that physical arrangements can influence student contribution. For teachers such as Jolene, Debbie, and Melissa, participating in a variety of discursive situations in the research setting and processing their thoughts with one another afterwards helped them consider how physical arrangements of individuals (how the teacher/leader positions themselves relative to the rest of the group, but also how group members are positioned relative to one another) can communicate messages about who has power in the setting and who is authorized to contribute. In particular, it foregrounded the idea that different instructional arrangements can help shift the shared focal space and attention - from all students focusing on the teacher to focusing on each other (Goodwin, 1994; Kendon, 1990). It also helped them consider what spatial characteristics of the “figured world” of the professional lab setting they might want to represent in their own classrooms and what purposes they might want to employ them for (Holland et al., 1998).

Shifting Epistemic Authority: Engaging Students’ Equitable Contributions to Sense-making

In the following section, I examine teachers’ changing conceptions of power as shifts in their role as authority figures and in the new ways they thought about student contribution. In considering authority, I focus on teachers’ roles in conveying epistemic authority—or what counts as scientific knowledge and how that knowledge is obtained and warranted. In the larger Discourse of school science, teachers’ authority and control over speaking rights also convey who gets to have ideas about science and who gets to speak those ideas. Thus, pedagogical changes that scale back teachers' epistemic authority are tightly coupled to those that help increase students' equitable contributions to sense-making.

Shifting epistemic authority - teacher attitudes. In traditional teaching situations, educators maintain control of their authority not only through classroom management strategies but also through serving as an expert source of knowledge. One powerful shift that teachers made was to move towards co-managing epistemic authority with students, engaging their ideas as valuable and giving them an active role in building knowledge. Teachers who talked about shifting their authority in the classroom often employed metaphors of "stepping back," "creating space," "letting go," or being more of a "guide." The following are relevant excerpts from the end-of-year survey responses to the question, "Did your time in the lab influence how you thought about your role as a science teacher in your classroom?"

- [I] give students more time to discuss together without my influence, recognizing student need for autonomy within the confines of my classroom; taking myself out of the role of authority and expert in order to provide students with more opportunities to grow. (Randi)
- I have taken a very definite step back in my classroom this year, attempting to draw my students forward into a more direct and active role in their learning. (Jan)
- My lab experience previously had been pretty limited. This experience helped me think about being a teacher more as a guide through the science. I spend more time now asking students what they think and probing them for explanations about what they are observing. (Louise)

These teachers mentioned creating space for students' autonomy and growth by ceding some of their authority and referenced specifically how the lab experience helped them reflect on taking on a different role and position in the classroom.

Below, I discuss in more detail the experiences of teachers in the lab and their classroom enactments in the classroom. The examples fall into four main categories (Table 3: Shifting Epistemic Authority: Engaging Students' Contributions to Sense-making). In each case, a pedagogical instantiation (what the teacher does, or the classroom change they implement) is coupled to how students are positioned differently. In addition to positioning students, teachers' choices about D/discourse also influence how the discipline of science is positioned.

Table 3: Shifting Epistemic Authority: Engaging Students' Contributions to Sense-making

Dimension of Power Shift	Teacher Pedagogical Move	How Students are Positioned	How Discipline is Positioned	d/Discourse	Related Constructs from Literature
Discourse Structures: Shifting discourse structures to expand who has speaking rights and who can challenge the ideas of others	Creating opportunities and participant structures for collaborative student argumentation and sense-making (such as seminars)	Students are capable of meaningful, evidence-based discussions Students can evaluate and critique one another's ideas	Scientists engage in "figuring out" with each other by critiquing one another, attempting to persuade others using evidence and reasoning, and by making sense of findings together	Changes in language-in-use help create changes in Discourse in terms of how students and teachers see their roles/identity relative to discipline and each other	FCL: Dialogic base PDE: Accountability COP: Persuasive Discourse
Teacher Epistemic Authority: Scaling back teacher epistemic authority to promote student ownership of ideas	Not providing quick right answer or immediately correcting misconceptions Allowing more student "airtime" for discovery, processing, and reflection	Students' ideas matter and deserve to be heard Students' experiences and conjectures can contribute to larger sense-making	Science is not about providing correct answers to known-answer questions	Changes in language-in-use help create changes in Discourse in terms of how students and teachers see their roles/identity relative to discipline and each other	FCL: Active, strategic nature of learning), Metacognition, Agency PDE: Authority COL: Ownership of ideas
Science Learning Community of Practice:	Emphasizing how an individual is an important part of the larger group	Students are resources for each other (and the teacher)	Science is social; the work of scientists happens in communities	Changing game of school as project of	FCL: Community of practice

Fostering a culture of community and collaboration				individual mastery	
Activity Structures: Shifting activity and group structures to promote equitable participation	Implementing practice-based activities that generate productive uncertainty (Manz, 2018)	Every student has valuable contributions to make within activity (sharing power between students)	Problems and challenges in science benefit from the diverse thinking and contributions of participants	Changing game of school as project sorting and ranking students	FCL: Legitimization of differences, Contextualized and situated PDE: Problematizing, Resources IPT: Interpretive Power of Teachers

FCL: Fostering a Community of Learners - First Principles of Learning (Brown & Campion, 1994; Brown 1997)
PDE: Productive Disciplinary Engagement (Engle & Conant, 2002)
COP: Conceptualizations of Power (Cornelius and Herrenkohl, 2004)
IPT: Interpretive Power of Teachers (Rosebery, Warren, & Tucker-Raymond, 2016)

First, I discuss how teachers created space for student talk, positioning their students of capable of managing a productive and meaningful conversation. Second, I provide examples of how teachers restrained their power as a dominant voice and resisted the urge to quickly correct misconceptions and answers, positioning students as having consequential ideas. Third, I discuss teachers' desire to create a culture of participation and collaboration, positioning students as resources for each other. Finally, I explore how shifts in practice were connected to enhancing equitable participation, positioning each student as capable of valuable contribution and acknowledging the unique resources that they bring.

Creating space for collaborative student sense-making: Positioning students as capable of discussing ideas with others. At the end-of-year Reflection Day discussion, Michelle and Sandra shared specific examples of how they had altered instructional and discourse structures in their classroom to provide more epistemic authority and control to students.

Michelle: "I ended up not managing the discussion". Michelle did a heart dissection with students, but instead of telling them how to dissect the heart and what the parts where, she asked them to hypothesize how blood flows. Students made claims based on data such as the measurements they made of the thickness of the internal structures. She then had them use red and blue pipe cleaners to model the flow of oxygenated and deoxygenated blood. After she had questioned them and discussed their work, she introduced some new vocabulary for the concepts they had been working with and followed up with a lab meeting seminar discussion. She noted that she was not particularly prepared for the discussion but decided to let things unfold, was pleasantly surprised at the results, and intended to use her new strategy in the future.

> Michelle: It was one of those things where I didn't really plan the lab meeting…I ended up not managing the discussion and just letting them talk about their reflection questions that I left on the board…I'm just gonna sit here and I'm gonna not do anything and see what happens.
>
> Jeanne: Was it hard to stay out of it?
>
> Michelle: Yes, but it was so much better because when I would let them sit in silence, some kid would just ask some brilliant question after like 30 seconds of silence because they had time to think about it…So now that's my strategy and it's way better. (Michelle, Reflection Day discussion)

Sandra: "I took a step back...and it was amazing". Sandra also talked about stepping back in discussion and making space for students to use evidence to engage in argumentation to resolve conflicting ideas.

> I have kids model what they're thinking about on their whiteboard. So, they've taken all this information, they've gone back and revised their models and then come up with a final model...the next thing to try is to get them engaged in argumentation. I had one class [where students] already feel comfortable around each other and the classroom is already safe, and they had conflicting ideas…I took a step back and I said, "You guys need to find consensus." Then I just didn't do anything, and it was amazing...They argued it out and they knew that they had to use evidence from the activities that we had done, and it was kind of incredible. (Sandra, Reflection Day discussion)

Brown and Campione (1994) highlighted the importance of a dialogic base within the classroom where discourse is shared, and meaning is negotiated and defined collectively through talk. Michelle and Sandra expressed excitement and surprise about the capabilities of their students that were revealed when they granted more authority for collective sense-making to students, using terms such as "brilliant" "amazing" and "incredible." In stepping back from their role as "authority and expert" they broadened who "counts" as knowledgeable in their classrooms, elevating the voices and ideas of their students. In order to do that, they needed to ensure that students had the opportunity to exchange ideas with one another by creating a broader discourse space. These actions required teachers to trust students, acknowledge the strengths that they bring, and to position them as intellectually capable of sorting through scientific ideas with one another.

Sandra highlighted the importance of evidence in students' argumentative discussions, as a way for conflicting ideas to be evaluated. By allowing students to rely on evidence in making their persuasive claims, Sandra sent a message about disciplinary work: that scientists engage in "figuring out" by critiquing one another, attempting to persuade others using evidence and reasoning, and by making sense of findings together (Engle & Conant, 2002). Persuasive discourse is one conceptualization of power and that "certain ways of communicating can in themselves affect the relationships of power among people" (Cornelius & Herrenkohl, 2004, p. 471). While the authoritative discourse of traditional classrooms requires students to cede their own power in evaluating claims and accept the teacher's authority over the subject matter without question, in disciplinary and academic settings colleagues evaluate claims of others and have the power to decide what to accept and believe (Bakhtin, 1981; Cornelius & Herrenkohl, 2004). Sandra also noted that power issues can arise between students and tied that to the need for creating a safe discourse environment (issues of relationships between students are explored further in Chapter 4). These examples show how teachers altered the social and cultural dimensions of their classroom, creating opportunities and participant structures for collaborative student argumentation and sense-making. In doing so, they positioned themselves and their students in new ways, expanding students' speaking rights and ability to challenge the ideas of others.

Stepping back from providing the "right answer": Positioning students as having consequential ideas. Randi and David also shared experiences from the school year that illustrated how they stepped away from serving as the primary intellectual authority in their classrooms. Randi pulled back from immediately correcting student misconceptions with a "right answer," whereas David stopped being the primary source of critique of student work during student presentations. Both emphasized the intellectual perspectives and resources that other students can contribute to help shape the understandings of their classmates. As Smith, diSessa, and Roschelle note, students' prior conceptions can serve as productive resources for growth and more refined knowledge and understanding (1993).

Randi: "I have pushed myself to let the misconceptions play out." Randi wrote the following in response to a prompt asking teachers to provide an example of how their thinking about communication in science and argumentation as a practice changed since they started the workshop:

> I have found that giving students more time to discuss/argue with each other in class is strengthening their ability to communicate their ideas. I have personally found this very challenging because my instinct is to correct misunderstandings as soon as I hear them. Instead I have pushed myself to let the misconceptions play out between students as they debate and argue their points regarding a specific lab or lesson. I have observed students become much more persuasive when I avoid inserting myself in the dialogue…in general it has increased the quality of dialogue and communication in my classroom…(Randi, end of year survey)

Randi noted how difficult it was to counter the instinct to correct misunderstandings or misconceptions. But by holding her own concerns back, she observed that the students were able to focus on their persuading others and "debate and argue their points." Randi observed that students not only grew in their ability to communicate ideas, but also that the overall quality of discourse in her classroom improved.

David: "I was the main input students had in developing their thinking...now it is all my students." David created discourse opportunities that allowed him to take a step back from being the primary source of feedback for students and instead allow students to be intellectual resources for one another. In his end-of year survey, he remarked that focusing on argumentation in the summer workshop helped him see how important that practice was for his students. Once back in the classroom, he instituted a routine for his biotech students to present lab results at least quarterly. He noticed that they had become more attuned to how to interpret data and present it, as well as defend their results and conclusions. He also commented that students became more open to the critique, feedback, and interpretations of their fellow classmates, and began to recognize that bias can be a part of science. Moreover, they could listen to each other's ideas and not be threatened by alternative interpretations. Significantly, he noted that "*Prior to [TSP], I was the main input students had in developing their thinking in science. Now it is all my students* —at least in my biotech class" (emphasis added). By providing students with the opportunity to build their understanding through challenging each other's ideas, David made visible both the importance of argumentation in building scientific knowledge and the idea that the teacher is not the only "input in developing their thinking". Students can be intellectual resources for one another, and in doing so, reflect the ways in which scientists interrogate each other's ideas and theories in an effort to minimize bias. In making these moves, David also shifted from projecting a positivist view of science (which holds that objective truths can be known through observation, experimentation, and logical proofs) to one more in line with post-positivist ones (where the thinking and input of others can help reduce bias and increase objectivity).

Brown and Campione (1994) emphasize that learning is active and strategic, and they highlight the important role of metacognition and reflection for student learning. In particular, the ideas of “self-monitoring and other-monitoring for the common good” and “reflective practice” (pp. 265-6) emphasize the significance of cultivating students’ awareness, ideas, and perspectives. Similarly, Engle and Conant (2002) highlight the importance of providing students with authority to address problems and Cornelius and Herrenkohl (2004) stress the importance of students’ ownership of their ideas. Randi and David illustrate how teachers made discursive changes to their classrooms to decenter their traditional role as the main intellectual authority to promote such ownership of ideas on the part of students. This included not providing quick right answers or immediately correcting misconceptions, and allowing more student time for discovery, processing, and reflection. These shifts allowed students to discuss competing positions, critique them, and marshal evidence in support of their claims, thereby disrupting the normative view that the teacher’s ideas are the only ones that truly count in the classroom. In doing so, teachers such as Randi and David positioned their students as having the ability to contribute to larger sense-making efforts by contributing ideas worthy of being heard. They also provided students with a chance to participate in social practices that position science as a discipline where knowledge is built and refined through discursive processes, not as one where “right answers” to known-answer questions are the most important feature. As a result of their research experiences and their efforts to align classroom discourse practices more with those of professional science, teachers not only sent messages about what science is and who gets to participate in it, but also shifted power dynamics in their classrooms in ways that positioned students’ ideas as important resources for learning.

Creating a culture of participation and collaboration: Positioning students as resources for each other. Teachers also noted the importance of creating a culture of collaborative sense-making similar to what they observed in the research setting. For example, Mollie shared that she asked her students to solidify their ideas individually and then have a conversation about their ideas, working collectively to create a model for a scenario. Significantly, she made a connection back to her lab experience when she noted (in her end-of-year survey) that, "This is similar to how separate scientists work collectively to further their research." Michelle and Anna also shared their ideas related to creating a culture that encouraged communication and collaboration, and the implications of that stance for student learning.

Michelle: "How can I get my students to talk to each other like this?" Michelle thought about student contribution in terms of developing a culture where students could talk to each other in ways that she observed them talking in the lab. She noticed how open the scientists were working together to question protocols or analyze results and jokingly referred to one post-doctoral student who seemed to mostly be involved in such conversations and nothing else. She also noted how open they were to suggesting ideas, even if those ideas ended up being wrong. She wondered, "How did that culture develop…How can I get my students to talk to each other like this?" Michelle's experience during the school year (the heart dissection and related seminar discussion mentioned previously) demonstrated her willingness to try some new talk strategies that allowed greater student participation.

Anna: The culture set by a "surfer dude." Anna was reminded of some of her existing strategies for engaging students as she observed the ways her PI approached the scientific team. She was discussing the question "How do you get [students] all to communicate?" with another teacher. Anna relayed her experience in the lab with a PI whom she called a "surfer dude" and who wandered around with his coffee cup engaging his lab members in informal conversation. She noticed how this easygoing, fluid interaction set the tone for the lab and for its communication style. Anna noted that she had a similar style to that of her PI, which she described as being mobile, observing, listening, and perhaps adding a question before leaving, which "kept the pressure off people" but at the same time "allowed him to be a part of their communication". Her vision of how to get all students to communicate centered on creating an environment similar to what she saw in the lab - one where students and teacher are often involved in informal interactions and where teacher serves as listener and questioner.

Anna stressed that the interactions she saw in the lab, and the realization that those interactions were key to scientific practices, made a significant difference in her teaching: "watching the way each scientist interacted with the others, and how essential that was, shifted how I approached the teaching in my classroom. *Instead of allowing students independent mastery exclusively, I focused on bringing students together as collaborative colleagues*" (end-of-year survey, emphasis added). Thus, part of the culture that Anna worked to established disrupted the Discourse of schooling that takes learning as a project of individual and independent mastery.

The idea of developing a culture and community of scientific practice within a school setting is a first principle of learning and cornerstone of the Fostering a Community of Learners work of Brown and Campione (1994). Within that work, the emphasis is on the shared values created within the community and many overlapping roles that students may take. After observing the actions of PIs and the culture they helped create, teachers reimagined how they could architect their classrooms to emphasize a community where students could more readily (and more equitably) contribute to discourse and sense-making. This included creating a relaxed, informal environment where teacher questioning and listening (as opposed to lecturing) were foregrounded and sustaining a culture where it is safe to suggest ideas, even if they end up being incorrect. By positioning students an important part of a larger group, who can serve as resources for each other, teachers such as Anna focused on shifting the Discourse of the game of school away from a project of individual uniform mastery to one where students are "collaborative colleagues." By privileging sense-making processes and allowing conceptual ideas to develop at a later time, teachers can attend to how students frame and build their own epistemological understandings (Hammer & Elby, 2002; Hutchison & Hammer, 2010). Such moves also result in the discipline of science being positioned by teachers as social, with an emphasis on how scientific knowledge work happens in the context of communities.

Broadening participation through practice-focused instruction: Positioning all students as capable of valuable contribution. Melissa (whose case is presented in more detail in Chapter 2) came to develop a strong appreciation for the importance of scientific practices through her lab placement. Her case demonstrates how a pedagogical shift in emphasis towards a focus on practice (more argumentation in her classroom) also broadened opportunities for equitable student participation. Below I highlight two aspects of Melissa's thinking about power dynamics in the classroom. First, I focus on translating the importance of contributions in team science to her classroom. Second, I describe her development and implementation of a practice-focused lesson that generated a productive level of uncertainty (Manz, 2018) and broadened student participation.

Melissa: "Whatever you are...each of you is expected to contribute." Melissa's experience in the lab helped her shift her ideas about student contributions to modify her practice. In her lab placement, she became aware of the importance of the contributions that each of the lab members made to the overall team effort of the research. She observed a lab meeting, where, despite the clear power differential between the PI and a lab tech who was presenting data, she felt that the tech "had equal play along with everybody else there. She was treated like a full member." Melissa recognized the lab as a distributed cognitive group, where knowledge is spread across individuals and where people have interrelated roles and complementary strengths (Newstetter, Nersessian, Kurz-Milcke, & Malone, 2002). In addition, people at various stages in their scientific careers have opportunities for increasingly central participation in activities such as lab meetings (Lave & Wenger, 1991).

After the school year, during an interview, Melissa reflected back on how sitting in the lab meeting and watching the PI expect input was "really powerful" for her and changed how she started to think about lab groups in her classroom. She particularly noted that "whether you're a post-doc or grad student or whatever you are…You're a team but each of you is expected to contribute." When I asked her whether that was something she took away and was able to communicate to her students, she replied, "Yeah, that was kind of how I began to see lab groups. That you're a team but everyone is expected to contribute." Melissa outlined a clear parallel between the "team" that she saw in the lab and the way she viewed her student lab groups in the year after her experience. Significantly, she thought her week in the lab had a "huge bearing" on her actions during the school year:

> Melissa: Throughout the year it sort of threaded through my thoughts as we went into lab experiences and that was why, like, [I said] "Make sure you're not taking over because it means you're silencing the voices and thoughts of other people if you're constantly being in charge of everything and you're the only one whose hands are touching the material."
>
> Jeanne: You mean in terms of talking to kids about that and being more conscious?
>
> Melissa: About how to be a lab member, how to collaborate. It's a team effort.

Melissa was able to bring a vision of what it means to be a collaborative lab member to her students, and to encourage them to make sure that they were valuing each other's voices and input and also engaging in using materials and tools equitably. Importantly, she was also able to use her experience as a way to validate the approaches she was taking in her classroom with her students, telling them, "This is how it works in an actual science lab, and I really didn't know this until I went there and saw it."

Melissa: "Students were more on equal footing than in other lab activities." After her TSP lab experience, Melissa wanted to design an activity that would promote opportunities for collaborative sense-making and engage students in understanding the value of their own thoughts and ideas. Melissa referenced how modeling seminar-style discussion structures in the workshop had inspired her to shift some of the epistemic authority to their students. She described the experience of having participated in the seminar session as part of the teacher workshop (using results from a complex experiment) as a pivotal moment – which helped her think about letting students "go and do their own thing" in discussions, implying a step back from her own role in leading them:

> This is fertile ground for me because I haven't ever done the scientific seminar, and that experience was kind of watershed for me because it's like, ok, it's time, Melissa. I need to let students go and do their own thing and by the end of the year or the middle of the year, they're totally capable and I understand all their dynamics…not all of it but I know them well enough to do that. (Melissa, summer small group discussion)

Melissa underscored that once she knows students well enough and understands their dynamics, she needs "to let students go and do their own thing" in terms of taking responsibility within a sense-making discussion. She acknowledged that she is the one who needs to orchestrate this shift in authority. Melissa went on to try a seminar discussion with positive results in her classroom during the following school year. Building off of the idea of the value of student contributions to an experimental effort, Melissa created an opportunity for students to design their own experimental protocols. In small groups, students created procedures for extracting DNA from strawberries (a situation where there was no clear “right answer” that anyone knew). Afterwards, she commented on how both student engagement and equitable participation by a range of students increased:

> Tremendous student engagement on an experiment of their own design for which "an answer" was not known…Students were *more on equal footing than in other lab activities* and I saw considerable planning going into the experiment…I also saw *less "taking over" by stronger students, I think less assertive students felt a bit more at liberty to offer their ideas*. (Melissa, end-of-year survey, emphasis added)

The lab supported students from across traditional academic ability levels in contributing ideas for a procedure to try; the “stronger” academic students were not necessarily able to drive the team, as there was no clear right answer, and the less assertive ones had the opportunity to make a meaningful contribution (see Chowning et al., 2019 for a detailed description of the activity). In her design, she also noted that her lab experiences had pushed her to build in opportunities for student discussion:

> Due to my increased awareness of promoting student communication as a scientific practice I have been more conscientious about building opportunities for student discussion into lessons. My TSP project is the best example….[My] students prepared for and conducted their own mock "lab meeting." I provided guidelines but students ran their own meeting. (Melissa, end-of-year survey)

Melissa’s students had opportunities for equitable contribution both during the development of their protocols as well as in the discussion after the results (when the class tried to determine what would be the best procedure for the whole class to try). Significantly, students “ran their own meeting” - a clear demonstration of the the trust she placed in them to make sense of their results and have the authority to manage their own talk.

The shifts in activity and group structures that Melissa made helped promote equitable participation among students, demonstrating an important link between implementing practice-based activities and tasks that can generate productive uncertainty (Manz, 2018) and opportunities for equitable participation. As Melissa noted, opening up student agency in decision-making through the activity structure and emphasizing the resources that each team member could bring to developing a novel solution shifted participation dynamics to be more equitable (where students were more "on equal footing"). This potential for certain activity structures to change the Discourse of school away from a project of (re)producing known answers is coupled with opportunities for students to be positioned as having valuable contributions to make (Brown & Campione, 1994; Bruner, 1960). At the same time, she positioned the discipline of science as benefitting from the diverse thinking and contributions of participants (Bang, Brown, Calabrese Barton, Rosebery & Warren, 2016).

In summary, the findings demonstrate how TSP teachers made meaning of the experiences in research labs (and in the workshop) that had bearing on power relationships in the classroom. They particularly focused on areas related to student discourse and to their conceptions of their own role. Teachers identified both with those in power (the PIs) and with those traditionally less powerful in classrooms (their students). They were positioned as a learner in the lab experience, which afforded them both heightened awareness of their power in their role as teacher and empathy for the position of their students. They also considered how physical arrangements can communicate messages about power and can influence power dynamics in both lab and classroom settings. Teachers commented on the ways they subsequently shifted epistemic authority in their classrooms as they themselves stepped back while positioning students as knowledgeable and capable. In classrooms such as Michelle's and Sandra's, that meant seeing students rise to the occasion in ways that surprised them. Teachers also created opportunities for a broad range of students to contribute to sense-making by focusing them on working as members of a team and by creating structures and activities that supported more equitable participation in collaborative argumentation.

Discussion

This study investigated two questions about how teachers come to think about power and discourse in their classroom following experiences in research settings and the professional development workshop. First, I asked how secondary science teachers learn about power and its connection to argumentation and scientific sense-making discourse through their participation in research experiences. Second, I considered how teachers' observations in professional science research settings help them move away from hierarchical power arrangements and towards collaborative and equitable sense-making discourses in their classroom. From a design-based research perspective, I also considered how professional development could be designed to help teachers consider how their pedagogical choices can shift epistemic authority to students and promote equitable student participation.

This research was part of a larger study focused on expanding teachers' conceptions of argumentation through observations in research labs, discussion and reflection with peers, and participation in modeled examples of classroom discourse structures such as seminar discussions. The following were high level conjectures for the larger research project:

(a) Broadening teachers' abilities to enact productive instances of argumentation with students is facilitated by experiencing the central role of argumentation in science and strategies for transforming student discourse in classrooms.

(b) Scientific argumentation as a practice involves the coordination of claims with evidence through reasoning, but also involves sense-making through collaborative and discursive processes of critique and deliberation.

The conjectures were embodied through tools/materials that served as resources to promote classroom discourse as well as guide observation/reflection in the research setting. Included among the reflective questions that teachers considered and discussed were ones that asked them to consider how power and position influence discourse in the lab and what a classroom focused on equitable and inclusive student argumentation and sense-making would look like. Teachers also engaged in a variety of task and activity structures, including being immersed in a research setting, engaging in discussion/reflection with peers, developing curriculum resources to take back to the classroom, and participating in pedagogical modeling of classroom practices.

The conceptual ideas of D/discourse and social positioning help provide a larger framework for understanding the shifts that happened to teachers as they moved through the program and back to their classrooms. Prior research has identified first principles of learning within a Community of Learners (Brown & Campione, 1994), components of Productive Disciplinary Engagement (Engle & Conant, 2002), and conceptualizations of power in classrooms (Cornelius & Herrenkohl, 2004). These ideas helped clarify how D/discourse and positioning were operationalized in the settings of the study. Within labs, teachers identified with the positions of PIs as well as students, and also noted how positioning in space influenced discourse. Teachers wondered how they could imbue their classrooms with the kind of discourse structures and community that they observed in the professional settings. This resulted in an "epistemic motivation" to make the discourse practices in their classroom more reflective of how they saw knowledge-building and sense-making happening in the lab. Within classrooms, changes that teachers made in talk structures and language-in-use were connected to how they positioned themselves, their students, the discipline of science, and the broader Discourses of schooling. Shifting discourses and positions influenced social power relations but also contributed to the development of classroom cultures reflective of particular values and goals related to participation and learning processes (Brown & Campione, 1994). Below, I explore the implications of a practice-focused approach for decentering the teacher's role as sole authority, disrupting hierarchical power arrangements in the classroom, and desettling traditional taken-for-granted views of science.

Scientific Practices and Power

The shift in science education towards a more practice-focused approach reflects the importance of practices in scientific inquiry and investigation (NGSS Lead States, 2013) as well as educational research that theorizes learning as increasing participation in the practices of a community (Lave & Wenger, 1991). Many science practices have social components, such as the persuasive and sense-making dimensions of argumentation. In order for students to fully engage in argumentation in ways that reflect practices of the broader scientific community, they need classroom experiences that allow them to puzzle through problems and make meaning with others.

Power relationships are learned, develop, and become part of identity through participation in the practices of communities (Foucault, 1975; Gutierrez et al. 1995; Lave & Wenger, 1991). Placing more emphasis on the discursive dimensions of practice necessitates a change in both the traditional discourse practices of science instruction and Discourses that help define what being a science teacher or science student looks like. Shifts in classroom power dynamics are an integral part of this change, as teachers need to decenter their role as both the primary speaker and as the sole knowledgeable authority for practice-based instruction to be effective. However, long-standing Discourses contribute to the resistance to change, and teachers are understandably nervous about losing control by ceding power to students.

This study suggests spending time in a research setting and observing the pervasiveness of collaborative argumentation and sense-making discourse in scientific activity, can provide powerful motivation for teachers to consider ways to take up a more practice-based focus and alter the cultural production of authority in their classrooms. Opportunities for teachers in the TSP program to identify with, and take the perspective of, multiple roles across scientific and educational sectors (Principal Investigator, teacher, student/novice) helped them make such consequential shifts in their classrooms.

Desettling Traditional Science Education

Traditionally, science education has consolidated power in the teacher's authority as well as in taken-for-granted routines, materials, and approaches to making meaning in science. This has been manifested in many ways, including in the patterns of language and discourse that teachers and students engage in. Upon returning to the classroom, teachers made moves not only to decenter themselves as the sole authority, but to "desettle," or disrupt, traditional elements of their science instruction in specific ways. Settled views and expectations of science are culturally produced and sustained and are associated with historical inequities (Bang et al. 2012; Warren & Rosebery, 2011) As Bang and colleagues note, "When applied to schooling, the construct of settled expectations can usefully articulate and problematize entrenched, usually hidden, boundaries that tend to control the borders of acceptable meanings and meaning-making practices" (Bang et al., 2012, p. 303). I focus on four dimensions of desettling which teachers enacted in the year after their lab experience: (a) shifting discourse structures to expand who has speaking rights and who can challenge the ideas of others; (b) scaling back their epistemic authority to promote student ownership of ideas; (c) fostering an intellectual community of learners; and (d) shifting activity structures to promote equitable participation and de-emphasize the uniform mastery of each individual student.

First, teachers desettled traditional classroom talk patterns away from teachers primarily asking known-answer questions and students responding (Cazden, 1988). By engaging students in seminar-style “lab meeting” discussions to ask questions, resolve conflicting ideas, determine procedures, and discuss results, teachers such as Michelle, Melissa, and Sandra positioned their students as intellectually capable of having meaningful ideas to contribute and able to evaluate one another’s ideas using evidence and justification. Moreover, by placing an emphasis on using evidence in these discussions, teachers positioned the discipline of science of one where scientists engage in critique, persuasion, and reasoning to build a collective understanding. Theoretically, such work builds off of the dialogic focus of the Community of Learners described by Brown & Campione (1994). Brown noted that, “Reflection and discussion are essential to the FCL (Fostering a Community of Learners) ...FCL encourages newcomers to adopt the discourse, structure, goals, values, and belief systems of research practices. The FCL community relies on the development of a discourse genre in which constructive discussion, questioning, querying, and criticism are the mode rather than the exception” (Brown, 1997, p. 406). Closely connected is the work of Productive Disciplinary Engagement by Engle & Conant (2002), particularly the principle of holding students accountable to others and to disciplinary norms: “students are expected to consult others in constructing their understandings in a domain; they cannot purposely ignore the relevant work of others without justification. Thus, such accountability does not require acceptance of others' views, but instead responsiveness to them” (p. 405).

Second, teachers scaled back their epistemic authority, providing students with more agency and ownership of ideas. A settled view of science engages students in the traditional sees student views that are not clearly in line with established textbook knowledge as "misconceptions" to be corrected. In this view, the teacher, in their position of power, has the obligation to challenge and correct students. However, after the summer, Randi was able to recognize the value of letting ideas play out in student exchange and being comfortable allowing students moments of uncertainty and ambiguity. Notably, Randi was able to "push" herself to "let the misconceptions play out." If students are granted authority to wrestle with confusion and possibly "wrong" ideas, and yet eventually arrive at their own solutions and understandings, they have done more intellectual heavy lifting than if they had been simply told what to think. Similarly, in many classrooms, teachers feel the need to provide a quick "right answer" to questions students pose or that they themselves pose. Such teachers, in their positions of power, are the ones holding the knowledge. Quickly correcting students, in this view, brings students to the correct understanding more efficiently and prepares them for tests that reflect such learning. This discourse move has the effect of reinforcing the certitude of science as a static field of established knowledge, divorced from the processes that lead to new discoveries and understandings. If science is conveyed through schooling as a "simple, algorithmic form of reasoning" (Chinn & Malhotra, 2002, p. 213) there is no need for students to engage in discussion with one another about ideas, as they are rewarded primarily for having correct answers (Berland & Reiser, 2011). That the teacher (or text) is the holder of the right answer also imbues teachers with power relative to students - they know something that students do not - and it is up to the students to find the one answer the teacher is looking for. As Cornelius and Herrenkohl note, "When the teacher enters into the discussion as an evaluator of statements and claims, she delegitimizes the whole basis for students' debate with one another. What would be the point in trying to convince your classmates that your idea has merit if the teacher would step in and solve the controversy with a simple yes or no?" (2004, p. 485). Similarly, Donnelly and colleagues explored how classroom talk both structures and perpetuates power relations that can support or constrain student inquiry. They suggest that "lack of student engagement in ownership of scientific ideas" is one of the features of power inside the classroom that constrains learning (Donnelly et al., 2014, p. 2029).

Third, teachers recognized the value of establishing a culture of intellectual community and collaboration, desettling ideas of uniform, independent mastery and emphasizing the sociocultural nature of learning and sense-making. A settled vision of school focuses on individual students gaining content expertise. That is, students listen to the teacher, read their texts, and take individual examinations to determine how well they each have learned (the Discourse of the "game of school"). Brown & Campione's work (1994) in FCL was groundbreaking in its focus on establishing a community of practice and its elevation of culture as a first principle of learning. As Brown (1997) noted, "a culture of learning, negotiating, sharing, and producing work that is displayed to others is the backbone of FCL" (p. 411). Teachers such as Melissa and Anna recognized the value of different students' ideas and contributions in the classroom in terms of working as a "lab member" or "collaborative colleagues" on a "team effort" instead of focusing "independent mastery exclusively." As they positioned students as resources for one another, they simultaneously positioned the discipline of science as one that is contextualized in communities. After participating in the summer workshop, and particularly after observing the collaborative and discursive sense-making that was so common in their lab settings, teachers made efforts to build a more collaborative culture and challenge the idea that students should all achieve mastery independently of one another. Finally, teachers desettled the project of school where mechanisms of sorting and ranking students by their ability to quickly reproduce correct answers is the primary focus. Not only is content presented as unproblematic in this view, but students' participation is focused on who knows and who doesn't. Schwab bemoaned this teaching of science "as a nearly unmitigated rhetoric of conclusions in which the current and temporary constructions of scientific knowledge are conveyed as empirical, literal and irrevocable truths" (Schwab, 1966, p. 24). Equitable participation in group work and collaborative sense-making can disrupt the unjust distribution of power that exists in classrooms based on prior perceptions of academic ability (Cohen & Lotan, 2014), and can allow all students to exercise their intellectual abilities in productive ways.

Practice-focused activity structures that problematize content, legitimize and encourage respect for difference, and generate productive uncertainty foster increased participation across diverse students (Brown & Campion, 1994; Engle & Conant, 2002; Manz, 2018). This sensitivity of teachers to equitable sense-making opportunities and the classroom structures that foster it is an example of their growth in "interpretive power" (Rosebery, Warren, & Tucker-Raymond, 2016). "Interpretive power refers to teachers' attunement to (a) students' diverse sense-making repertoires as intellectually generative in science, and (b) expansive pedagogical practices that encourage, make visible, and intentionally build on students' ideas, experiences, and perspectives on scientific phenomena" (Rosebery et al., p.1571). Melissa's lesson redesign of the traditional DNA extraction protocol to be "in the [NGSS/scientific] practices" not only helped increase engagement and elevate students' authority over ideas but encouraged more equitable participation among her students. She noted how students were "more on equal footing" and that there was less ‘taking over’ by stronger students...less assertive students felt a bit more at liberty to offer their ideas.” Such lesson structures also position the discipline of science as one that benefits from the diverse thinking and contributions of participants. Melissa’s growth in her interpretive power, particularly in cultivating expansive pedagogical practices, served to center the contributions of her students in her classroom. Teachers’ growth in interpretive power is discussed in more detail in Chapter 4.

My research suggests that teachers can promote a more equitable and practice-focused approach to instruction by introducing discourse and task structures motivated by, and based on, their research lab observations and participation in professional development. Teachers shifted the language-in use between themselves and their students, repositioned what the discipline of science is about, and reframed the broader Discourse of what it means to do science in school. The activities they developed and the talk opportunities they created emphasized how argumentative discourse can help shape new understandings in science, pulling the focus away from the image of science as simply a collection of known answers and facts (Duschl, 1990). David’s emphasis on the importance of having students interrogate one another’s ideas emphasized the epistemic role critique plays both in helping to shape understanding and in minimizing bias in science (Ford, 2008). The classroom experiences shared by Michelle (the seminar-style heart discussion), Sandra (asking students to resolve their conflicting ideas and come to consensus), and Melissa (the DNA extraction protocol and lab meeting) highlighted those teachers’ new emphases on discursive and cultural processes of science. The pedagogical moves teachers made repositioned students as capable, with ideas worthy of exploring and discussing. Teachers also saw themselves as learners through the various roles they identified with and the perspectives they took on as they participated in lab experiences. Being able to empathize with students supported teachers in attempting to shift their role and the culture of the classroom community in meaningful ways.

Caveats and Limitations

There are several important caveats to this research. First, scientific lab environments are clearly quite different from classroom ones and this study does not intend to imply that they are inherently more important or valuable. Classrooms communities are unique structures onto themselves and with different purposes than research communities. However, teachers shifted their instruction and decentered their power to allow students to participate in core elements of scientific practices in meaningful ways, inspired by what they observed during their time spent in scientific research labs. Second, there are discourse practices that occur in scientific settings that teachers and students would not want to emulate. For example, some teachers noted examples of unnecessarily harsh critique in the scientific setting. Third, there are power structures within labs that are also problematic. While none of the teachers was placed in such a lab during this study, teachers who had worked in science previously related negative experiences in overly rigid, authoritarian labs. Finally, this research recognizes that the power being discussed is being re-distributed within an existing system and not fully re-negotiated; teachers' attempts to reshape their classroom are still happening within the context of larger institutional systems that resist change. Prior research illustrates how difficult it is for reform-based teachers to innovate within existing educational power systems (Carlone et al., 2010). Teachers within "formal" classroom environments do not always have the flexibility of after-school programs or ones that operate out of non-profit organizations. Teachers may also adhere to normative practices that are deeply institutionally rooted. Secondary science teachers such as the ones in this study may view themselves as "content specialists" with concerns about covering fixed amounts of material within certain time limits. Teachers acknowledged these limitations and spoke frankly about the challenges being situated in larger social and institutional contexts that reflected power imbalances: high-stakes testing, short classroom periods, and the expectations of parents, other teachers, and administrators about what "rigor" in the classroom looks like.

This study focused primarily on the experience teachers had as they went through a three-week summer workshop with a brief research exposure and follow-up at the end of the next school year. One of the limitations of this work is that it does not extend to observations of the direct classroom experiences of students and teachers. As such, I was also unable to explore how gender, race, or other sociopolitical factors such as the role of institutionally privileged dominant societal discourses contribute to power in science classrooms. I also could not observe micro-enactments of power such as methods of surveillance and behavioral regulation (Donnelly et al., 2014). Additionally, the TSP cohort examined was unusual in that only one male teacher participated; although data from his contributions aligned with those of the women, it is possible that a more gender-balanced cohort would yield different results. Similarly, the group was overwhelmingly white; the findings may have also varied had a more ethnically and racially diverse group of teachers participated (data on socio-economic status were not collected).

Conclusion

Through their experiences in lab settings, teachers realized that scientific argumentation and sense-making discourse is situated in, and influenced by, power relations. The power that the Principal Investigator (PI)/Lab Director has over people who work in the lab or that the teacher has over students has a great impact on the discourse in their respective environments, and the language-in-use in turn reinforces the ways in which power is distributed. The dynamics of how power is manifested and sustained in both settings is based on interactional and discursive choices. Teachers gained insights into their own classroom power relations by observing the dynamics in the lab between the PIs and their teams. While teachers identified with the PIs and their leadership roles, many teachers also reported feeling like “students” and empathizing with them after their experience. These observations helped teachers realize that how they positioned themselves and how they positioned their students (for example, as capable or as people whose ideas had worth) had an impact on learning (Harré et al., 2009). They considered how their authority in the classroom could be decentered based on their own actions and thought about the possibilities of ensuring a more equitable distribution of power in their classrooms.

Although teachers noted that the way the physical environment is arranged impacts power dynamics, most of their emphasis was on how language and discourse was used in the labs and in their classrooms. By providing opportunities for more student-focused collaborative knowledge-building discourse, teachers send a message about the practices valued in science classrooms as well as in science itself. When teachers take a conscious step back from quickly correcting misconceptions or providing right answers, or when they allow students to engage intellectually with one another in persuasion, critique, and sense-making, they shift intellectual authority in the direction of their students. They also help position students as capable and knowledgeable. This is an important and necessary dimension of moving teachers towards more equitable science education practices that value noticing and supporting students’ sense-making repertoires and engaging their diverse sense-making (Bang et al., 2016).

While the full design of the teacher professional development and the multiple conjectures behind that design are described elsewhere (see Chapter 2), one key feature of the TSP program is the opportunity for teachers to spend multiple days in scientific research settings focused on observing argumentation and related scientific discourse practices. While the TSP program has placed teachers in labs for over two decades, this was the first year that teachers were asked to attend lab meetings, train an ethnographic lens on their experience, consider power dynamics, and bring exemplars of argumentation that they observed in the research setting back to the teacher cohort for discussion. Importantly, without this specific focus, prior cohorts of TSP teachers did not reach the same conclusions about power or the role of argumentative discourse in science. Additionally, many TSP teachers in the study (such as Randi and Jan) had worked in labs previously. However, without a specific emphasis on "what to look for," opportunities to process their findings with others, practice engaging in modeled classroom strategies, or reflection on the implications for students, teachers had not previously been able to incorporate such discourse practices into their classrooms.

The deeply ingrained Discourse of conventional schooling holds teachers as powerful authority figures who tightly control student speaking rights—and hence the teaching and learning process. For teachers to cede some of that power to students can be a potentially challenging prospect. Of particular importance is the need to attend to how intellectual authority needs to be shifted from teachers on to students as students take increased responsibility for guiding the discussion, asking questions of one another, and challenging each other's claims (Crawford, Kelly, and Brown, 2000; Ford, 2012; Engle & Conant, 2002). This type of shift in power can potentially be threatening for educators who may be used to being the primary authorized speakers within the classroom or to closely managing speaking rights within it (Hudicourt-Barnes, 2003; Cazden, 1988). Not only must an instructor relinquish some of the power associated with controlling classroom discourse, but he or she must also trust that students will be able to take some responsibility for the discussion.

This research contributes a perspective of power relations to the work on Community of Learners and Productive Disciplinary Engagement (Brown & Campion, 1994; Engle & Conant, 2002). The importance of classroom community to developing a culture of learning has been long-recognized but finding ways to promote classroom shifts continues to be difficult given the institutional history and cultural reproduction of schooling. The professional development model described herein emphasizes a focused immersion in laboratory life and opportunities for teachers to process their experiences collectively. It offers one promising way for teachers to reflect on and refine their understanding and approach to classroom culture.

My findings also provide an account of how teachers think about power in the classroom. It suggests how shifts in hierarchical power structures in classrooms might be accomplished through a professional development design strategy that can help teachers muster epistemic motivation to try risky and new approaches that more closely align with knowledge-building practices at the heart of the professional scientific work. Teachers in this study shifted the d/Discourse of traditional school science to position students as thinkers capable of using evidence to evaluate competing claims in discussions with one another, and whose important ideas deserve to be heard. They also positioned science as a social endeavor, where scientists engage in sense-making, and where problems and challenges benefit from the ideas and contributions of others. As they provided students with a more authentic view of, and experience with, scientific practices, teachers also desettled normative ideas about their duty to provide quick right answers and to correct misconceptions as the singular voice of authority. Teachers reconsidered their over-emphasis on independent mastery at the expense of opportunities for collaborative discussion and problem-solving. Ultimately, engaging students in science in ways that value their intellectual contributions and sense-making repertoires can help promote more equitable participation among science students and also help foreground for students the fundamental practices that constitute scientific activity.

References – Chapter 3

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Chapter 4: Strengthening Teachers' Interpretive Power Through Collaborative Autoethnography: Engaging Students' Cultural and Everyday Resources in Argumentation

Abstract

This study focuses on cultivating teachers' *interpretive power*: their ability to be sensitive to the broad range of ways students make sense of science, and to use expansive teaching strategies to surface, support, and build from those perspectives (Rosebery, Warren, & Tucker-Raymond, 2016). This includes expanding teachers' conceptions of what appropriate discourse looks like in school settings in order to provide youth with meaningful educational experiences and recognize the strengths that they possess. There is a need for accounts of professional development models that help teachers think expansively about the key scientific practice of argumentation with a focus on students' cultural and everyday resources. Additionally, little is known about design principles that help teachers strengthen their interpretive power so that they can recognize students' argumentative resources. My research questions focused on how teachers can promote inclusion of culturally responsive argumentation and sense-making practices in their classrooms, and how collaborative autoethnography, or CAE, (Chang, Ngunjiri, & Hernandez, 2012) can contribute to professional development that cultivates science teachers' interpretive power. This study is part of a larger body of work that studied secondary science teachers' conceptions of argumentation as part of a professional development program at a cancer research center. In this study, a subset of six teachers participated as co-researchers in four school-year meetings. The specific design of the sessions was driven largely by the interests of the teachers but had an overarching goal of working to expand teachers' interpretive power relative to student argumentation in their science classrooms. Using collaborative autoethnography, teachers considered how argumentation in their classrooms could attend to students' personal and cultural

histories and resources. Teachers then identified themes that emerged from their written materials and discussions. To further analyze the collective findings, I used Haraway's (1992; 1997) construct of "diffraction." Diffraction provided an alternate metaphor to reflection: it not only provided a more situated, entangled account of the complexity of the discussions, but also how ideas traveled within and between individuals and across time. Our findings emphasized the foundational importance of establishing classroom relationships in order for productive argumentation to occur. Teachers need those relationships in order to know their students, which in turn allows them to design relevant learning experiences and understand the kinds of sense-making their students are engaging in. Students need those relationships in order to be able to begin to feel comfortable talking with one another. We also identified the value of creating trusting communities, where students can feel safe engaging in the vulnerability that accompanies argumentation. Significantly, we were able to reconceptualize and reclaim the idea of rigor to reflect argumentation and sense-making discourse that is connected to students' lives and that engages them in knowledge-building with others. Teachers found that the CAE approach provided opportunities to reflect on their own positions and histories, encounter new ideas, examine their thinking, and process with other teachers. Such an orientation not only disrupts long-standing, taken-for-granted ways of interacting and talking in the classroom, but it also expands possibilities for teaching and learning. This professional development model offers a promising strategy for helping teachers develop their interpretive power and enact expansive argumentation practices that center students' experiences, value diverse sense-making, and increase equitable opportunities for learning.

Overview

In order to provide more equitable science learning environments, researchers have argued for cultivating teachers' *interpretive power*: their ability to be sensitive to the broad range of ways students make sense of science, and to use expansive teaching strategies to surface, support, and build from those perspectives (Rosebery, Warren, & Tucker-Raymond, 2016). This includes finding ways to broaden conceptions of what appropriate discourse looks like in school settings in order to provide youth with meaningful educational experiences and recognize the strengths that they possess (Heath, 1982; Rosebery, Ogonowski, DiSchino, & Warren, 2010; Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001). Learning environments that support and leverage cultural practices such as argumentation can help students have more equitable access into similar scientific disciplinary practices.

In this chapter, I provide an account of teacher professional development that was part of a larger design-based research study (Brown, 1992; Collins, Joseph, & Bielaczyc, 2004; DBR Collective, 2003). The professional development program, the Teacher-Scientist Partnership (TSP, a pseudonym), is a three-week summer program for secondary science teachers that is embedded in a cancer research center. A subset of six teachers from the larger TSP summer cohort of 21 teachers (Phase I) participated in four additional focused sessions during the school year (Phase II). This chapter focuses on findings from these Phase II school-year sessions. The design of the sessions was driven in large part by the interests of the teachers but had an overarching goal of working to expand teachers' interpretive power relative to student argumentation in their science classrooms. We used elements of the methodology of collaborative autoethnography (CAE) to think about how argumentation in their classrooms could attend to students' personal and cultural histories (Chang, Ngunjiri, & Hernandez, 2012).

Research Rationale and Purpose

Recent research has investigated how teacher professional development can cultivate interpretive power (Rosebery et al., 2016). However, there is a need for accounts of professional development models that help teachers think expansively about the key scientific practice of argumentation with a focus on students' cultural and everyday resources. Additionally, little is known about design principles that help teachers strengthen their interpretive power so that they can recognize students' argumentative resources.

The purpose of this study is to investigate how teacher professional development can contribute to the development of interpretive power in teachers. It particularly examines the affordances provided by the methodology of CAE. This chapter provides an account of how science teachers can expand their conceptions of scientific argumentation and sense-making in order to attend to, and value, the personal and cultural resources that students bring to that practice. To this purpose, the following research questions guided this study:

Research Questions

- How can teachers promote inclusion of culturally responsive argumentation and sense-making practices in their classroom teaching?
- How can collaborative autoethnography support professional learning that cultivates science teachers' interpretive power?

Background

Broadening Conceptions of Student Discourse, Argumentation, and Resources

It is important not only to look at the competence that children bring into a science learning context, but also to acknowledge the deep "funds of knowledge" that arise from students' participation in, and lived experiences with, the sociocultural communities they belong to (Basu & Calabrese Barton, 2007; Moje et al., 2004; Moll, Amanti, Neff, & González, 1992). Bricker and Bell (2008) argue specifically for broader conceptualizations of argumentation, including drawing on young people's "everyday argumentative competencies" (p. 495) and coordinating these with theoretical perspectives on argumentation from across various fields and domains (for example, from the inscriptional, persuasive practices of scientists emphasized in science studies). Simply teaching students the appropriate forms and structures of argumentation may not be enough to help them to argue scientifically. Bricker and Bell (2012) suggest that starting with students' everyday knowledge and argumentative resources, and drawing explicit attention to shifting between discourse structures, may be more productive. Below, I detail three previous studies that provide examples of how teachers can support and engage students' varied discursive sense-making practices. I highlight these studies here because I also selected them for teachers to read and discuss in the CAE sessions.

The first study, *"Everyday" and "Scientific": Rethinking Dichotomies in Modes of Thinking in Science Learning* by Warren, Ogonowski, and Pothier (2004), focuses on how reconceptualizing the boundary between "everyday" and "scientific" thinking can help teachers take an asset-oriented view of the argumentative forms (Bricker & Bell, 2012) and epistemological resources (Hammer & Elby, 2002) that students bring to argumentation. Warren et al. (2004) argue that dichotomies are common across domains in Western thinking and also play out in science education research. There is tension between those who believe that scientific worlds are discontinuous with ordinary ones and those who believe that the relationship between scientific and everyday experience is continuous. The authors note that, "The main point of contention is whether students' ways of conceptualizing, representing, and evaluating their lived experience should be viewed and treated as errors that impeded learning or as generative resources in learning new ideas and traditions of inquiry" (p. 121). A discontinuous view, for example is often found in research on student misconceptions, which aims to investigate/correct errors in student thinking and to bring them in line with scientific concepts. In this perspective, students from groups traditionally underrepresented in science are perceived to be at a disadvantage because their everyday experience differs the most from "Western science." In contrast, those who adhere to the continuous view (such as the authors), believe that students' experiences are constantly used as a reference and a resource - and that teachers should be concerned with "uncovering children's' competence" (p. 122).

Warren and colleagues provide a compelling case to illustrate the need for educators to have a broadened view of students' assets and capabilities. One young African American young woman, Letisha, exhibited talk and ideas that, viewed through the lens of traditional dichotomous thinking, looked "outside of the boundaries of the task." The authors and the teacher had to actively work at recognizing the value of this student's "expansive thinking" (p. 143). "However, rather than assuming that the problem resides in Letisha – in something about the way she thought or spoke, in some deficit in her background of life experience, or in the incompatibility of her ways of knowing with those valued in sciences – we assumed that the problem resided in our norms of interpretation, in our assumptions and expectations regarding what counted as a meaningful response to the teacher's questions; in other words, in our own trained inability to see and hear the intellectual substance of Letisha's talk" (p. 144). Afterward, the teacher shifted her way of engaging with Letisha, framing her as more intellectually competent and asking more expansive questions of her. The authors note that how educators view students and their experiences has great import for how they interact with students, and how students are, in turn, able to engage and participate in science. This research aligns with other work that emphasizes the importance of not localizing the root of problems within students, but to consider assumptions about what science is and who it is for when considering how to broaden participation within it (Basu & Calabrese Barton, 2007; Mutegi, 2013).

The second study, *Questioning at Home and at School: A Comparative Study,* (Heath, 1982) explored the implications of different types of language use in homes and schools. Heath, as part of her long-term ethnographic study of neighboring cultural communities in the southeastern United States (1982), examined disconnections between how young African-American students in "Trackton" were raised to use language and respond to questions and the expectations that their white teachers held for talk in school. At home, Trackton children were generally not expected to engage adults as conversational partners or provide information to them until they were able to engage in conversation in competent ways. Thus, Trackton children did not come to expect to engage in such conversations with adults. While they grew up in a linguistically rich environment, the talk of adults was not structured specifically around their input. When adults did ask the children questions, they often asked them in a form that invited analogical comparisons. These practices were in contrast to those of the white teachers, who socialized their own young children to respond to the types of questions that are also dominant in school (for example, providing names or labelling parts). Heath noted that the ways in which the different language practices Trackton children had learned left them confused or unprepared for common classroom questions, which reflected more closely the cultural practices of their white teachers. These included questions that were actually directives, questions with answers that the teacher clearly already knew, and questions that asked students to demonstrate familiarity with particular ways of interacting with books. Not surprisingly, the teachers judged students' academic abilities based on their own referential framework for language use until they understood the linguistic cultural differences between different populations of students. Heath's study illustrates not only the power of culture to shape patterns of normative discourse, but also how students' cultural differences can be judged as student disinterest, unwillingness to learn, or even antagonism towards school rather than as assets for learning. In her study, knowledge about different cultural language practices informed teachers and helped them adjust their instruction to broadly support student learning in their classrooms. As Heath notes, the rationale for her study was that "if change agents (teachers and parents) were willing and involved, knowledge about language use could proceed along a two-way path, from the school to the community, and from the community to the school" (p. 125).

The final study*, The Use of Argumentation in Haitian Creole Science Classrooms*, centers specifically on cultural dimensions of argumentation. Hudicourt-Barnes (2003) describes her instruction for Haitian Creole science students that intentionally utilized argumentation practices common in Haiti. As a classroom teacher, she drew on a discourse practice *called bay odeans* (literally, "give talk", or chatting) that is often performed publicly and that focuses on skillful use of words and storytelling. One form of *bay odeans*, *diskisyon*, centers on arguments related to topics of broad public interest. These discussions are passionate and animated, and while they may seem like fights to those unfamiliar with the form of discourse, they are considered entertaining and enjoyable to those involved. Hudicourt-Barnes notes that participants in such arguments often take on specific roles (theoretician, challenger, audience member) akin to actors in a theatrical performance. In addition, she demonstrates that science instruction that incorporates cultural dimensions of argumentation in alignment with students' own lived experiences reveals the sophistication of the students in ways that conventional Western assessments do not. The boisterous *diskisyon* stands in contrast to the measured and teacher-oriented discourse styles emphasized in typical school settings. A student who excels at *diskisyon*, she noted, would likely be dismissed from an ordinary classroom for being considered disruptive - despite engaging with peers and with the subject matter. Her view of Haitian Creole science students as capable and highly skilled in scientific argumentation contrasted with prior research, which had cast doubt on their scientific abilities based on question-and-answer assessments. Those assessments did not reveal the students' ability to engage in sophisticated argumentation and reasoning that was culturally specific and that made sense to them. Not only were students' cultural discourse patterns restricted in conventional school settings, but their scientific abilities and argumentation skills were also underestimated.

These three studies provide compelling examples of how teachers can draw on the strengths of students and expand their vision of what productive talk looks like in school, which was why they were also selected as readings for teachers participating in the CAE. However, accounts of teacher professional development models are needed that can help teachers cultivate interpretive power to support argumentation and related scientific practices. This study addresses that need by investigating how teachers make meaning about their pedagogical choices related to argumentation and sense-making discourse in collaboration with other educators. It also examines their thoughts about how to foster an accessible, culturally-responsive, and inclusive community with their students.

Conceptual Framework

In this section, I explore the notions of *interpretive power* and *diffraction* in turn and discuss the valence of these ideas as tools for the design and analysis of teachers' collaborative work and professional learning.

Interpretive Power of Teachers

Gutiérrez and Rogoff describe repertoires of practice as "linguistic and cultural-historical repertoires" that students draw on as "ways of engaging in activities stemming from observing and otherwise participating in cultural practices" (2003, p. 22). Such repertoires have implications for schooling, as students may have different cultural traditions for responding to situations that are common in schools and that are often mistakenly associated with characteristics of individuals: for example, responding to authority figures, asking and answering questions, being praised, or working independently. These repertoires of practice can also apply to sense-making; students may bring many different resources and approaches to understanding science from their personal and cultural histories.

Interpretive power refers to: “teachers’ attunement to (a) students’ diverse sense-making repertoires as intellectually generative in science, and (b) expansive pedagogical practices that encourage, make visible, and intentionally build on students’ ideas, experiences, and perspectives on scientific phenomena” (Rosebery, Warren, & Tucker-Raymond, 2016, p.1571). It emphasizes the ability of teachers to use their professional experiences in the service of a broader vision of teaching and learning. Ball and Cohen (1999) describe a vision of teacher professional development as grounded in possibility, centered in teachers’ own inquiry into teaching and learning, and developed collaboratively in communities of practice:

> The more teachers developed methods of professional inquiry, articulated ways of knowing, and determined standards for knowledge in practice, the more teachers would have interpretive power, which could contribute to improving both their own teaching and their own and others’ learning. They should be less likely simply to see in terms of what they bring, but might be able to see new things and consider more alternatives, analyze students’ learning more finely, and consider their practice more deeply and in more complex ways. (Ball & Cohen, 1999, p. 16)

Rosebery et al. (2016), building off their own earlier work and the work of others (Ball & Cohen, 1999; Rosebery & Warren, 2008; Warren & Rosebery, 2011) use the idea of interpretive power as a way to focus attention on the “student’s diverse sense-making repertoires as intellectually generative in science learning and teaching” (p. 3). In their professional development work with early career teachers, they highlight the need to move away from deficit approaches (particularly with respect to students from non-dominant cultures), “desettle expectations” of what science is and who it is for, and be attuned to the generative resources for learning that students possess (Bang, Warren, Rosebery, & Medin, 2012; Bricker & Bell, 2012; Heath, 1983; Nasir, Rosebery, Warren, & Lee, 2006;). Being responsive to, and building upon, those resources "is a source of creativity in socially just teaching and learning in that it propels expansive consideration of entrenched ideas and settled perspectives about people, disciplines, phenomena, and their interrelationships" (Rosebery et al., 2016, p. 1575). The research conducted by Rosebery and colleagues (2016) involved two design cycles of a professional development seminar for teachers working with students from communities underrepresented in science. The seminar integrated teacher learning of plant science, analysis of classroom case studies, opportunities to test discourse practices with students, and discussion of their classroom results of those tests. The authors found that teachers grew in their ability to attend to complex student ideas and see students' sense-making as resources, developed an understanding of the role their pedagogy plays, and demonstrated increased commitment to fostering expansive practices in student discussions.

Bang, Brown, Calabrese Barton, Rosebery, and Warren (2017) have connected the shift to a three-dimensional view of science learning (centering on disciplinary core ideas, science and engineering practices, and cross-cutting concepts) in the *Framework for K-12 Science Teaching* (National Resource Council, 2012)and the *Next Generation Science Standards* (2013) to opportunities for more equitable learning for students:

> [An emphasis on science practices] "expands the territory of sense-making in science to include more wide-ranging, intellectually powerful practices than what has conventionally been highlighted in school science…a focus on science practices invites teachers to attend closely to the varied ways in which students argue from evidence or interpret data as a foundation of learning in science, and to build on students' ideas, experiences, and perspectives as a core part of teaching. *By attending closely to what students actually say and do in science, teachers can expand the relationships that are possible among themselves, their students, and science*. In this way, they can begin to create more equitable opportunities to learn in science for historically underserved students. (Bang et al., 2017, p. 33, emphasis added)

Bang et al. (2017) expand on ideas of interpretive power by setting forth three pedagogical principles to facilitate meaningful science learning:

> (a) Notice sense-making repertoires: Attend to, listen to, and think about students' diverse sense-making as connecting to science practices
>
> (b) Support sense-making: Actively support students in using their sense-making repertoires and experiences as critical tools in engaging with science practices
>
> (c) Engage diverse sense-making: Engage students in understanding how scientific practices and knowledge are always developing and how their own community histories, values, and practices have contributed to scientific understanding and problem solving and will continue to do so. (p. 39).

I draw on these principles in analyzing how the teachers in the CAE workshop thought about scientific practices in their classrooms, their own interpretive power, and the argumentation and sense-making of their students.

In this study, I examine how teachers think about the resources and assets students bring to argumentation and related discursive practices. Because I am interested in how teachers can interrogate their own ideas and assumptions about students and how they can develop strategies for professional inquiry, interpretive power provides a useful lens for analysis. These efforts reflect a desire not only to broaden teachers' views of the practice of argumentation in terms of how it is enacted in scientific research settings (see Chapter 2), but also to make science education more equitable by opening avenues for student engagement and access to argumentation. Thus, I am attempting to design for deep interpretive power that has both a disciplinary and an intercultural dimension and that expands what counts as sense-making in science classrooms.

Diffraction

I also use Haraway's (1992) notion of "diffraction" from feminist studies as a tool to understand how teachers made meaning from the themes that they identified and discussed in the group. Haraway and other feminist scholars argue for *diffraction* as a more situated and nuanced way to think about the impact of ideas and their meaning than the common metaphor of *reflection*. Drawing on prior work of filmmaker and feminist theorist Trinh Minh-ha, Haraway (1992) introduced the idea of diffraction as a metaphor by noting that “Diffraction does not produce ‘the same’ displaced, as reflection and refraction do: Diffraction is a mapping of interference, not of replication, reflection, or reproduction. A diffraction pattern does not map where differences appear, but rather maps *where the effects of difference appear*” (1992, p. 300, emphasis added).

Reflection as a metaphor is anchored to a reference of light waves interacting with an original image, showing us a representation of that image. It draws forth ideas of mirrors or still surfaces of water where we see a (somewhat distorted) representation of reality - and often, ourselves. Reflection highlights sameness; the underlying reference point from which to compare is the original. In contrast, diffraction suggests the complexity of how light interacts with objects, gaps between objects, and with itself - reinforcing itself in ways that build on or diminish its effects. Diffraction as a metaphor is rooted in ideas of difference and can thus be productively mobilized to use in work seeking to disrupt conventional and taken-for-granted patterns in the world (Haraway, 1997).

The diffraction metaphor was further expanded upon by Barad (2007), who emphasized the *relational* and *entangled* dimensions of diffraction. She notes that diffraction “attends to the relational nature of difference; it does not figure difference as either a matter of essence or as inconsequential” (2007, p. 72). Drawing on her background in physics, Barad also describes how reflection can be explained without taking into account the wavelike property of light, whereas explanations of diffraction rely on that property and make it explicit. Furthermore, diffraction highlights the paradox of how light can be both a wave and particle, a foundational idea of quantum theory[1]. In mapping diffraction as a methodological metaphor against reflection, Barab argues that diffraction emphasizes patterns that "mark differences from within and part of an entangled state" while reflection emphasizes a mirror image and the "reflection of objects held at a distance" (p. 89). It is this emphasis on entanglements - on how we engage in the world through our practices, how we account for the learning of those practices, and how we participate in using them to create and understand the world - that makes a diffractive lens productive and responsive to the situated nature of learning (Lave & Wenger, 1991). Diffraction has subsequently been taken up in over fifty peer-reviewed papers as a feminist perspective and methodology (see Uden, 2018).

Bozalek and Zembylas (2017) described using a diffractive analysis in a group similar to the CAE featured in this study. The group of faculty and graduate students read about and discussed ideas, and that explored the many threads of the entanglements within their group: "the entangled intra-actions in our research group include the emerging questions, the embodied or virtual presence of assembled members, a history of working together as collaborating authors, colleagues and researchers, the physical space of the meeting place and the space of distance communication for those who join the group electronically from around the world, and decisions 'how' to read texts and entangled realities" (p. 119). Their diffractive reading and analysis of the texts emphasized "a more-than-representational approach of engaging with the materiality and entanglement of reading; this kind of engagement does not remain within the 'boundaries' of

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[1] *In physics, diffraction has historically referred to how waves react to obstacles, and interference to how waves react to each other when the encounter each other and overlap - both are wave interactions and here I use them to refer to the same general phenomena. Barad (2007) notes that the physicist Feynman also suggested the idea of a distinction between them in physics was a purely historical artifact.

reflective reading which usually focuses on providing ‘interpretations’ of the texts at hand” (p. 120).

Metaphors are powerful ways of understanding the world, and the ones we choose have the potential to shape our interpretations in starkly different ways (Becker, 1998). Because reflection is such a well-worn description of how we engage with, process, and react to phenomena, it is difficult to step away to examine how such a metaphor may be limiting or how alternate ones might be productive. Within education and education research, reflection is firmly embedded in the language of professional development and program evaluation. It also appears, in the form of reflexivity, in research reports. In this chapter, I explore how the alternate optical metaphor of diffraction can provide a productive way to think about the methodology of CAE: how teachers experienced the process, how our learning was entangled with various dimensions of our social contexts, the insights and connections that teachers reported, and my own role in the research process. This focus on the complexity of our shared learning and our differences supported the development of interpretive power amongst our group members.

Methods

Research Design

My research questions lend themselves to qualitative methods (Merriam & Tisdell, 2016) because I seek to understand how teachers interpret and assign meaning to their experiences. This study also utilizes design-based research (Brown, 1992; Collins, Joseph, & Bielaczyc, 2004; DBR Collective, 2003) to contribute to understanding how professional development for teachers can be architected to promote a broader understanding of argumentation and help teachers translate their experiences into educational approaches that foster expansive sense-making discourse practices in school settings. In this section, I first describe the methodology of collaborative autoethnography. I discuss how we applied the method to our group, including the texts we read and the questions on which we focused our autoethnographic research. I also briefly describe the design-based research component. I then introduce the site and participants of our group. Finally, I discuss the data and analysis methods.

Collaborative autoethnography (CAE)

Collaborative autoethnography (CAE) is a "qualitative research method in which researchers work in community to collect their autobiographical materials and to analyze and interpret their data collectively to gain a meaningful understanding of sociocultural phenomena reflected in their autobiographical data" (Chang et al., 2012, p. 23-24). CAE draws on the strengths of both autoethnography and collaboration: Autoethnography provides an interpretive framework to situate self-reflection in broader social and cultural contexts and meanings, while collaboration allows researchers to join together to deepen and enrich their understanding (Chang et al., 2012). As a method, collaborative autoethnography builds on three interrelated analytical elements: (a) an emphasis on deepening learning and understanding through discourse and engagement with others, (b) a focus on self-examination, and (c) a commitment to ethnographic methods. In CAE, the researchers (in this case, teachers) are not only visible, but at the center of the research—working in collaboration with each other and me (as the study coordinator). By shifting traditional relationships in researcher-participant interaction through its commitment to power sharing, CAE also takes a more critical approach to ethnography and elevates an insider point of view (Chang et al., 2012). CAE provides an appropriate methodology for addressing my research questions because it can make visible how teachers' conceptions about argumentation and its cultural dimensions influence their views about their teaching practices and what students are capable of. Examining how teachers think about social and cultural dimensions of argumentation in their classrooms represents a novel use of CAE.

The CAE group consisted of a convenience sample of 6 interested teachers from a larger cohort of 21 who had participated in a summer professional development program at a cancer research center that focused teachers on argumentation in professional science (See Phase I, Chapters 2 and 3). The group met four additional times during the school year (Phase II) to participate in CAE sessions to consider the cultural, historical, and everyday resources that students bring to argumentation.

Teachers wrote autoethnographic responses to prompts that addressed the overall research questions and were either provided by me or agreed upon by the group (Appendix E: CAE Professional Development Summary). At each meeting, we read the autoethnographic reflections of each group member. We annotated them, and then discussed themes that we saw emerging across the responses. Teachers also divided up the three research articles mentioned earlier (Heath, 1982; Hudicourt-Barnes, 2003; Warren, Ogonowski, & Pothier, 2005) and a book, *Culturally Responsive Teaching* (Hammond, 2015), to read and discuss. Each article was read by at least one teacher, although some chose to read more than one. Teachers were given free choice to decide which pieces of the book they wanted to read and share with others.

Process. The first three sessions were three hours long, while the last one was two hours. After "checking in" with each other, we spent approximately the first half of each meeting discussing readings or background information. Then, we would individually read and notate/code the responses each team member had written prior to the session. After we had reviewed all the responses, we discussed them as a group and surfaced emergent themes. Before adjourning, we settled on the questions and readings for the next session. In preparing teachers to respond to the agreed-upon questions, I encouraged them to take an ethnographic lens to their experience, look out for exemplary or memorable cases, and tell their stories with an eye to social and cultural context. I also asked teachers connect relevant ideas from the readings to their own classroom experiences and pedagogical approaches.

Design-Based Research

Design-based research (DBR) offers a productive approach for innovating, testing, and refining learning interventions in real-life learning environments (Brown, 1992; Collins, Joseph, & Bielaczyc, 2004). The interventions that are tested through DBR methods represent specific "conjectures about learning within educational designs" (Sandoval, 2004, p. 222); these conjectures (and the specific task structures and lesson materials, participation structures, and tools and material support elements they embody) can provide an empirical framework to help test designs and advance theoretical understanding. A design conjecture map for this research (Sandoval, 2014), alongside findings from the sources of evidence detailed below, helped derive design principles (Appendix F: Conjecture Map Phase II). The high-level conjecture for this Phase II work was that students' own personal, historical, and cultural resources can serve as expansive resources for scientific argumentation in the classroom. Ultimately, the design was structured to help teachers foster connections between student argumentation practices and scientific research practices, valuing the resources that students bring and promoting equity in access to science.

Setting

The Teacher-Scientist Partnership (TSP) is a professional development program for secondary school science teachers embedded in a scientific research institute of over 3,000 people. Since 1991, TSP has been offering teachers direct experience in research labs, curricular support, and access to molecular biology equipment and supplies. The 2017-2018 TSP program (Phase I) included: (a) A 13-day Summer Session in which teachers worked closely with each other, TSP staff, and scientist mentors to gain skills and expertise in molecular biology. This included 5 days of direct experience working alongside scientists in research laboratories and attending lab meetings; (b) Time and assistance during the session to develop a curriculum project related to the program that was designed to be used in their classrooms; (c) Access to an extensive kit equipment loan program so students could conduct hands-on molecular biology investigations; and (d) Additional meeting times throughout the school year to prepare teachers for the experience, reflect on its impacts, and bring the larger community of teachers together. The additional meetings times included a full day orientation, a follow-up reflection day at the end of the school year, a kit-sign up day, and four topical one-day workshops. The program also included “Lead teachers”- TSP teachers who participated in the summer program in prior years and who returned to help teach some of the content and to serve as trusted intermediaries between new teachers, staff, and scientists. Lead teachers also visited participants in their lab placements and helped participants develop lesson ideas based on the research experience. Phase I (described in Chapter 2) had an emphasis on teachers experiencing scientific argumentation as it is practiced in professional research settings and provided supports for bringing epistemic dimensions of argumentation to classrooms. Towards the end of the TSP summer program, I invited teachers to participate in Phase II - the CAE subgroup. The CAE group met during the 2017-2018 school year on the research center campus in a conference room.

Participants

Table 4: Study Participants summarizes the composition of the CAE group. All of the teachers identified as female. Most identified as white, but 2 had mixed European/Asian ancestry and one identified as Punjabi. The teachers Amongst group members, there was a range of

teaching experience (from 2-10 years). Teachers also taught in a variety of school settings and had varying amounts of prior professional development (PD).

Table 4: Study Participants

Name	**Years Teaching**	**School**	**Research (in addition to TSP)**	**Other Relevant Professional Development (PD_**
Manat	4	Suburban public, high proportion of low-income students and students of color	Had conducted research as part of undergraduate classes	University of Washington / Ambitious Science Teaching (Windschitl, Thompson, & Braaten, 2018).
Sylvia - TSP Lead Teacher for one year	7	Small urban public school	Had conducted some research (6 months)	University of Washington / Ambitious Science Teaching
Liza - TSP Lead Teacher for eight years	9	Urban public school with culturally and linguistically diverse population	None	Worked on curriculum and assessment at the state level and district level. Was part of a 5-year collaboration of TSP AP Biology teachers.
Jolene	9	Parochial middle school. In the year prior to her participation in TSP, she had transitioned to a large public suburban high school	None	Professional Learning Community at School
Raven	10	Public high school (was in transition to a new position)	Genetic Epidemiology Master's degree Had conducted research in ecology and in genetic epidemiology	University of Washington/Institute of Science and Math Education – PD related to STEM Teaching Tools Bioethics PD provided by Jeanne Chowning
Anna	2	Public suburban	Had conducted some research	Influenced by observing her mentor teacher. He had students doing sophisticated biotechnology work and modeled being a "guide" for students.
Jeanne (primary researcher/study author)	5	Public suburban	Had conducted research (2 summers plus Master's project)	Past TSP participant, now director

Data

The data corpus consisted of: (a) Participant-written autoethnographic material: Teachers recorded autoethnographic reflections to prompts agreed upon by group in advance. Each session generated six written 1-2 page reflections (I also contributed written material to the first session) that were annotated by seven other people, for 25 unique reflections and roughly 200 annotated pages overall; (b) Video recordings of teacher discussion of the autoethnographic data. Over 11 hours of discussions were reviewed and transcribed from video and analyzed using Dedoose® qualitative analysis software.

Coding. In coding, I sequentially relied on theoretical *a priori* codes, themes identified by teachers during the CAE sessions, and codes that emerged from coding using a modified grounded theory approach (Glaser & Strauss, 1967). I drew some of the theoretical codes from the sense-making ideas in Bang et al. (2017) such as *sensitivity to sense-making* and *engaging students in sense-making*. I also included codes related to my research questions and the broader theme of argumentation (e.g. *student argumentation* and *sense-making discourse*). Themes that teachers noted in discussions of autoethnographic work, such has the importance *of interpersonal relationships*, were prioritized in the coding and analysis. These codes included the importance of teacher/student relationships, student/student relationships, and safety to do sense-making in the classroom. Finally, I used open coding (Merriam & Tisdell, 2016) to identify codes (such as race and gender equity issues) directly from the data.

Validity. I triangulated data sources to confirm my interpretation of the findings and shared my analysis with the participating teachers to member-check my interpretations (Merriam & Tisdell, 2016). I also engaged colleagues in my university academic research group as informed experts in order to provide checks on my interpretations.

Findings and Analysis

This research project focused on the professional learning of teachers as they engaged with one another in thinking and learning about the social and cultural dimensions of scientific argumentation in a small learning community. Below, I describe the major findings of our efforts as a group. Two main themes diffracted (Haraway, 1992; Haraway, 1997) through the four sessions: (a) Relationships: the characteristics of intellectual relationships in a knowledge community, and (b) Sense-making repertoires: teacher efforts to recognize and leverage students' sense-making repertoires of practice (Gutiérrez & Rogoff, 2003). I use the diffraction of these themes over time and across participants and settings to organize the stories of our discussions, with a focus on what the themes can tell us about student argumentation in the science classroom. I also use a diffractive lens to show how the CAE process supported learning within the group and how ideas traveled between texts and among different participants, becoming reinforced and modified as they moved. I then provide examples of how diffraction of ideas occurred within individual participants as filtered through their own histories as well as new information they encountered. Finally, I discuss how my role within the group was also a diffractive one.

Session One: "*We all sort of jump to that relationship piece*"

Participants came to the first session with responses that they had written to our first prompt: How do your own past experiences (family, cultural, professional) influence how you talk with your students and/or how you incorporate talk into your classroom? After I provided a short presentation on the CAE methodology, we read the responses and discussed them. I chose this prompt to ground our learning and discussion in our own histories and identities, and also so that we could learn more about one another. In the written responses as well as in our discussion, the importance of relationships became immediately apparent.

Relationships. Relationships emerged as our first large theme that was diffracted through our sense-making. Below, I discuss some aspects of how we thought about relationships between teachers and students as well as between students and other students.

Teacher to student relationships. Teachers made reference to the importance of building relationships with students and knowing about their lives and interests. Raven noted that former students who came back to school to visit were asked what they remembered, and they answered that it was the relationships with teachers that mattered most. “You can’t,” she noted, “get to some of this [academic] stuff until that’s there.” Teachers also connected these ideas to their own lives and histories as parents and children. For example, Liza mentioned that none of her own adult children had science teachers they “liked or respected” and that “they missed opportunities because of this.” Her children did not remember any content, only whether the teacher liked them, made them feel important, or gave them confidence moving forward. Her discussions with her children had changed her, she wrote. She still felt that what she taught her students was important, but she also just wanted to “listen to them so I know what is important to them and how to build on their own dreams.”

Sylvia also brought up a connection to family after reading Liza’s response. She had written an exclamation point next to Liza’s comment about her children’s science teachers and relayed a story: The prior week, she had asked her own kids, “Who’s your favorite teacher and why?” Her older child, who is transgender, said that it was the math teacher who respected them when they were transitioning in name and pronouns. She noticed her child now loves math, and she believes that it has a lot to do with how they felt in that classroom.

Group members also surfaced strategies for building relationships with students. Liza wrote that in order to build connections, she asks a lot of questions of students, including “their outside interests, what they do with their free time, how their other classes are going, what is their homework load like for the week, what types of tests are helpful, what type of homework is helpful, etc. to applications of the class content." Anna wrote about how her family had an expectation of talking with one another and asking questions about their world, something she brought into the classroom: "Following a similar model of behavior as demonstrated by my parents, I began engaging students in simple communication about one another and myself – favorite movies, oreos vs. chips ahoy, weekend plans, etc…Getting students and teacher to talk about themselves began to establish emotional equity in the classroom – we know each other and are invested in the lives of one another." Thus, both Liza and Anna used the strategy of asking simple questions about students interests or lives helped strengthen relationships with students. They also connected family experiences to thinking about communication between teachers and students.

Student to student relationships. Teachers also discussed the importance of relationship-building between students. They noted that students needed to be comfortable talking with one another before they could talk about science content or engage in argumentation with each other. Jolene wrote about the need to provide structured opportunities for students to engage with one another if they do not already know one another. She described her move from a small parochial school with a homogenous, close-knit population to a larger public school where students did not know one another well:

> Because of my experience in Catholic school, I assume the students sitting together at a table know each other, but many students enter my class as strangers, they may not feel comfortable talking with students, let alone talking about science content with each other. For so long I taught a group of students that knew each other intimately, that I got out of the habit of providing structured opportunities for students to engage with each other. Now, teaching HS students who come from very diverse backgrounds…I need to focus on providing opportunities for all students to connect with other students on a regular

> basis, and…incorporate opportunities for them to participate in structured talk. (Jolene, written response)

There was much animated discussion about how students needed safety to engage in argumentation and sense-making discussions and how knowing one another can lead to richer conversation. Liza built off of Jolene's writing to note the importance of feeling comfortable with others in order to contribute. In doing so, she emphasized how knowing others and having relationships with them can lead to richer conversations. She also connected her comments back to the TSP teacher professional development, where teachers were asked to contribute to a sense-making conversation in the role of students and without knowing each other very well:

> I don't think you can get kids to talk in class when they're strangers with each other. We're getting to know our kids...but it wasn't until I changed seats recently, I didn't realize that they didn't even know their new lab partner's name...I don't think I can continue to get conversation and any kind of valuable talk going until they're not strangers with each other. When we were in the circle this summer, did you guys all feel comfortable talking with the 20-something teachers?...I have to think about how to make the students know each other as well as us knowing the student, because that will make richer conversations. The richest conversations I've had in my classroom were definitely with my COE [Collection of Evidence] kids where they all knew each other, they'd been together. (Liza, discussion).

Student-to-student discourse and relationship-building were seen by the teachers as highly valuable but under-emphasized in their professional experiences. Sylvia commented how teachers are often asked to focus on building relationships with students, but that there is little emphasis on the importance of students knowing each other. She talked about how she had spent the morning reviewing one of the standards for her National Board Certification that emphasized teacher-student relationships: "I just sat down with my first standard of National Boards all morning, 'Knowing Your Students' and *it doesn't really talk about the students knowing each other* (emphasis added)." Jolene extended Sylvia's idea, noting the importance of intentional structures to help scaffold students getting to know one another: "[The National Board] is assuming they will just figure it out but [students] need those structures in place."

Sylvia also noted how factors that might not be evident to teachers can impact student to student discourse: “I once taught an ecology class...and they were really, really quiet. Finally, I said, ‘What is going on?’ and they said...We are all sophomores and there are five juniors in here.’ It had never occurred to me that in a class of 20, if one quarter of them are older, it would just shut them down.” Anna emphasized that students do not necessarily have to be friends but can be colleagues or have a “professional interpersonal relationship” to “work together to come to a common consensus or come up with an answer.” I referenced how that orientation also reflected the professional context of scientists working with one another to problem-solve.

Teachers acknowledged the importance of relationships for argumentation and sense-making discourse, academic learning, and students’ connection to school. Sylvia mentioned how noteworthy it was that they all commented on the importance of relationships in supporting classroom argumentation in their written responses: “*I find it interesting that we all sort of jump to that relationship piece, which is a big part of argumentation but not something that you would ever talk about* (emphasis added).” Relationships were seen as the foundational layer to making discursive practices such as the collaborative dimensions of argumentation possible.

Sense-making Repertoires. The ability to recognize and support students’ sense-making repertoires emerged as a second theme. This theme was closely connected to the first in that teachers recognized the need for safety in order to participate in sense-making, and that the feeling of safety emerged from trust built through relationships. Raven identified the idea of safety after reading everyone’s reflections:

> A lot of people mentioned the difficulty of having to feel safe about doing their own sense-making. The difficulty of it either from scaffolding, how you do it well, to like students can be "wrong" and to discuss their actual ideas, particularly in a classroom. There really needs to be a safety in the rapport and there's the emotional side of it, and then how do we do it coming from our middle class or whatever class perspective we come from, those different pursuits. (Raven, discussion)

As Raven noted, teachers connected the idea of needing safety in the classroom to support argumentation and sense-making discourse with their own personal histories ("coming from our middle class or whatever class perspective we come from"). They acknowledged that their own history, privilege, and intersectional aspects of their identity can impact students' abilities to engage in the classroom. Raven referenced how impactful being bussed to a different part of town as a youth and meeting students who had less opportunity to access resources than she did impacted her from a justice perspective. In some of her classes, while growing up, she was in the racial/ethnic minority and would not know what was culturally acceptable. That experience encouraged her to "elevate marginalized groups or people who are different." She also wrote about how she was always curious as a youth and recognized that "being middle class and having the luxury of being able to go on vacations and to museums helped me to have the resources to ask those kinds of questions easier." Similarly, Sylvia wrote that students told her she was using what they saw as white, middle-class examples to explain scientific principles of force and motion (for example, skateboarding and parkour). She also wrote that she had a "very cis-female, white, middle-class, parental way of asking questions and especially giving feedback" and that students of color have told her that they are "less likely to share or argue ideas because of safety issues" (the majority of her students are white and middle class). However, her background and familiarity with LGBTQ+ communities made her classroom "very safe for these voices."

During our first session, the conversation also turned to ways to help elevate students' cultural and everyday resources to support sense-making. Manat described how she asked students to talk to their families about topics that were being addressed in school in order to connect home and school experiences. For example, she asked students to talk to their families about what the weather and climate is like where their families were from and if they had noticed differences in the last 30 years. She also asked students to talk to their families about fireworks ("When have you done fireworks? What's inside of the firework? Why do you think they're different colors?") and mentioned that one student's father shared his experience with military explosives. She emphasized to students that it is important for them to speak with their families in their own language and to write their experiences in their home language ("It's been cool to get them back in different languages"). Manat provided other teachers with examples of how she had engaged student in seeing how their own family and community can be resources for thinking about science (Bang et al., 2017). This consideration of ways in which to recognize and value students' diverse resources was also taken up in later sessions.

Overall, the first session laid an important foundation for our work together. It established the major themes (reflection and sense-making repertoires) that would diffract across our study, orienting our discussions. Significantly, grounding the initial session in our own cultural and personal histories helped to animate these discussions and emphasized how important those factors can also be for learners. For example, Liza and Sylvia both made connections between their roles as parents and teachers. Liza's adult children remembered primarily how they felt in classrooms more than any particular instructional content. Sylvia believed that her child was drawn to particular subject matter because of the relationship her child had with the teacher, who recognized and validated the child's identity. Anna also connected her personal history with her teaching: expectations for talk in her family translated into her classroom practice of beginning relationship-building among students using low-stakes conversations. We surfaced how important relationships (both teacher-student and student-student) are in cultivating an environment that promotes productive argumentation, echoing the connection Bang et al. (2017) make between relationship development and equitable opportunities to learn science. However, teachers noted that in their professional experiences, the quality of student relationships was not something commonly associated with the teaching of scientific practices.

Participants noted that their sensitivity to, and support of, student sense-making was also grounded in their personal and cultural histories. Sylvia connected her experience with LGBTQ+ communities to her ability to make her classroom a safe place for students who identified in that way, but she also recognized that some of the examples she used in class as well as elements of her discursive style reflected a white, middle-class orientation that alienated other students. Her experience highlights the complexity of cultivating classroom environments that can support a range of student identities and cultural histories.

Session Two: "*Argumentation leads to vulnerability*"

The questions for pre-writing that teachers decided upon for the second session were: (a) What does argumentation allow my students to do? What is it a gateway to?; (b) How do our own relationships with students ("knowing them") impact classroom talk and argumentation? How do we build those relationships? How can we be close, yet professional?; (c) How do students' relationships with one another ("knowing each other") impact classroom talk and argumentation?; and (d) What kind of instructional structures support talk and argumentation? What kind of instructional structures support relationship-building? These questions built directly off of our discussions in the first session and extended them.

Relationships. The second session started on a somber note, as Raven had two tragedies in her classes. One student was in a train accident and was still hospitalized with severe injuries and the other had taken their own life. She noted that she had been thinking a lot about student relationships as a result. She had been very honest with her students and emotionally vulnerable in front of them, and it reinforced for her that relationships are paramount. The theme of vulnerability in relationships also emerged in the written responses and the discussion that followed.

Vulnerability and safety in relationships. When I asked group members what patterns they saw in the data, Liza answered that the responses connected argumentation to both relationships and vulnerability:

> It seems like there was a subtle if not obvious thread throughout that *argumentation leads to vulnerability*, so it is harder to present any kind of evidence that it is to just answer questions in class…the relationship piece has to be there because there is a vulnerability there. You're thinking something and you're making a hypothesis. Why did this look like that? Why did it turn out this way? You don't know and you're putting it out there to 32 kids. That's pretty vulnerable. (Liza, discussion, emphasis added)

In our conversation, I then noted that Sylvia's writing also referenced how the quality of student contributions is often tied to their established academic and disciplinary identities. Sylvia had previously raised safety in the first session when she noted in discussion that, "the number one challenge is creating that safe classroom where students can be wrong." In her writing, she noted:

> My students have mainly been using formal argumentation to reach consensus on ideas. They will start with conflicting ideas or models, and then after describing how their model answers specific questions, they wrestle and argue with refining these models to make them more predictable...The issues come up when students are still 'playing the game of school' in which there is a right or wrong answer. [These students]...resist change because they have their egos tied up in getting the right answer...*Students must feel safe in order to be willing to talk and argue with ideas*….adolescents are unlikely to feel okay with being 'wrong' (as they see it)...*Knowing students is a first step in creating a community that helps them feel safe*. (Sylvia, written response, emphasis added)

Jolene also wrote that "students who feel safe and cared for are willing to share and talk with their classmates. So, before we start teaching kids how to participate in scientific argumentation, we have to get them talking to each other and to the teacher." She went on to note that once students are talking, discussion protocols can help ensure equitable participation but that students needed a sense of safety first.

Liza, Sylvia, and Jolene all emphasized that students needed to feel safe in order to make themselves vulnerable to putting out (possibly inaccurate) argumentative claims and to wrestle with competing ideas. Liza referenced the importance of relationships to creating an atmosphere where it is alright to be vulnerable, and Sylvia emphasized how knowing students helps foster a community that is safe for argumentation.

Another dimension of vulnerability that we discussed was the willingness of the teacher to be wrong in front of the students. In the first session, Anna had noted how being open about her errors in front of students had helped them feel safer talking. In the second session, Liza took up this idea again. She described how she was trying a new curriculum with planarian worms where she did not know the answers to the questions students were asking: “I think there’s something when you’re not afraid to fail, they love it. I mean I’m taking a lot more risks...I thought I killed them because the liver [their food] was in the water all weekend, so they all laughed...it’s been great.” Modeling vulnerability as a teacher was a powerful way to help send a message to students that it’s okay to be wrong and make mistakes. Yet teachers also raised the need to maintain professional boundaries when learning about students and building relationships with them. Manat wrote, “I think it’s possible to be close yet professional...I think the students also know that I’m their teacher and not their friend because of how I interact with the whole class.”

Across the data in the second session, the connection of relationship to vulnerability was frequently raised and cited as critical to enacting expansive pedagogical practices. Teachers connected ideas of vulnerability back to the prior discussions on relationships in the classroom.

Anna noted that across the written responses, “the best strategy that all of us implemented was relationships.” They emphasized how creating a classroom environment that fosters open and constructive communication and argumentation not only requires relationships, but also safety and trust.

Accountability in relationships. Sylvia also highlighted the importance of accountability (Engle & Conant, 2002) as a key factor in successful discursive argumentation, noting how many written responses implied its importance: “When I was reading everybody’s papers, people sort of hinted on but nobody explicitly stated...it’s the accountability piece that contributes.” She also noted that the accountability could be from the teacher (top-down), the classroom culture, or other students in class. I connected accountability to Sylvia’s work on building consensus around models: “In order to really build consensus, you have to listen to other people and be accountable to your and their ideas and trying to put them together. It’s not going to work if you’re just kind of sitting there not hearing other people.”

Challenges in student relationships. Teachers also discussed challenges in student relationships in the classroom. One aspect of student-to-student relationships that came up in our discussions was how to address student conflict and partisanship that are often entangled with personal or cultural histories (Cornelius & Herrenkohl, 2004). Anna noted how students’ beliefs about what other students were capable of could limit willingness to participate, and followed up with her belief that the way around that was to instill student-student classroom talk throughout all activities so that it became the norm:

> The students who think, ‘Well that’s a smart kid so they know everything but I said something stupid’ and then the smart kid who responds like, ‘Well, I know the answer to this, I’m not really going to entertain what you want to say about it.’ It seemed like that was a dynamic...that is encountered. Sylvia, you mentioned in part of this about how in students’ relationships with one another...just kind of make it a norm...This is what we do

> now in here. This isn't like...this section of our day is talk time. It's just like this is the style that you keep in this space…(Anna, discussion)

Other teachers mentioned the challenges of working with culturally heterogeneous student populations or the impact of race, gender and socioeconomic class dynamics. Sylvia noted that she felt she was building relationships successfully but that her students were largely the same race and culture despite having different ways of learning and views of science. She wondered how her classroom would change if she had students from many different backgrounds. Raven noted that "white boys or just boys in general are more likely to...just think that they're right to argue...How do we raise up voices of those who have all those intersectional things that affect them?" Liza agreed, sharing that in her school "white males can dominate really fast at about 15-16 [years old]."

In summary, as the theme of relationships diffracted into the second session, it took on added dimensions of safety for sense-making, vulnerability on the part of the teacher and students, and accountability. It also raised the issue of problematic relationships between students and the influence of race and gender on their interactions. Below, I discuss how the theme of student sense-making repertoires also diffracted from the first session into the second.

Sense-making Repertoires. The discussion about fostering students' sense-making repertoires in Session 2 grew mostly out of the research articles that teachers had divided up to read, particularly the paper by Warren and colleagues (2004) that focused on reconceptualizing the boundary between "everyday" and "scientific" thinking.

Sensitivity to student sense-making. We discussed the research papers with an eye to what we could learn about cultural dimensions of classroom talk, including argumentation and questioning. The importance of *teacher sensitivity to student sense-making* (Bang et al., 2017) came out particularly strongly in the discussion of the Warren et al. paper (2004). Anna noted the assumptions that educators and sometimes researchers make that "if the syntax and dialogue and discourse of academic language isn't present, then the kids aren't getting it...The way we hear it might not be something that is related to us and because of that, we dismiss it or maybe we say you don't understand, or we say if it's not communicated in this specific way, it's not relevant, or you don't get it, or it's not scientific." Sylvia picked up the thread and cited a particular passage from the paper: "It says on page 143, 'you had to work at learning to see and hear the intellectual substance in Letisha's talk', so the idea is that it's not up to the kids, right? It's really up to the teacher to hear really what's happening and what their ideas are…" Sylvia emphasized that it is the responsibility of teachers to expand their sensitivity to student sense-making and not assume that because students are expressing themselves differently that intellectual substance is lacking in their talk.

Anna echoed the importance of teachers taking responsibility for being open to students' diverse ways of figuring things out. She commented that preservice teachers are instructed to record in their lesson plans the specific vocabulary they want to hear students use as indicators of learning. In reading the Warren et al. (2004) article, she realized that students are using their own talk and experiences to make sense of the world, and that hearing students use a particular vocabulary word is not necessarily indicative of their understanding.

> ...The students are talking to each other, *they're figuring out how to say it as they are doing it...they're using their everyday talk, their everyday life to figure out how to tell you or tell themselves what they're seeing...this is where they're making meaning, this is where these principles are finding root and your inability as a teacher to know that or hear that or see that isn't their problem*...I think a lot of times our assumption is, well if you didn't say 'inertia', you don't get it (laughter from the group)...They mentioned students who come from different linguistic backgrounds...or cultures that don't use these words as part of their life, we just assume they are...not getting it or they don't understand or we make an assumption that they're not meeting the standard…[when] they are probably are either meeting or exceeding, based on their life experience. (Anna, discussion, emphasis added)

The readings helped provide examples of how students' cultural and everyday resources can be assets for learning. They served as a way to center the discussion on the responsibilities that teachers have to try to understand students' sensemaking and to recognize that students are learning *through* their engagement with scientific practices. Ultimately, as Anna recognized, teachers need to check their assumptions about student understanding as it relates to traditional scientific vocabulary and discourse and search for the meaning that students are making. As the *Framework for Science Education* (NRC, 2012) notes, relating youth discourses to scientific discourses in an important strategy for promoting equity in classrooms.

Session Three: "*Moving students to a higher level of rigor could potentially be a product of engaging them with one another*"

The questions for pre-writing that teachers decided upon for the third session were: (a) What types of discourse/ argumentation scaffolds am I currently using? (b) What are my own ideas about "learning" and "rigor"? How these ideas relate to argumentation? What classroom moves are integral to my beliefs about learning? (c) How can we combine engagement and "rigor" among diverse students?

Relationships.

Rigor, engagement, and relationships. Rigor had come up at the close of the second session and we decided to explore it more thoroughly in the third. Teachers were concerned about the assumption they encountered from parents and administrators that classrooms where sense-making and argumentative discourse was prioritized did not look rigorous in the traditional sense of school. Teachers made interesting connections between student-student relationships, engagement, and rigor. For example, Anna noted that:

> We know if students are included in the classroom, made to feel like a part of the team, their willingness to engage goes up. So, maybe we could use engagement as the

> mechanism for rigor? Moving students to a higher level of rigor in the classroom could potentially be a product of engaging them with one another in the classroom. When they connect with one another, when they feel heard and understood, students may engage further in our lessons and use their classmates as tools to reach higher levels of rigor. (Anna, written response, emphasis added)

Anna emphasized how teachers could create a strong classroom community, build a feeling of belonging to a team, and engage students with one another in order to help them reach "higher levels of rigor." Teachers who bring students with diverse histories and viewpoints together and support them in leveraging their differences to build understanding recognize that heterogenous student sense-making is an asset for collective learning (Rosebery et al., 2010). Just as heterogenous views and sense-making in professional science can improve objectivity and rigor (c.f. Harding, 1998), classroom communities can draw on the deep funds of knowledge that students bring in order to strengthen the learning of their participants (Basu & Calabrese Barton, 2007; Moje et al., 2004; Moll et al., 1992).

Sense-Making Repertoires.

Rigor and sense-making. Teachers also connected rigor to sense-making and cultural experiences of students, based in part off of their readings of the book *Culturally Responsive Teaching and the Brain* (Hammond, 2015). Liza noted traditional views of educational rigor, particularly as viewed by parents, included: "'How challenging is it? How hard is it? How much homework are you giving my kids? How rigorous of a teacher are you? How hard are your tests? That's sometimes the parent disconnect." She mentioned that the book gave her a "whole different idea" around rigor, one that centered on diverse sense-making. Liza noted that Hammond talked about the connections between input, elaboration, and application as students take in information, process and build on it, and extend it. Liza recognized that students receive inputs across the broad contexts of their lives ("whatever was happening in the hall or on their phone...that has nothing to do with the classroom"). Liza then connected the idea of the importance of students taking significant and meaningful inputs and elaborating and applying them: "...when [Hammond] said elaboration and application, I think if a student can elaborate on what you taught them and then apply it to something else, that *I really liked her take on what rigor would be. You've hooked it to the kid, you've hooked it to their experience or their experiences and their culture, they now understand what you're talking about from their own experience and now they can elaborate on it and apply it from their own cultural experience* (emphasis added)." Liza was able to reconceptualize rigor in the context of students' ability to connect their own cultural experiences with instructional ones and to extend and apply their ideas.

Collaborative sense-making and model-building can support equitable learning, allowing all students to participate in rigorous experiences in science classrooms. In describing her own experiences with enacting rigorous pedagogy for all students, Sylvia contrasted prevailing conceptions of rigor with her view on rigorous learning:

> There is currently a fight in the district between parent and teacher perceptions of rigor and science learning. In the standard model of learning, students learn something, then are able to regurgitate facts and apply them to some degree. In the newer thinking about learning, students engage with each other and activities to build knowledge and conceptual or mathematical models...this work HAS to be done in a group and ideas often do not match up. However, as my pedagogy has changed, I have found that this type of work is rigorous for all students. We can give more sophisticated model expectations...to students who traditionally learn more quickly and give more simplistic model ideas to students who struggle with learning. However, this means that learning is accessible to ALL within a classroom. (Sylvia, reflection)

Whereas Liza focused more on "hooking" students' cultural and everyday experiences to something they could elaborate on and apply, Sylvia emphasized how opportunities for argumentation, model-building, and collaborative sense-making could provide rigorous learning for all. Sylvia had also emphasized in her reflection that if "you listen to the ideas that students are really entering the door with, then you as a teacher are embracing the diversity. Students are more likely to engage if they feel listened to, and special, and if they have a voice in how the learning is going. I believe that we are meeting where they are at, and the conversation actively becomes more diverse and more rigorous." Thus, Sylvia connected the ability of teachers to be sensitive to student sense-making and to be able to listen to student ideas with increased rigor in the classroom. Both Liza and Sylvia argued for a reconceptualized view of rigor, one that is linked to students' abilities and experiences and that is made possible by teachers' attunement to students' diverse sense-making. Teachers also acknowledged the challenges of trying to make learning rigorous for all students. For example, Anna noted that she envisioned rigor in her classroom as happening when students have an appropriate challenge "that pushes their boundaries while also supporting their skills," but that she felt "my lesson regularly fails to meet the expectation of rigor for all my students."

Engaging diverse sense-making. Teacher examples of engaging diverse student sense-making by incorporating relevant personal and cultural connections continued in the third session as we discussed the importance of leveraging local settings and phenomena. Raven suggested that in teaching evolution, "Why not do it in the kids' neighborhood? When I was in New York...we'd go around and talk about it, like what they saw, the urban wildlife. How have we changed? The stuff that they see. I think [other students] went around and took pictures of lichen or moss [to answer the questions] 'How does pollution from the airport...affect people living there, and how could it affect them?'" Raven also mentioned an example of how to use a cultural formative assessment to surface the interests, experiences, and identities of students in order to guide instruction. She had learned about student self-documentation in school district training conducted by colleagues in my research group. Students took pictures related to health practices from their cultures and that they used at home and then shared those with other students and the teacher (Reeve & Bell, 2009; Tzou & Bell, 2010). She noted, “we looked at all the pictures and they got a really deep science talk with it.” Building on Raven’s suggestion, I mentioned the work of Calabrese Barton and Tan (2008) that examined pedagogical approaches to including elementary students’ everyday knowledge and home/cultural cooking practices in a unit on food and nutrition. Raven and I provided the group with concrete examples of elevating students’ diverse experiences (health or food-related practices from their family or community lives), making them visible and centering them, and using them as resources for learning.

Manat called out a tension between scientific and everyday evidence and wondered how to reconcile them: “How do you teach kids to have this evidence that’s privileged in science and important to science but also still honoring the types of evidence that they bring from their everyday lives and like the other ways of knowing? I think that’s kind of a tension.” This allowed me to share the work of Megan Bang and her colleagues on desettling expectations in science (Bang et al., 2012). I recounted how that work had led me to question and challenge my own assumptions of what is ‘living’, which resulted in a major shift in my own thinking.

The conversation turned to the power differential between teachers and students and the importance of not overly prying into students’ home lives. Anna mentioned students who might have the attitude that “you can ask me those questions and you can’t know about my life that way or you pretend to know about my culture and have an understanding.” I mentioned that there “has to be an acknowledgement of the value of what they’re bringing and to appropriately use that information.” Raven picked up on that, suggesting that positioning students as experts “can go a long way.” I then shared that Shirley Brice Heath had told me that she asks students about their expertise in order to be able to position students as successful and good at something, which can be leveraged in later conversations or when the student encounters challenges. We agreed that valuing student expertise was a respectful way to set the stage for students to share about their family lives and outside interests.

As the theme of student sense-making repertoires diffracted into the third session, it also intersected with ideas of rigor. Some of these ideas came from the text, some from experience. Participants examined how rigor could connect with ideas of students' personal histories and cultural experiences, and how sense-making argumentation and model building could provide rigorous opportunities for student engagement. Ideas about bringing in, and connecting to, student cultural and everyday resources also traveled from the prior session (Manat's firecracker example) into this one (Raven's example of self-documentation of family health practices). The two exchanges above (about other ways of knowing and student expertise) also demonstrate how ideas diffracted rapidly between participants, texts, and personal histories. For example, when Manat raised concerns about how to balance knowledge privileged in science with students' everyday knowledge, I was able to share ideas about desettling traditional science education from a research article, and also bring in a story of my own change and growth. In another example, when Anna voiced a concern about teachers needing to be cautious about prying into a students' personal life especially given the power differential teachers have, Raven introduced the idea of positioning students as experts, which allowed me to diffract in a story about a past conversation that stressed the importance of learning about students' expertise in order to know their strengths and leverage them for learning, and how intrigued I was by that idea.

Session Four: "*I don't know if I totally recognized how much culture...can influence how and when these components of the brain are triggered*"

The autoethnographic writing prompts for the last session were: a) How has my thinking about argumentation and other scientific practices changed as a result of my reflections, readings, and discussions in our argumentation research group? b) How can we design the Teacher-Scientist Partnership (TSP) summer PD to best help teachers address scientific practices such as argumentation? In particular, how can we: Emphasize the professional practices of scientists and have teachers reflect on how knowledge is constructed in science? Help teachers draw on the cultural and everyday resources that students bring to practices such as argumentation?

Much of our discussion in the last session veered towards the broader purposes of school. Liza revisited the idea of rigor and voiced concern about whether students would be prepared for college if teachers implemented the types of ideas we had been discussing. Sylvia was able to share her long-term experiences having the same students in her 9th/10th grade classes now in her AP biology classes. She described how she had made pedagogical shifts based on the *Next Generation Science Standards* (2013) and Ambitious Science Teaching (Windschitl, Thompson, & Braaten, 2018). Specifically, several years ago she began using anchoring phenomena and instruction that led to students to developing explanatory models with her younger students. Now that these students were older and were taking her AP biology course, they could do much more than her previous AP students did: "The things my students can do in terms of thinking critically and making sense...they've gotten better and better at it...I do feel like they're more prepared. It doesn't look like it because it looks so different from college, but I do actually think they're more prepared."

Relationships.

Teachers in the CAE group. Most of the focus on relationships in the last session was centered on our experiences within the CAE group itself. We felt the CAE process was a productive way for us to learn from each other and stay engaged in thinking about dimensions of argumentation. One particular advantage was the ability to talk deeply about practice with other professionals who were not in the same school. Anna mentioned that "there's a lot of bliss in this experience of having a shared experience but not an experience we share everyday together. That's been really valuable and being able to reflect upon the components of myself and my teaching that maybe I wouldn't otherwise do, or I would do alone and be nervous to share with an administrator or to share with my co-teachers." She specifically referenced her vulnerability around reading the Hammond book and being reflective about where her "pitfalls" were. Thus, the idea of vulnerability mentioned in earlier sessions diffracted into Anna's thinking about her own learning in our group. The CAE process supported teachers at different stages of their careers, and serving a range of student populations, with the opportunity to build professional relationships and learn from one another.

Sense-Making Repertoires.

Sensitivity to student sense-making. We continued to explore how sensitivity to student sense-making could be enacted in the classroom. In this last session, we discussed how a teachers' inability to consider or understand students' cultural frames could hinder sense-making. For example, Anna talked about how culture can be related to stress triggers for students, based upon her further reading of the Hammond (2015) text. In the quote below, she first cites the text (in the first two sentences) and then goes on to discuss her thoughts about it:

> Culture influences the ways [the brain] works…[and] when their flight or fight picks up. When that happens, that can be completely cultural...Something could be a part of the culture that I don't understand and I tap into it the way I say something or approach something or ask for an interpersonal dynamic that those students are not prepared for, and then students just immediately are having a lot of anxiety or freaking out about something and they sense they're not safe…I don't know if I totally recognized how much culture...can influence how and when these components of the brain are triggered...(Anna, discussion)

Raven picked up on the idea and extended it to trauma students may have experienced: "Sometimes we blame the kid or we're just like, 'Oh why can't they concentrate?'...It's just because...their brain is processing differently." Raven shared how the Special Education teacher at her school had helped her understand dissociative behaviors, which are coping mechanisms for students with trauma. She felt that with the knowledge of where students were coming from, she could work to foster neural plasticity and change. Anna then quoted the Hammond text directly to emphasize the importance of centering students: "Your definition of what feels threatening or welcoming may be different than the student's definition…It's important to act according to students' definitions, not your own" (2015, p. 47). Anna and Raven recognized that what appears as student disengagement may be connected to deeper issues such as trauma or to ways of seeing the world that are not always immediately transparent to teachers.

Engaging diverse sense-making: equity. The idea of equity also came up explicitly in connection to opportunities for deeper sense-making. Jolene introduced an element of equity when she described the interesting projects that honors students do and "why do we not do that in regular [biology]?" Jolene described how "perpetually those types of projects are restricted for the honors kids" and her sense of unfairness at the inability for students at all levels to have access to engaging work. Anna noted how she had previously thought about equity in terms of access to computer equipment or other resources, but realized that equity also manifested in the ability of students to engage with classroom activity: "when a kid just cannot engage with anything you're talking about...you don't have access...how do I fix that?" Anna was thinking about equity more expansively than she previously had and was now considering it the responsibility of teachers to ensure that students can engage in classroom activity.

Overall, the fourth session allowed us to take stock of the benefits of a CAE learning community, which allowed participants to be vulnerable with other professionals outside of their district and school building context. We also continued to discuss the responsibilities that teachers have to try to understand how students' cultural histories as well as traumas may influence students' reactions and ability to engage in certain activities. In particular, we discussed not making judgments and assumptions about students' learning based on our expectations or what feels safe for us. Finally, we tied the idea of the importance of diverse sense-making to equitable learning opportunities for students—all students should have the chance to engage in interesting, relevant, and challenging work and to find meaningful ways to engage with the activities of the classroom.

Diffraction in the Collaborative Autoethnography Study

The CAE process naturally lent itself to the diffraction of ideas: Teachers reflected independently first, then put those reflections out to others to interpret, find patterns in, and make meaning from. As individual teachers identified themes from the collective written reflections or readings, those ideas diffracted in different ways against their own experiences, interacting in entangled ways with memories or stories from areas as diverse as their past teaching, their own family experiences, or their cultural background. The data presented so far have focused on how the main themes that teachers identified diffracted between individuals and across the four sessions. Below, I first summarize the findings related to the diffraction of those main themes. I then describe three additional examples of diffraction: two examples of diffraction *within* individual teachers and one example of diffraction *between* teachers.

Diffraction of major themes.

Relationships. The main themes of this study emerged in the first session and continued to surface in different ways across the remaining sessions. Early on, the importance of relationships for learning in general, and argumentation in particular, was evident in the data. In the first session, we focused on teacher to student relationships as well as student to student ones. In the second session, this led to a broader discussion about the role of vulnerability, safety, and trust within relationships—as a response to processing difficult and tragic situations that had happened to students between our sessions. In the third session, Anna raised idea of building relationships between students themselves and engaging students with one another as a way to think about increasing rigor in the classroom—an entanglement of ideas that was unexpected given early discussions of rigor. In the last session, we mostly talked about relationships in the context of the CAE group and approach itself, and specifically of the importance of safe learning spaces where teachers can have professional support but that are outside of their regular work contexts and networks. The focus on relationships shifted from a focus on student-teacher relations to the very operating nature of those relationships. It moved from there to a focus on peer relations and a realization that increased attention to cultural diversity could increase rigor. We ended with the realization that teacher learning could be enhanced when the operating relationships in the group were not directly associated with teachers' everyday workplaces.

Sense-making Repertoires. The ability of teachers to be sensitive to, engage, and support student sense-making repertoires was the other major theme that diffracted across the sessions. In the first session, we talked about safety for sense-making and how that connected particularly to their own personal histories. We discussed how their own intersectional backgrounds might result in some students feeling safer to engage in sense-making in their classrooms than others. We also began a conversation that continued through the remainder of the sessions about engaging students in science by leveraging their cultural and everyday resources. In the second session, we explored the idea of teachers' responsibilities to look for student sense-making, particularly when student discourse diverges from teachers' expectations for classroom talk. In the third session, rigor was discussed in the context of relationships but also emerged in the context of sense-making: Liza contemplated how the idea of rigor related to students' ability to connect their own personal and cultural experiences to science class and Sylvia noted how collaborative sense-making makes learning more rigorous for participants. We also continued to explore specific pedagogical strategies to engage diverse student sense-making. Finally, in the last session, we discussed the importance of teachers' sensitivity to the ways that students' culture or prior trauma may impact how they react and make sense of what is happening in a learning environment. Teachers also identified the ability of students to engage in meaningful learning experiences as an equity issue. Overall, the focus on recognizing sense-making repertoires began with the impact of teachers' own experiences and cultural histories on creating environments conducive to learning. It then shifted towards the responsibilities that they have for recognizing the strengths and resources that students bring to the classroom. Teachers' reconceptualization of rigor also diffracted into this theme; rigorous instruction engages students, connects to their lives in meaningful ways, and provides diverse sense-making opportunities that foster equity.

Diffraction within individual teachers. Manat wrote about rigor and learning in conjunction with the idea in the Hammond text (2015). Paraphrasing Hammond, she noted that "we tend to give more challenging and interesting questions and learning tasks to students that we think are 'ready' and emphasize more 'rote memorization' for other students." She connected this idea to an experience when she was a Teaching Assistant for a summer program: One of the teachers told her, '"I don't want ELL students in my science class because it's a safety concern. If I said 'STOP' they wouldn't understand." She recalled her hurt and frustration by diffracting that experience against another, one from her own community where members are underestimated or seen as 'dumb' because they don't speak English as a first language: "For example, there's this uncle in my community who writes beautiful poetry in Punjabi but speaks what people term 'broken' English, and I've seen how people in dominant culture treat him as stupid - not knowing how beautifully articulate he is. I think my connection to my community and seeing this first-hand has impacted my lens as an educator…" Thus, ideas from the reading diffracted through her past teaching experiences as well as through elements from her cultural community as she considered what it means to provide all students with appropriately challenging and interesting work and not to make assumptions about students' capabilities (e.g., based on narrow expectations or lack of understanding of student assets).

Anna provided another example of diffraction within an individual teacher's ideas. She expressed the changes in her attention to elements of interpretive power over time and as a result of discussions and readings. In the third session, Anna shared with others how annoyed she initially was with the Hammond (2015) text, and how her views slowly changed as she read it: "I was super annoyed and kind of offended...and then...I got really kind of into it (laughter)...and I think it's meant to be because it needs to be pretty accusatory because of the way we teach and how bad we are." She noted that she recognized she was a white teacher with who grew up in the U.S. and had parents that also did so, that she had enjoyed a culturally responsive teaching course in graduate school, yet she was agitated and defensive in looking through the book: "How am I supposed to understand any of this? I am trying my best as a teacher…" She noted that the book made her realize that teachers need to "start figuring out why learners are dependent, and a lot of it has to do with our inability to be culturally aware and recognize how brains work, how we develop and teach them...the idea that really resonated was that a lot of the students we have that we assume are really struggling with their independent learning strategies come from this deep cultural root of collective habitual life of learning collectively and where we teach, that's not what we do." Anna then diffracted in the earlier research from Hudicourt-Barnes (2003), noting that "Tying it back to the Haitian article...What we hear in these classrooms might sound like they're not paying attention, they don't know what's going on, [it's] really their way of understanding what's going on around them. It's their cultural experience, a way of having/making connection with learning, having context, and so now I've made a date with myself to keep reading this book (laughter)." By the last session, Anna noted how the CAE process had expanded and complicated the idea of "growth mindset" (Dweck, 2006) for her and made her reconsider her own assumptions. In particular, she had previously believed that schools could be the "great equalizer" for students:

> Many of our interactions and readings have revealed my own limitations in being able to invite, encourage, and engage students of varied backgrounds. The commonality of U.S. science classroom is not enough, and many students are left without a voice, a sense of relevance, or an access point to even begin their road into argumentation. As we worked through our readings, my perspective on my practice shifted. No longer can I expect or demand students to share their understandings in ways that only make sense to me, or fit a script for communication that I am familiar with....I just need to meet them, greet them, and invite them on our journey from their starting point, not mine. While this sounds a lot like what I already do...the part that feels different is that students are not simply arriving at varying levels of Maslow's [hierarchy] with a need for compassion on my end. Instead, *students are carrying a culture, a tradition, a style of understanding their world that I need to identify and welcome into the mosaic of traditions that will build a classroom community, working toward scientific dialogue and argumentation*. (Anna, written reflection, emphasis added)

Anna diffracted ideas of history, culture, and diverse communication styles into her past emphasis on growth mindset, differential readiness, and compassion. She described a newfound understanding of the need to center a “mosaic of traditions” to meet students where they are, listen to them, and begin from “their starting point,” not hers.

The CAE processed fostered the diffraction of ideas within individual teachers and supported their development of interpretive power. Manat diffracted ideas from the text against her own teaching experiences as well as those from her cultural community. Anna explicitly talked about her newfound understanding that what may look like student disengagement may reflect a disconnect the student has with the traditional school learning environments of the dominant culture, and how her responsibility is to identify student assets and leverage them to build a practice-focused science learning community. Manat and Anna were able to diffract their own personal and cultural histories against the readings and discussions, recognizing the many forms that student assets and resources for learning can take.

Diffraction across teachers. At other times, ideas diffracted between individuals over time. Diffraction reinforced and amplified ideas within our small learning community. For example, teachers actively shared pedagogical strategies for fostering student-to-student communication within groups. In the first session, Anna shared that she focused first on having students talk to one another about low-stakes, non-scientific topics so that they could begin to feel more comfortable talking with one another and in the class: “I’ll just...have them talk to each other about nothing, just like share your name and tell your table mate [what you would pick if] you had to eat one type of ice cream forever?” Manat had written very honestly about the struggles she was having getting some groups to talk. By the last session, Manat had picked up some of Anna’s strategies to normalize talk between students and support collaborative group work in her classroom: “I’ve been struggling with group work and I know Anna is really strong at fostering that...I’ve been trying one of her simple strategies...when student get into new groups, I now have them first discuss a non-science question to get them to start talking to each other and build community so they can then be comfortable with talking science with each other...this simple strategy has definitely helped a couple groups start to talk to each other more." Manat went on to also include ideas from Hammond's (2015) discussion of the role of collectivism in many cultures into her ideas of group work, noting that:

> I tend to frame group work in terms of soft skills and being able to work with others in the workplace, but I think I could also frame it in terms of 'community' and how we are a community of learners that need to support each other...I think that students that come from a background with more of an oral tradition (vs. written), and collectivist tradition (vs. individualistic) also need space, and I want to try to make space for that in my classroom, so that my students feel like science is meant for them. (Manat, written response)

Thus, a strategy for building group communication and cohesion from Anna was picked up and tried by Manat. Ideas from the text also helped Manat reframe the importance of group work using a cultural lens that incorporated awareness of diverse cultural traditions.

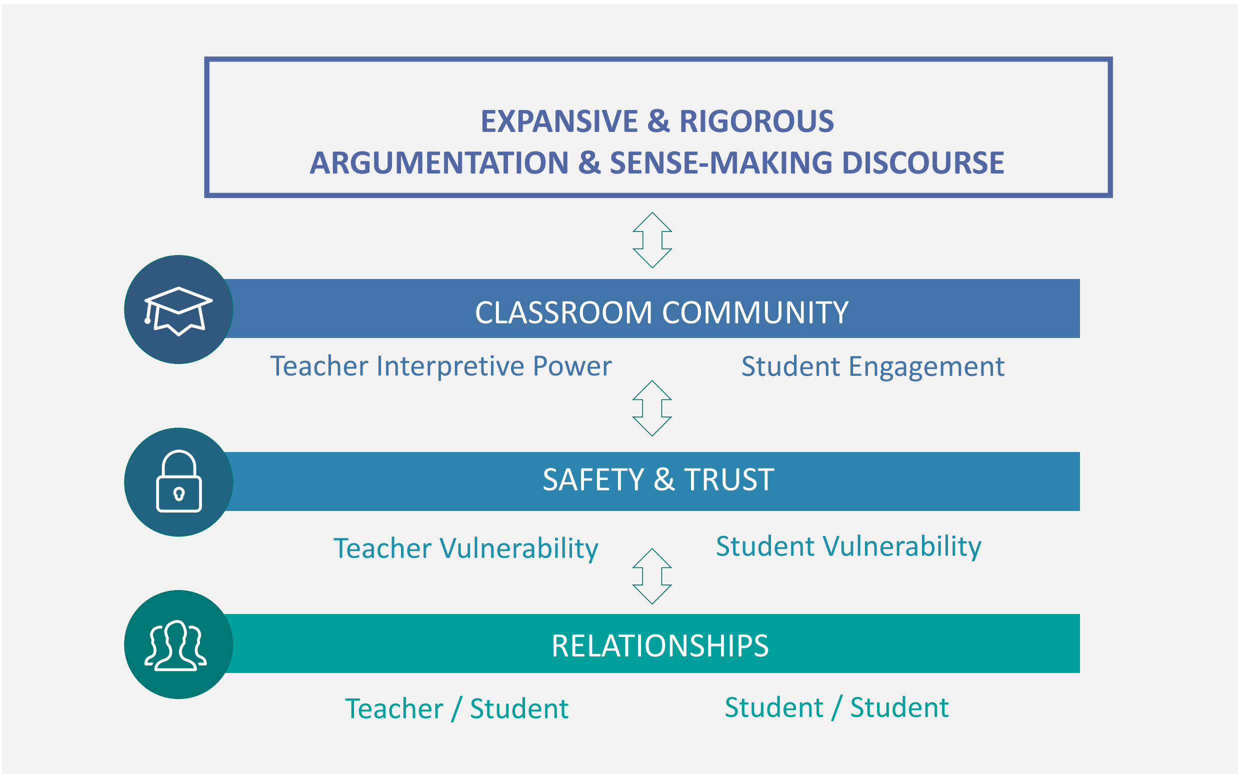
The CAE process allowed the teachers' differential expertise and specific contextual examples to diffract between and across participants. Ideas such as low-stakes student-student dialogue as a community building tool were reinforced, taken up, and trialed by others. Ideas that originated in discussion also interacted with ideas from the readings and text, amplifying them and shifting them in new directions. As ideas diffracted, they opened possibilities for teachers to develop new understandings and collectively cultivate their interpretive power so that they could ultimately help students feel that "science is meant for them."

My own diffractive role. In this study, my role diverged from a participant/observer (Merriam & Tisdell, 2016). Instead of immersing myself in the teachers' cultures and classrooms, I engaged with them in a space we were co-creating. In the role I took on, traditional ideas of participant and observer were diffracted against each other - I was in one sense both participant and observer and in another sense not quite fully either. In many of the discussions, I contributed as a participant, albeit one with more influence. Although I have not been in the classroom for many years, I was able to add in ideas from educational research or my own experiences and history as data to entangle with the mix of teachers' ideas. While my research commitments helped outline the overall structure and the organization of our findings, other participants also played a large role in driving the direction of the research. I chose the initial questions, selected readings, and generally tried to keep the conversation connected to the larger ideas we were discussing, but the participants were also actively involved in shaping the course of the research, identifying themes in data, and contributing to the analysis. Although this final paper was ultimately assembled by me, the plan is for the teachers to serve as co-authors when this work is published. They have had the opportunity to review this draft and will also have the opportunity to fully review and edit the manuscript prior to publication.

Discussion

This research set out to examine how teachers can promote inclusion of culturally responsive argumentation and sense-making practices in their classrooms. In particular, I was interested in how collaborative autoethnography could build on the shared immersion experiences the teachers had the prior summer with professional science research groups and cultivate science teachers' interpretive power relative to argumentation. Below, I present a model of the elements that can contribute to productive and rigorous argumentation and collaborative sense-making, and that draws on students cultural and everyday resources (Figure 1: Sociocultural Foundations for Expansive and Rigorous Argumentation and Sense-making Discourse in Classrooms). One important dimension of the model is that it emphasizes elements both for teachers and students; these are interrelated at each level. The model is not intended to show causality between named variables, rather it emphasizes sociocultural concepts and conditions that help lay the foundation for the next layer. As layers are built, they help strengthen and reinforce previous ones.

Figure 1: Sociocultural Foundations for Expansive and Rigorous Argumentation and Sense-making Discourse in Classrooms



At the foundation is the importance of relationships. As more classrooms focus on engaging in argumentative practices as a result of the NGSS, the importance of relationships to making argumentation in the classroom possible also needs to be elevated and addressed. Sylvia emphasized an important pattern in our first set of data - “that we all sort of jump to that relationship piece, which is a big part of argumentation but not something that you would ever talk about.” Teachers mentioned the importance of their own relationships with students and the long-lasting impacts those relationships can have. They also saw how their own histories and cultural connections impact those relationships. We discussed how important it is to invest in cultivating collaborative student-to-student relationships. Teachers provided many examples for how students knowing each other makes a difference in the discourse environment of the classroom. Simple opportunities for informal talk can build those relationships, which can later be leveraged for purposes of argumentation.

Once relationships are established, an environment of safety and trust can be fostered. This environment can represent a hybrid learning environment (or "third space") that brings together school science spaces with the space of home. New opportunities for learning are fostered as different ways of knowing, talking, and relating are generated in such spaces (Barton, Tan, & Rivet, 2008; Moje et al., 2004). Teachers can model vulnerability and demonstrate their own fallible humanity to students, which disrupts traditional classroom hierarchies of power (see Chapter 3). Engaging in argumentation, we decided, requires students to be vulnerable in class; they must defend their ideas with evidence, and may have feelings of self-worth wrapped up in being correct. We felt that an environment of safety and trust was essential for students to be vulnerable enough to put forth ideas that they might need to publicly revise. This was strikingly similar to the qualities of the CAE learning environment that allowed the teachers to be vulnerable and explore new possibilities outside of the context of their workplace communities.

Building on interpersonal relationships and an environment of trust, teachers can begin to mobilize interpretive power (Rosebery et al., 2016). Knowing students allows teachers to select appropriate phenomena to engage students, and it allows them to be sensitive to the different sense-making approaches students may bring to trying to understand those phenomena (Bang et al., 2017). In addition, opportunities to bring practices and resources from home, families, and broader communities into the science classroom through strategies such as self-documentation (Reeve & Bell, 2009; Tzou & Bell, 2010) can validate student experiences and their different ways of knowing. Interpretive power thus promotes the "rightful presence" of youth: "a way of being in a place where one is legitimately welcomed" (Tan & Calabrese Barton, 2017).

Interpretive power can also be developed through professional development for teachers (Rosebery et al., 2016). For example, in our CAE, teachers realized that what might look like disengagement might be the result of cultural conflict or student trauma. Similarly, teachers can begin to reconceptualize student misconceptions or erroneous student thinking as resources for productive engagement and deeper understanding (Campbell, Schwarz, & Windschitl, 2016; Smith, diSessa, & Roschelle, 1993; Stroupe, 2014). Within professional development, specific strategies for fostering equitable participation can also support productive argumentation. Finally, professional development that cultivates teachers' interpretive power can also help teachers reclaim and reconceptualize the concept of "rigor," reframing it as a way to ensure students are engaged in argumentation with other students and with content in ways that are meaningful to them. Ultimately, we decided that argumentation serves as an entry point to other science and engineering practices, a gateway to real communication, and a way for students to experience the processes that professional scientists use. Notably, Manat cited the importance of argumentation as a foundation for students' advocacy; with stronger abilities to marshal evidence in support of claims, students are better prepared to be change agents within and for their communities.

Limitations

This study involved a small number of teachers who were self-selected and expressed a prior interest in the research topic. The primary limitation of this study is that I was unable to observe classrooms and how teachers interacted with students, so I relied on the summaries of classroom practice from participants. While our focus was on how teachers made meaning from their own reflections (and those of others), it would have been interesting to observe whether teachers enacted practices with students that corresponded with their changes in interpretive power.

Design Recommendations

For the purposes of educational equity, I argue that we need to develop professional learning approaches to develop the interpretive power of teachers. Successful elements of the CAE design included: (a) Opportunities for teachers to "check-in" and get to know one another better at the beginning of each session; (b) Weaving in selected readings to spark conversation and diffract into sense-making; (c) Providing time during the session for teachers to read and annotate the reflections of others; and (d) Allowing teachers flexibility and autonomy in driving the discussion and in crafting questions to respond to for subsequent sessions.

Teachers particularly liked the inductive approach of eliciting themes from the autoethnographic reflections (which were subsequently used in qualitative theme coding). Raven noted that, "I don't think we'd get the same if we were just discussing it. I liked this way of...the stuff coming from the data." Manat agreed, noting that she enjoyed the different perspectives and thinking each person brought to the same question. Manat also noted that the support from the CAE helped her think about the need to try to incorporate argumentation throughout the school year.

One concrete suggestion that teachers made for improving the CAE was to intentionally incorporate the discussion of student work in the future. I had described this as a possibility for the group to add when I introduced CAE but did not build that explicitly into the structure. Another design recommendation was to provide shorter research-related articles or excerpts for teachers to read. It was a struggle for some teachers to read the articles in detail given other demands on their time.

Teachers also provided recommendations for how to incorporate some of these ideas into the summer Phase I professional development that involves a larger cohort. In particular, they suggested that teachers bring their own self-documentation images of their classrooms to share with other teachers as they become part of the TSP community. Not only would that allow teachers to see into each other's classroom worlds, but it would model for them the power of self-documentation strategies. This is a suggestion that we plan to implement in the next cycle of programming.

Conclusion

The vision for equitable science instruction laid out by the *Framework for Science Education* (National Resource Council, 2012) emphasizes the deeply cultural nature of learning. The authors stress the importance of connecting learning to students' interests and identities, as well as the cultural and everyday experiences of students and their communities. They also note the importance of supporting students in bringing their unique ways of understanding and communicating about science to their classroom experiences.

How can a cultural lens be applied to social, discursive argumentation and sense-making? Much educational research has focused on classroom approaches to incorporating argumentation as a scientific practice (e.g. Azevedo, Martalock, & Keser, 2015; Bell, 2004; Bell & Linn, 2000; Berland & Hammer, 2012; Berland & McNeill, 2010; Berland & Reiser, 2011; Chin & Osborne, 2010; Duschl & Osborne, 2002; Erduran & Jimenez-Aleixandre, 2007; Ford, 2012; Kuhn, 2010; Sampson & Clark, 2008). Researchers have also investigated the important role of the teacher and of teacher professional development in influencing argumentation in science classrooms

(Crippen, 2012; Knight-Bardsley & McNeill, 2016; McNeill & Knight, 2013; Sadler, 2006; Simon, Erduran, & Osborne, 2006).

This study adds to the existing base of research by providing an account of how the methodology of CAE can be used in a small professional learning community of teachers to explore an expansive and cultural view of argumentation: one that values the diverse resources that students bring to science learning and the many different ways students engage in science and make sense of the world around them (Bang, et al., 2016; Nasir et al., 2006; Banks et al., 2007; Bell, Bricker, Reeve, Zimmerman, & Tzou, 2013; Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001; Zimmerman & Bell, 2014). It also demonstrates how a diffractive lens (Haraway, 1992; Haraway, 1997) can help analyze complex, situated, and entangled interactions that accompany collaborative examination of autoethnographies and professional learning.

Our findings emphasized the foundational importance of establishing classroom relationships in order for productive argumentation to occur. Teachers need those relationships in order to know their students, which in turn allows them to design relevant learning experiences and understand the kinds of sense-making their students are engaging in. Students need those relationships with peers in order to be able to begin to feel comfortable talking with one another. We also identified the value of creating trusting communities, where students can feel safe engaging in the vulnerability that accompanies argumentation. Significantly, we were able to reconceptualize and reclaim the idea of rigor to reflect argumentation and sense-making discourse that is connected to students’ lives and that engages them in knowledge-building with others.

The CAE structure supported a robust exchange of specific ideas and strategies that can help teachers create relationships in the classroom and surface the everyday and cultural resources that students bring to the classroom. The text and articles we chose helped to foster such discussion, but more research is needed to determine which kinds of resources can best support teachers in enlarging their views of argumentation and growing in their interpretive power. We also need more insight and examples of how teachers' attunement and support of diverse sense-making aligns with the teaching of specific disciplinary content.

Teachers need opportunities to reflect on their own positions and histories, encounter new ideas and examine their thinking. That is, they need opportunities to cultivate what Gutiérrez and Calabrese Barton (2015) call "a pedagogical imaginary" where teachers assume, and work towards understanding, the diverse sense-making of students. Such an orientation not only disrupts long-standing, taken-for-granted ways of interacting and talking in the classroom, but it also expands possibilities for teaching and learning. Within the CAE process, teachers navigated their own growth towards interpretive power based on their history and understanding, but they also shared their perspective with others in a way that amplified ideas across the group. Diffractions that happened within individuals became resources for the thinking and growth of other teachers. The collective processing with other teachers was a critical dimension of how participants built interpretive power. Ultimately, this CAE professional development model offers a promising strategy for helping teachers consider how to enact expansive argumentation practices that center students' experiences, value diverse sense-making, and increase equitable opportunities for learning.

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Chapter 5: Conclusion

This dissertation examined how professional development embedded in a research center could expand secondary science teachers' conceptions of scientific practices along two dimensions, professional and cultural. It focused on how access to professional scientists in their work settings could be leveraged to help teachers understand the role that collaborative argumentation and sense-making discourse play in building scientific knowledge. It also demonstrated how collaborative autoethnography (CAE) can help teachers develop their interpretive power by considering the cultural and everyday resources that students bring to argumentation. In addition to qualitative and design-based research, this study used participant ethnographic methods to help teachers explore the sociocultural contexts in which argumentative practices are situated. In this conclusion, I first summarize findings from the three empirical chapters. I describe how, taken together, these studies describe a learning pathway for developing teachers' interpretive power. Next, I discuss implications of my findings for different stakeholders. I follow by describing key mediating processes and design principles, as well as possible future design modifications and research efforts. Finally, I describe the contributions of this work to education and education research.

Major Findings

Chapter 2: Brokering argumentation practices from scientific research settings to science classrooms: *I had not really thought of what scientists do as "scientific argumentation."* My first study examined how science teachers learn about argumentation and scientific sense-making through participation in professional development that includes an immersive research experience. It also explored how those experiences influence teachers' conceptions of the role of argumentation both in professional science contexts and within science classrooms. Overall, teachers highlighted argumentation as a form of basic discursive communication among scientists, and also noted its epistemic role in making knowledge and meaning across scientific activities. They broadened their idea of "what counts" as argumentation to include collaborative forms of argumentation and recognized that argumentation can occur across varied timepoints in an investigation, not just in conclusions.

Observational scaffolds helped sharpen teachers' professional vision (Goodwin, 1994) by helping them know where to look, and what to look for, as they observed scientists engaging in argumentation. The professional development also built on teachers' relational agency (Edwards, 2011) and ability to engage with one another to process their observations and build a broader picture of argumentation across lab settings.

In Chapter 2, I introduced the idea of "epistemic motivation" as a driver for professional change: First, teachers need to recognize the importance of practices such as argumentation within the professional scientific culture and community. Then, they need to recognize the similarities or disparities in how practices are enacted between that community and their classrooms. Finally, they need to be epistemically motivated to broker selected elements of practice to the classroom in service of reflecting practices more authentically. This process helps build stronger connections between youth discourses in the classroom and scientific discourses, the importance of which is addressed in the *Framework for K-12 Science Education* (NRC, 2012).

Conclusions:
Observation scaffolds used by teachers in professional science contexts broadened their idea of "what counts" as argumentation to include collaborative forms of argumentation. Their observations helped them recognize that argumentation can occur across varied timepoints in an investigation, not just in conclusions.

Immersive research experiences provided teachers with "epistemic motivation" to shift classroom discourse practices. Epistemic motivation can be defined as a driver for change resulting from the process of noticing disconnections between the central role of *argumentation in professional science and the ways that argumentation has been represented in classrooms.*

Chapter 3: Science teachers decenter classroom power following experiences in professional research settings: *I took a step back...and it was amazing*. The second study grew out of the first one. It investigated how TSP teachers made meaning of power-related dimensions of their research experience and how they subsequently shifted power relationships in their classrooms. The findings suggest that spending focused time in a research setting and observing the pervasiveness of collaborative argumentation and sense-making discourse in scientific activities can provide powerful motivation for teachers to consider ways to take up a more discursive and practice-based pedagogy. This, in turn, helped alter the cultural production of authority in their classrooms. Teachers identified with the Principal Investigators (PIs)—who are leaders within their laboratories, much as teachers are leaders within their classrooms. However, they also identified with students, who traditionally have less power. Being in the role of the student helped increase their empathy for the challenges their students faced participating in science.

Teachers described how they shifted epistemic authority in their classrooms: they stepped back from being the sole authority and arbiter of knowledge, while also positioning students as capable. They created opportunities for a broad range of students to contribute to sense-making by focusing them on working as members of a team and by creating structures and activities that supported more equitable participation in collaborative argumentation. Teachers shifted the d/Discourse (Gee, 2014) of traditional school science to position students as thinkers whose ideas deserve to be heard. They also positioned science as a social endeavor, where problems and challenges benefit from the ideas and contributions of others. As they provided students with a more authentic experience with scientific practices, teachers desettled normative ideas about their duty to provide quick right answers and to correct misconceptions. Teachers also elevated opportunities for collaborative problem-solving, decreasing emphasis on independent mastery. As teachers made pedagogical shifts to emphasize the value of students' intellectual contributions and diverse sense-making repertoires, they promoted more equitable participation among students while also foregrounding for students the fundamental practices that constitute scientific activity.

> *Conclusions:*
> *Science teachers who engaged in a cross-sector experience by immersing themselves in the work of a professional science lab used that experience to engage in productive perspective-taking. They observed the impact that leadership has on knowledge production in a community. Being positioned as learners also cultivated teachers' empathy for their students.*
>
> *Shifting classroom discourse to better align with practices of professional research altered the cultural production of authority and power. Pedagogical changes impacted how teachers and students were positioned relative to each other and how the discipline of science itself was positioned in the classroom.*

Chapter 4: Strengthening Teachers' Interpretive Power Through Collaborative Autoethnography: Engaging Students' Cultural and Everyday Resources in Argumentation. Findings from the third study revealed how teachers' interpretive power (Rosebery, Warren, & Tucker-Raymond, 2016) could be fostered by using collaborative autoethnography within a small professional learning community. This study also demonstrated how diffraction, an alternate metaphor to reflection, can be used as a productive analytical tool for qualitative and ethnographic data. The major findings are summarized in a model for sociocultural foundations for expansive and rigorous argumentation and sense-making discourse in classrooms. In this model, strong relationships (both between teacher-student and student-student) provide the foundation for productive argumentation. As more classrooms focus on engaging in argumentative practices as a result of the *Framework for K-12 Science Education*

(NRC, 2012), the importance of relationships to making argumentation in the classroom possible also needs to be elevated and addressed. Once relationships are established, an environment of trust begins to emerge.

Vulnerability is another important factor in creating an environment conducive to productive argumentation. When teachers model vulnerability in the classroom, they disrupt traditional hierarchies of power and contribute to a safe learning environment. Engaging in argumentation also requires students to be vulnerable in class; they must defend their ideas with evidence and may have feelings of self-worth wrapped up in being correct.

Knowing students allows teachers to mobilize interpretive power to select appropriate phenomena, engage students, and recognize and welcome diverse sense-making approaches (Bang et al., 2017). In addition, students' experiences and their different ways of knowing are validated by opportunities to bring practices and resources from home, families, and broader communities into the science classroom (Reeve & Bell, 2009; Tzou & Bell, 2010). Significantly, teachers broadened their conception of rigor to encompass meaningful and relevant engagement in argumentation and sense-making with others.

> *Conclusions:*
> *Collaborative autoethnography created a productive learning community for teachers—one that fostered development of their interpretive power and provided them with a broader vision of the resources that students bring to argumentation.*
>
> *Teachers recognized that expansive and rigorous argumentation relies on social and cultural factors: Classroom relationships play an important role in creating an environment of trust. The ability of both teachers and students to be vulnerable encourages students to risk engaging in social dimensions of argumentation.*

Toward A Learning Pathway for Developing Interpretive Power. This research suggests a learning pathway that leverages participant ethnographic methods (micro-ethnography and collaborative autoethnography) for developing teachers' interpretive power (Rosebery et al., 2016). Teachers crafted micro-ethnographic reflections as observers of discourse in the cultures of professional science laboratories. By engaging in an immersive, focused research experience coupled to professional development, teachers expanded their views of disciplinary dimensions of argumentation to include an emphasis on collaborative argumentation and sense-making approaches. Teachers also developed expansive ideas about argumentation; they noted the range of resources that different members of lab communities brought to the collective scientific work and the importance of contributions from diverse lab members to sense-making discussions. As they experienced feeling overwhelmed, unsure, and confused by new environments and new information, they also grew in their sensitivity and empathy to the perspectives of their students.

Following the lab experience, teachers had the opportunity to discuss their experience with others who also had immersive experiences (but in different lab contexts); this allowed teachers to process their experiences and to appreciate the range of possibilities for argumentation within professional scientific contexts. In the classroom, changes in discourse strategies that teachers used also shifted power dynamics between themselves and their students. In multiple ways, teachers centered students' thinking and reasoning and positioned them as capable people whose ideas mattered.

The subset of teachers who participated in the collaborative autoethnography during the following school year were able to further expand their views of argumentation and increase their sensitivity to the cultural and everyday resources of students. By crafting their own autoethnographic reflections, relating them to selected research studies and texts, and then diffracting them through the CAE process, teachers were able to further cultivate their own interpretive power. In particular, they acknowledged the importance of recognizing and engaging students' diverse sense-making in the service of rigorous and equitable learning.

Implications for Different Stakeholders

Science educators. Science educators are professionals who play a key role not only in ensuring that students who are interested in science have access to career opportunities, but also in helping all students see the relevance of science to their lives. This research study demonstrates that when teachers change classroom discourse to reflect scientific practices such as argumentation, they help students grow in their understanding of how new knowledge is generated in science. At the same time, teachers shift the ways that they, their students, and the discipline of science are positioned relative to one another. Teachers also have the ability to grow in their interpretive power through professional development. They are able to broaden their view of how varied student contributions (even ones that might look like misconceptions or disruptive speech when referenced against traditional schooling) can be resources for learning. Interpretive power also provides teachers with greater ability to leverage students' family, cultural, and historical resources in the service of science learning.

Professional development providers in research settings. Research settings offer a unique opportunity to engage teachers in thinking about scientific practice in real-world contexts. This study shows that it is not necessary for these experiences to be of long duration, which makes them accessible to a wider range of teachers. In one week in a lab, teachers can make important shifts in their thinking—provided that their experience is scaffolded and time for processing and discussion is included. This study also provides design principles for such work. It demonstrates how micro-ethnographic observations of argumentation can focus teachers' attention on the types of discursive and social practices that scientists engage in. It provides an account of how collaborative autoethnography can be employed in professional development to help teachers grow in their interpretive power and extend their repertoire for bringing argumentation to the classroom.

School districts. Teachers need administrative support to participate in professional development so that they can gain a greater understanding of how to adopt practice-focused approaches in their classroom. Further, they need the support of school and district leaders when they return to their schools: practice-focused instruction that engages students in productively uncertain science experiences or in figuring out and creating conceptual models of natural phenomena can look very different from traditional schooling. These shifts could be confusing or threatening to students and parents who might not understand the value of such approaches.

Pre-service providers and university certification programs. Lab research experiences should be a part of every new science teachers' training. Furthermore, it is important that these experiences be intentional in their design and focused on helping teachers observe and understand disciplinary dimensions of scientific practices as they happen in professional settings. Teachers also need opportunities to process such experiences with one another and more experienced teachers in order to see a broad range of examples and to develop pedagogical strategies that represent scientific practices in intellectually honest ways.

Design Principles: Mediating Processes

Across the broader study, the following design principles were key mediating processes in research:

- **Foster a vision of contextualized epistemic argumentation practices in teachers through gathered ("micro-ethnographic") evidence:** (a) Teachers need to experience argumentation-related scientific practices, including ones that involve dialogic sense-making, in professional settings such as lab meetings; (b) Teachers should gather “exemplars of argumentation” from “the field” and process their observations with peers. Sharing exemplars helps teachers to focus on particularly compelling examples of argumentation.

- **Create opportunities to collaborate and reflect with a community of peers and more experienced educators:** (a) Include multiple opportunities for teachers to first record their thoughts in their journals, then discuss them with small groups, and finally share them with the whole cohort. This allows teachers access to the wide range of perspectives of their peers; (b) Within the CAE process, teachers create autoethnographic reflections to process collaboratively through discussion.
- **Model discourse strategies from the learner perspective:** This includes strategies such as creating discussion norms, providing questions for accountable talk (Michaels, O’Connor, & Resnick, 2008), scaffolding idea coaching (Wingert, 2017), and engaging in seminar-style discussions (Griswold, Shaw, & Munn, 2017; Parker & Hess, 2001). These activities help teachers experience activities much as their students would, and also provide teachers with helpful resources and structures.
- **Support teachers in creating/modifying lessons to include elements of productive disciplinary discourse/uncertainty:** Encourage teachers to incorporate opportunities for collaborative discourse in lessons that they developed to take back to their unique classroom environments. In future iterations of our design, we plan to provide additional scaffolding for teachers to create tasks and activities that can foster productive collaborative argumentation (as further described below).

Future Design and Research

This research led to two major ideas for future iterations of the TSP professional development experience. First, we will strive to incorporate design elements that help teachers consider students' cultural and everyday resources as part of our main program design. This will include modeling cultural formative assessment / self-documentation techniques with the teacher group, as discussed in Chapter 4. Second, we will focus more explicitly on supporting teachers in developing lessons and activities for their classrooms that are designed to foster productive uncertainty (Manz, 2015), thereby providing students with task structures that include meaningful collaborative argumentation opportunities. We will also offer examples of specific ways that teachers might build such opportunities into lessons, such as allowing students to try to design optimal procedures, prompting decisions between competing explanations, or structuring labs to lead to interesting and ambiguous results.

This study also suggests several productive avenues for further research. One concerns the development of a pathway for interpretive power. What kinds of insights about students and argumentation would teachers have if they engaged in collaborative autoethnography without the prior lab experience and teacher discussion? Would video recordings of lab meetings help teachers achieve similar insights? What would happen to the autoethnographic dimension of CAE if student work was included?

Future studies could also investigate teachers' observations of how argumentation interacts with other scientific practices. We asked teachers to focus their observations on argumentation because of prior discussions with colleagues. They tried to have teachers look at all practices described in the NGSS (NGSS Lead States, 2013) while they were in labs, which ended up being overwhelming. However, future research could examine additional practices and how they interact with argumentation in professional settings. Ideally, future studies would also revisit teacher perceptions at far time points. How do teachers' ideas and classroom practices change over multiple years? Based on informal communications, some teachers have continued to include additional opportunities for students' collaborative argumentation over time.

Finally, the ways in which teachers enact their learnings about argumentation and interpretive power in the classrooms needs further study. What kinds of pedagogical structures seem particularly productive in fostering argumentation? Which elements of practice are most readily taken up and/or brokered by teachers? How do teachers frame their experience in the lab when encouraging students to adopt new discourse patterns that reflect professional scientists' work? What kinds of meanings and understandings about science are students taking away from classrooms where collaborative argumentation and sense-making are elevated?

Contributions to Education and Educational Research

The *Framework for K-12 Science Education* (NRC, 2012) and related standards provide both a vision of how scientific practices can be incorporated into science teaching as well as a new platform that can be leveraged to shift the culture of classroom learning environments. However, there is a risk that the images of practice that teachers provide to students can become essentialized and part of the "game of school" (Lemke, 1990). This is not surprising, given that many teachers have not had research experiences themselves. Even teachers who have spent time in research environments may not believe that disciplinary practices can be represented in the classroom in meaningful ways or may not feel comfortable trying to incorporate them.

This research contributes an account of how teachers can develop an appreciation of the role and importance of argumentation through focused laboratory experiences. It also explores the challenges and opportunities teachers encounter in bringing discursive dimensions of the research experience back to their students—in ways that highlight diverse argumentation practices of science and that also build upon the sense-making practices of youth. The findings demonstrate how shifts in discursive practices in classrooms can decenter teachers' role and open space for students' argumentation, critique, and sense-making contributions, while positioning science as a social enterprise. Finally, this research contributes to the identification of professional development design principles that promote understanding and uptake of argumentative practices in classrooms in ways that value students' cultural and everyday resources.

The natural world is awe-inspiring; understanding science helps make it more so. Every child has within them incredible potential, curiosity, and vitality. We must meet students where they are and help them flourish. We must also elevate the voices and support the agency of those who have been traditionally marginalized or excluded from science, while recognizing the value of different ways of engaging in science. Expanding teachers' views of scientific practices not only prepares them to engage students with science in ways that are more authentic to the discipline, but also helps teachers recognize and leverage the creativity and resources that students bring to their science learning. Ultimately, such pedagogical shifts can increase students' access to the social, cultural, and material aspects of science, broaden possibilities for their futures, and promote equity in science education.

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Appendix

Appendix A: Figures

Figure 2: Years of Teaching Experience

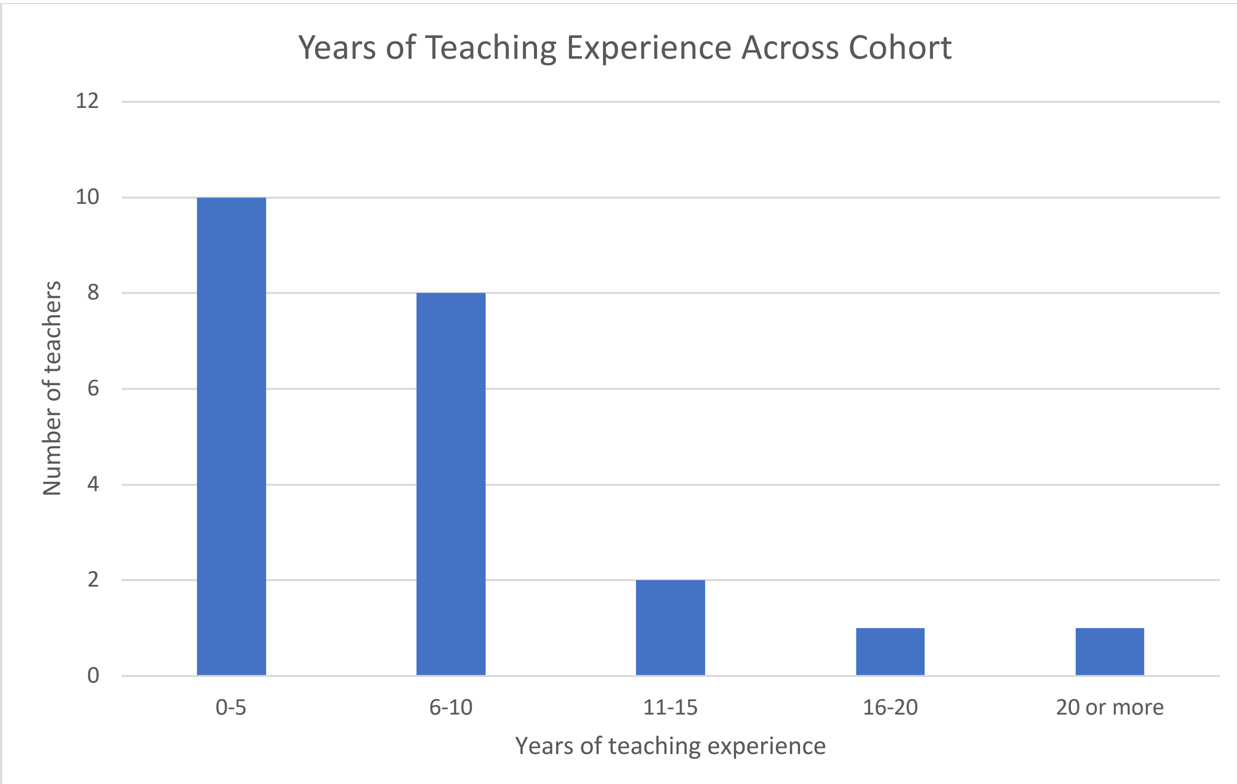


Figure 3: Student Demographics (Race/Ethnicity)

*as defined by the NSF (Hispanic or Latino/a, African American/Black, American Indian or Alaskan Native)

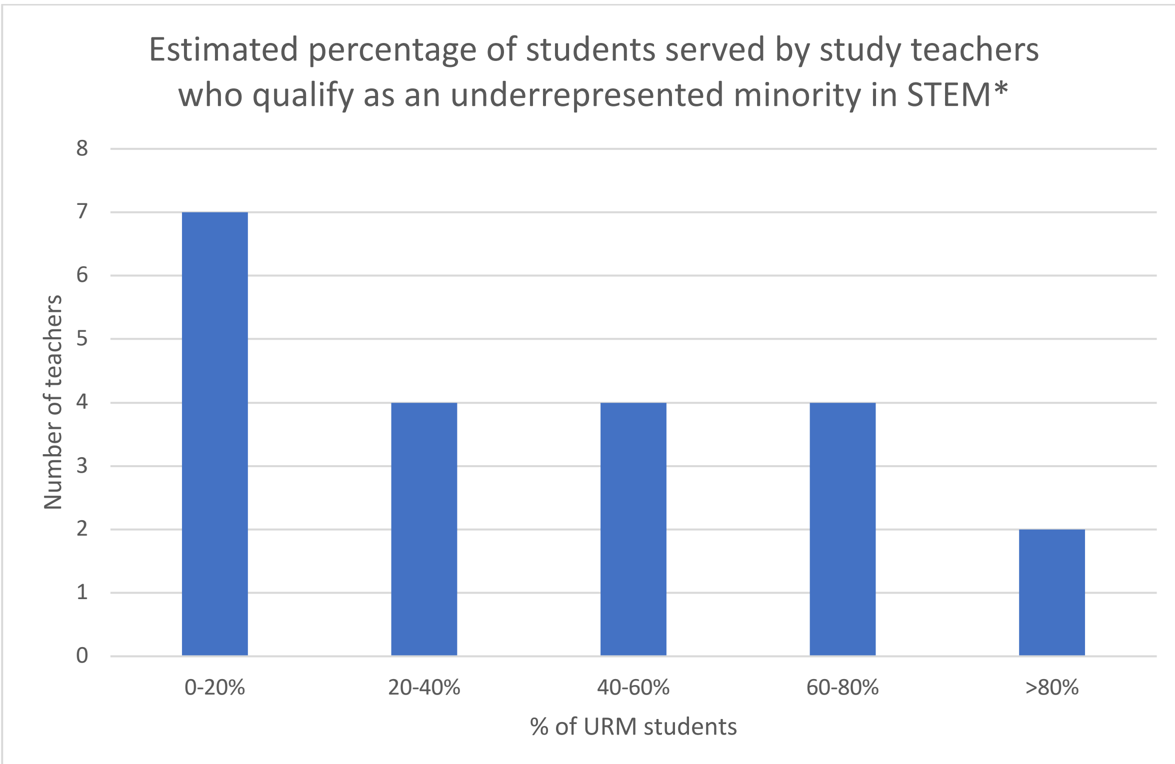
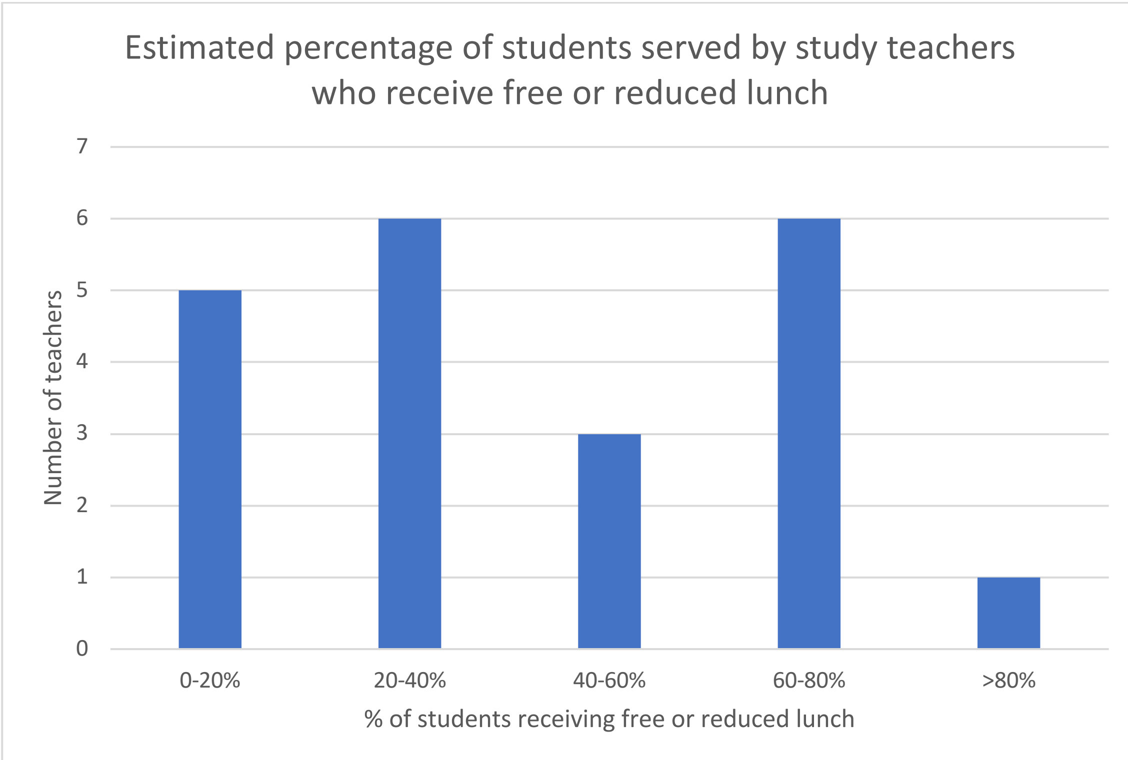


Figure 4: Student Demographics (Free and Reduced Lunch)



Appendix B: Conjecture Map (Phase I: Chapters 2 and 3)

High Level Conjectures	Embodiment	Mediating Processes	Intervention Outcomes
Broadening teachers' abilities to enact productive instances of argumentation with students is facilitated by experiencing the central role of argumentation in science and strategies for transforming student discourse in classrooms Scientific argumentation as a practice involves the coordination of claims with evidence through reasoning, but also involves sense-making through collaborative and discursive processes of critique and deliberation	**<u>Tools/Materials</u>** Resources to promote observation and reflection • Scaffolds that promote teacher data collection/written reflection on examples of argumentation in science settings in their lab notebooks Classroom discourse resources • Tools that support student discourse and argumentation **<u>Task/Activity Structure</u>** Immersive research experience including lab meeting • Engaging in and observing scientific practices in research settings, including observations of sense-making discourse Discussion and reflection with peers • Processing observations and reflections from research experience with other teachers, particularly "lead teachers" with more experience Curriculum development • Developing customized classroom resources that incorporate more student/student discourse, with support of lead teachers Pedagogical modeling of the following classroom practices: • Setting norms for discussion • Engaging students in strategies that support talk and sensemaking (idea coaching, generating sample questions for different purposes) • Fostering small and large group (seminar/lab meeting model) sense-making discussions focused on developing procedures, understanding lab results, or interpreting a text. **<u>Discursive Practices</u>** Epistemic • Language and norms related to making and defending claims based on evidence • Language and norms related to persuading, questioning, and critiquing the views of others Social • Language and norms related to building community and consensus	**Vision of contextualized epistemic argumentation practices through gathered evidence** • Participating in argumentation-related scientific practices, including ones that involve dialogic sense-making • Gathering "exemplars of argumentation" from "the field" and processing them with peers **Experiencing modeled discourse strategies from the learner perspective** **Creating/modifying lessons to include elements of productive disciplinary discourse/uncertainty** **Collaborating and reflecting with a community of peers and "lead teachers"**	**Epistemic** Teachers have broader understanding of "what counts" as argumentation and the epistemic role argumentation plays in science **Pedagogical** Teachers emphasize knowledge-building through argumentation by creating more opportunities for productive uncertainty, collaborative sense-making, and deliberative discourse in their classrooms **Decentering Power** Teachers consider how teacher moves, authorized speaking rights, and classroom structures influence opportunities for student voice and argumentation (Chapter 3)

Appendix C: Argumentation Work in the TSP Professional Development Workshop

Day 1:
- **Reflect on current practice of argumentation**
- **Clarify terms (claims, justification – evidence and reasoning)**

<u>**Argumentation Reflection (Journal, 15 min)**</u>

- What do you think the NGSS mean by the practice of scientific argumentation? How do you understand the practice of scientific argumentation as described in NGSS?
- Write a brief description of some of the ways you use argumentation in your classroom (if at all). Tell a story that illustrates one example.
- What about your own history / background influences how you approach scientific argumentation in your classroom?
- What might your students bring from their own history/culture/experiences that would impact how they view argumentation and engage in it?

<u>**Small Group Discussion – (Small groups, 5 groups of 4-5, 45min-1hr)**</u>
For each question, go around the circle and hear from each person before opening the question up to discussion.

Additional Question if time:
5) How is your district taking up NGSS in general and argumentation in particular?

<u>**Analysis of DNA LAB (Lab Team, 15min)**</u>
Clarification of terms: Claims, Justification (Evidence and Reasoning) in the context of C-E-R scaffold.
C-E-R conclusion
(Table discussion and sharing. Discussion of elements BEYOND C-E-R. Importance of fostering higher-level discourse/critique)

Day 2:
- **Situate argumentation as central to scientific practice**
- **Move beyond "C-E-R" conclusion writing**
- **Understand importance and role of argumentation norms**
- **Recognize that different scaffolds for talk are suited to different goals**
- **Generate question stems**
- **Practice idea coaching**

<u>**Discussion of DNA LAB Results (Whole/small group, 45 min)**</u>
(Modeling Student Analysis of Discourse)

General role of argumentation (10)
(Share diagram from Framework and quote about "scientific method" vs. practices)

Norms: Accountability to science and to classmates, equity, and respect

Generating ideas for example questions (large post-its): (15)
- Adding on to a peer's comment

- Asking for evidence or reasoning behind a claim
- Asking for clarification
- Respectfully disagreeing with an idea
- Evaluating evidence quality

Idea coaching: Utilize example questions in an "idea coaching" session? (20)
(Using STEM teaching tools talk handouts)

Day 3:

- **Observe videos/transcripts from lab meeting and from classroom argumentation to analyze argumentation moves**
- **Provide resources for argumentation**
- **Model whole-group argumentation structure**
- **Use "audience roles" to guide questioning**

Background: Argumentation as a Practice (Whole group, 1 hour)

[Argumentation Toolkit]
http://www.argumentationtoolkit.org/presentation-session-1.html
Student Discussion Video
1) Evidence; 2) Reasoning; 3) Student Interaction; and 4) Competing Claims.

Discourse Moves:
Probing questions
Follow-ups
Pressing
Wait time

Overview of Resources (Argumentation Toolkit, Ambitious Sci, STT)

View Video of Lab Meeting with transcript: https://www.youtube.com/watch?v=OuAAaxVJb64

Watch once, then discuss (15 min)
Watch again, then discuss (15 min)

- What is the purpose of this type of discussion? Are people trying to persuade each other or make sense of something together?
- Do you hear claims/justifications/competing claims?
- What types of evidence are presented? Do you hear references to prior work/work done by others? etc.

Lab Observations for Research Experiences

Discussion of TRANSFORMATION LAB Results (Whole group, 30 minutes)
(Modeling Student Analysis of Discourse)

Socratic Science Discussion

Reports of OWN EXPERIMENTS (Whole group, 1.5 hours)
4 min/group, 1 question (Present question, plan, prediction, results if available)
Model student audience roles
Clarifying questions
Asking for evidence

Comparing ideas to own or other ideas

RESEARCH LABS (5 days)

- **Observe practices in research settings**
- **Connect observations to teaching argumentation**

Journal:

As part of your Reflections, try to note at least one example of argumentation and sense-making talk each day. Be sure that you attend at least one lab meeting or discussion of procedures, analysis, or results between a group of scientists.

- Pay attention to argumentation and sense-making talk, and when it happens.
    - What is the purpose of the argumentation or sense-making talk?
    - Notice the many different forms argumentation can take. Were participants trying to provide feedback about a procedure or research design?
    - Were they trying to understand data?
    - Were they providing a competing hypothesis/claim?

    - Did you hear people trying to persuade each other? Or come to a shared understanding?

    - Did they give each other feedback or critique?

    - Did they bring in specific kinds of evidence (such as specific expertise/knowledge, or reference to another person's or group's work)?

- Science research labs are communities that do shared work, as are science classrooms. What aspects of argumentation and sense-making are important for the work that these communities do?

- Record any thoughts you have about how the argumentation and sense-making practices in the lab are similar to/different from what happens in your classroom or in schools generally. How is argumentation different when the answer is known vs. unknown?

- How does power/position influence who is talking or whose comments are being considered?

- What would a classroom that focused on including and valuing student argumentation and sense-making look like? How can conversation in classrooms be more equitable?

- What kinds of argumentation/sense-making talk do you hear in other settings of your life? How is it similar/different from what happens in the lab?

ARTIFACT – Argumentation Example

Please select one exemplar/artifact related to the practice of argumentation from your time in the lab and describe it in your journal. You'll share this with others in your cohort when you return back. Label it clearly as your **ARGUMENTATION EXAMPLE.** You can include a photo, a captured piece of dialogue, etc. Be sure to include:

    - **Context**: What was the larger context or activity?

- **Description**: What did you observe? You can document snippets of speech, behavior, photos, etc.

- **Analysis**: Why did you choose this example? What does it illustrate about argumentation and scientific sense-making? What are the implications for your own work with students?

Day 4:
- **Reflect on practices in lab settings**

Scientific Practice Discussion (Small group, 1 hour 45 min)
Debrief experience, share exemplars

- Share your exemplar/artifact.

- What did you learn from your observations? What are your 1-2 takeaways about practices in scientific research settings?

- What are the implications of what you experienced for your teaching?

Day 5:
- **Integrate argumentation and sense-making into curricular planning**

Teachers worked for 3 days on tailored lesson designs

Discussion of incorporating Argumentation/Sense-making in your Project (Whole group, 15 min)

Day 6: Closing Prompts
- **Questions for written reflection in lab notebook and for discussion**

- Look back at your definition of argumentation and description of the purpose of argumentation. How have your ideas changed/broadened, if at all?

Reflection Day (May): Prompts
- **Questions for and for discussion (selected relevant)**

- Did the SEP experience influence your classroom teaching this past year? If so, share the most impactful highlights.
- Did you end up doing your classroom project? If you did, how did it go? If not, what were the barriers?
- Did you try anything new in terms of argumentation in your classroom? What did you do and how did it go?
- Did observing how scientists talk to one another in lab meetings and during the course of the work influence how you structured talk in your science classroom?
- Did it make you think more about your role in managing discussions?

Appendix D: Research Questions and Data Collection

Research Questions:

- **How do science teachers learn about argumentation and scientific sense-making through participation in research experiences?**
- **How do teachers' observations of sense-making in professional research settings influence their conceptions of the role of argumentation in science and in the science classroom?**

Supporting questions:

1. What kinds of events do teachers identify as exemplars of argumentation? What criteria do they use to select exemplars and what reasons do they give for their selections?
2. What types of discourse do teachers observe between scientists engaged in sense-making?
3. How do teachers connect their prior knowledge and experiences of argumentation to their observations in research labs?
4. How do teachers' perspectives on argumentation and scientific sense-making change as a result of their experiences?

Data Source	**Description**	**SQ**	**Timeline 2017-2018**
Teachers' Journals	Teachers kept a Lab Notebook and also journaled their reflections daily during the PD. Teachers were asked to write about their encounters with new scientific content and practices they observed or participated in. They also recorded general reflections.	1 2 3 4	Throughout professional development (PD) experience
Teachers' Artifacts of Exemplars	Teachers chose one example that they saw/experienced in the lab that they think relates to the practice of argumentation. They described the larger context or activity and what they observed, explaining what their example illustrates about argumentation.	1	Teachers selected one instance from experience in lab during summer 2017 to write about. They share it with others at the final focus group/discussion session
Teacher Written Responses to Open-Ended Questions	Questions focused on teachers' prior uses of argumentation structures in their classrooms and their insights from their immersion experiences related to their teaching practice.	3 4	Written questions at the beginning and end of PD, and at a follow-up session in May 2018
Teacher Semi-Structured Interviews	Semi-structured interviews with selected participants helped clarify comments and member-check assertions.	1 2 3 4	Throughout professional development (PD) experience
General Discussions	Smaller discussions and conversations that were conducted as part of the TSP program (for example, between teachers who were developing lessons and their Lead teachers) and large-group discussions (including a culminating debrief at the end of the summer).	1 2 3 4	Throughout professional development (PD) experience
Focus Group Discussions	Teachers discussed their observations and reflections in smaller focus groups/larger groups. The discussion was audiotaped and transcribed.	1 2 3 4	At the beginning of the PD, at the end of the PD, and at a follow-up session in May 2018

Appendix E: CAE Professional Development Summary

	Session 1	Session 2	Session 3	Session 4
Autoethnographic Questions Discussed (Questions for Sessions 2-4 were co-developed by the CAE group)	a) How do your own past experiences (family, cultural, professional) influence how you talk with your students and/or how you incorporate talk into your classroom?	a) What does argumentation allow my students to do? What is it a gateway to? b) How do our own relationships with students ("knowing them") impact classroom talk and argumentation? How do we build those relationships? How can we be close, yet professional? c) How do students' relationships with one another ("knowing each other") impact classroom talk and argumentation? d) What kind of instructional structures support talk and argumentation? What kind of instructional structures support relationship-building?	a) What types of discourse/ argumentation scaffolds am I currently using? b) What are my own ideas about "learning" and "rigor"? How do these ideas relate to argumentation? What classroom moves are integral to my beliefs about learning? c) How can we combine engagement and "rigor" among diverse students?	a) How has my thinking about argumentation and other scientific practices changed as a result of my reflections, readings, and discussions in our argumentation research group? b) How can we design the Teacher-Scientist Partnership (TSP) summer Professional Development (PD) to best help teachers address scientific practices such as argumentation? In particular, how can we: Emphasize the professional practices of scientists and have teachers reflect on how knowledge is constructed in science? Help teachers draw on the cultural and everyday resources that students bring to practices such as argumentation?
Other Agenda Items or Readings Discussed	CAE Background Group roles and logistics	Heath (1982) Hudicourt-Barnes (2003) Warren, Ogonowski, & Pothier, (2004)	Hammond (2015)	Hammond (2015)

Appendix F: Conjecture Map (Phase II: Chapter 4)

High Level Conjectures	Embodiment	Mediating Processes	Intervention Outcomes
Broadening teachers' abilities to enact productive instances of argumentation with students is facilitated by experiencing the central role of argumentation in science and strategies for transforming student discourse in classrooms Scientific argumentation as a practice involves the coordination of claims with evidence through reasoning, but also involves sense-making through collaborative and discursive processes of critique and deliberation **Phase II** Students' own personal, historical, and cultural resources can serve as expansive resources for scientific argumentation in the classroom.	**<u>Tools/Materials</u>** Resources to promote observation and reflection • Scaffolds that promote teacher data collection/written reflection on examples of argumentation in science settings in their lab notebooks Classroom discourse resources • Tools that support student discourse and argumentation **<u>Task/Activity Structure</u>** Immersive research experience including lab meeting • Engaging in and observing scientific practices in research settings, including observations of sense-making discourse Discussion and reflection with peers • Processing observations and reflections from research experience and classroom with other teachers Curriculum development • Developing customized classroom resources that incorporate more student/student discourse, with support of lead teachers Pedagogical modeling of the following classroom practices: • Setting norms for discussion • Engaging students in strategies that support talk and sensemaking (idea coaching, generating sample questions for different purposes) • Fostering small and large group (seminar/lab meeting model) sense-making discussions focused on developing procedures, understanding lab results, or interpreting a text. **<u>Discursive Practices</u>** Epistemic • Language and norms related to making and defending claims based on evidence • Language and norms related to persuading, questioning, and critiquing the views of others Social • Language and norms related to building community and consensus	**Vision of contextualized epistemic argumentation practices through gathered evidence** • Participating in argumentation-related scientific practices, including ones that involve dialogic sense-making • Gathering "exemplars of argumentation" from "the field" and processing them with peers **Experiencing modeled discourse strategies from the learner perspective** **Creating/modifying lessons to include elements of productive disciplinary discourse/uncertainty** **Collaborating and reflecting with a community of peers and "lead teachers"**	**Epistemic** Teachers have broader understanding of "what counts" as argumentation and the epistemic role argumentation plays in science **Pedagogical** Teachers emphasize knowledge-building through argumentation by creating more opportunities for productive uncertainty, collaborative sense-making, and deliberative discourse in their classrooms **Phase II** **Cultural** Teachers increase their interpretive power relative to students' scientific argumentation, valuing the resources that they bring to the classroom and promoting equity in access to science