TOWARD EQUITABLE TEACHING AND LEARNING OPPORTUNITIES: AN EXAMINATION OF STEM EDUCATION REFORM IMPLEMENTATION

by

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Abstract

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Toward equitable teaching and learning opportunities: An examination of STEM education reform implementation

Thesis directed by Professor William R. Penuel

Despite the established view that STEM education should be accessible to all students, disparities continue to exist across gender, race, and social class with regard to who pursues and success in STEM fields. Organized as a three-article set, this work examines two lines of inquiry aimed at improving teaching practices and learning opportunities within STEM education. Specifically, these articles look across two separate research contexts to trace the ways that teachers and school leaders understand the current context of STEM education reform, what these calls mean for their organizational and instructional practice, and the ways these decisions impact student participation and learning in STEM. These findings point to the integral role of collegial networks in supporting enactments of reform. Additionally, findings from this set suggest that lasting STEM education reform efforts require attention to the local practices present within schools and the particular needs of the student population these institutions serve.

Dedications

To my parents, Jesse and Paula Allen, who instilled in me at an early age that I could "do great things" and whose guidance and unwavering love have supported me throughout my life.

To my husband, James Schaftenaar, who reminds me to take breaks, live simply, and practice regular self-care.

To my late grandma, Marie Findlay, who taught me a great deal about being a strong woman and making personal growth a life-long endeavor.

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CONTENTS

CHAPTER 1

Despite the established view through consensus (NRC, 2007 2012) and standards documents (NGSS Lead States, 2013; NRC, 1996) that science should be accessible to *all* students "regardless of age, sex, cultural or ethnic background, disabilities, aspirations, or interest and motivation," (NRC, 1996, p. 20) disparities continue to exist across gender, race, and social class with regard to who pursues and succeeds in STEM fields (AIR, 2012; NRC, 2011, 2012a; NSF, 2008, 2015; Ong et al, 2010). Educational systems fall short of providing students with equal learning opportunities, including access to high quality instruction (Banilower et al., 2013), advanced course offerings, and material resources needed for engaging in STEM practices (e.g. reliable technology or lab equipment) (Harris, 2004). Further, efforts to improve learning opportunities for and expand participation of students underrepresented in STEM fields (women, Black, Latino, Native American, and those economically disadvantaged) often fail to achieve these desired outcomes, or they exist only in specialized school contexts (e.g. STEM schools). Yet, some efforts do take hold and have incredible implications for the lives of students pursuing interests in STEM, and in the lives of educators working toward more just and democratic learning spaces. Understanding what of STEM improvement efforts work, for whom, and in what contexts (Bryk, Gomez, Grunow, & LeMahieu, 2015), then, is important for working toward equitable teaching and learning opportunities within STEM education.

In this dissertation, I take up these aims by examining two threads of educational improvement research focused on expanding learning opportunities for youth in STEM: (1) supporting teachers' learning and implementation of equitable instructional practices within middle school science, and (2) understanding the relationship between the practices of schools adopting education improvement efforts in STEM and the opportunities available for students to engage with and pursue interests in these fields. In what follows, I review literature salient to these research strands and discuss the contribution of this paper set.

Improving Science Instruction in the US

One common approach to improving learning opportunities within any subject is to focus on improving teacher instruction. Within science, the most recent efforts for improving science education, including teacher instruction, were presented through the *Framework for K-12 Science Education* (NRC, 2012) and Next Generation Science Standards (NGSS; NGSS Lead States, 2013). These current reform documents espouse an approach to teaching that engages students in a process of learning that integrates science and engineering practices with understanding disciplinary core ideas and crosscutting concepts that span scientific domains. Through this approach, students develop their understanding of content and crosscutting concepts through their engagement with science practices, and students demonstrate their understanding not through a recitation of facts but in their application of content and crosscutting concepts through science practices (called “performance expectations”). For example, a student who had an understanding of waves and wave properties might develop and use a model to describe how waves are reflected, transmitted, or absorbed through various materials (NGSS Lead States, 2013).

This approach to science instruction diverges from what is common in middle and high school classrooms. Science instruction is often structured around achieving known, "true" answers (Carlone, Haun-Frank, & Webb, 2011; Carlone, 2012), and teachers generally use hands-on and laboratory activities to *reinforce* content already taught through lecture or reading (Banilower, Smith, Weiss, Malzahn, et al, 2013), rather than as activities that introduce new disciplinary ideas or allow students to reason first with phenomena. Further, current instruction often follows an IRE (Mehan, 1979) structure, in which most classroom talk is between the teacher and individual students. However, instruction that integrates science practices requires that teachers make instructional shifts that impact the organization and nature of classroom talk. Many of the science practices – such as constructing explanations and developing models – require that students reason with and justify their ideas through talk and writing (NRC, 2013). In order to support students in their reasoning about disciplinary core ideas, practices, and crosscutting concepts, teachers need repertoires of questioning that facilitate this process (Weiss et al, 2003). With the majority of instructional time in science structured around whole class activity, students are generally not afforded the opportunities to engage deeply with science content or understand the purpose behind an activity (Weis et al, 2003; Banilower et al, 2013).

Engaging students in the practices of science is thought to expand learning opportunities for students while providing them with a deeper understanding of science content and phenomena. Through a practice-based approach, science can be framed as a process of investigating questions and using tools of science and engineering practices to support such investigations. This suggests a potential for more equitable participation in science classrooms, as the focus of science learning accomplishments shifts from knowing content quickly and independently (Carlone, 2012) to working collaboratively toward difficult questions. Further, through a practice-based approach, students are positioned as contributing to the intellectual community of the class, rather than working to achieve established answers known by the teacher.

Understanding Teachers' Views as Integral to Instructional Reform

When teachers aim to make changes to their instruction, like the instructional shifts toward a more practice-based approach, these efforts can be challenging to enact. Instructional reform often requires teachers to shift their views about teaching, learning, and the content they teach (Ball & Cohen, 1996). In science, current reform efforts pose an underlying epistemology regarding science teaching and learning that challenge commonly-held and historically-ingrained beliefs about how students best learn in science and how science knowledge is structured (Windschitl, 2002). Through the *Framework*, students are positioned as needing to engage in practices to construct explanations of phenomena in terms of disciplinary core ideas. At present, however, science teachers overwhelmingly hold beliefs about science teaching that place themselves in positions of intellectual control. For example, over 70 percent of science teachers believe that they should explain an idea to students before having students reason with that idea, and that students need vocabulary definitions provided to them at the beginning of instruction on a new science idea (despite overwhelming evidence to the contrary) (Banilower et al, 2013). Instruction that aligns with ideas in the NGSS should instead begin with students exploring questions and support students in "constructing a storyline" of how science content, practices, and crosscutting concepts build on each other over time (Krajcik, Codere, Dahsah, Baver, & Mun, 2014).

Professional development (PD) has typically served as the primary avenue for supporting teachers in their learning and implementation of reform. PD has the potential to influence teachers' knowledge, practice, and views (Garet, Porter, Desimone, Birman, & Yoon, 2001; Supovitz & Turner, 2000). Additionally, PD is particularly effective at supporting these outcomes when it focuses on content, provides teachers with active and inquiry-oriented activities, and is organized around activities that align with other reform activities and standards at teachers' schools (Penuel et al, 2007). However, PD is certainly limited in its ability to support teacher learning and their implementation of reform. Teachers also need instructional resources that scaffold their emergent views and understanding of reform, foster changes in their instructional practices required by reform, and make connections between the goals of the reform and states' accountability expectations.

Curriculum materials can offer this kind of scaffolding while bolstering teachers' understanding of reform. Teachers' content knowledge benefits from having texts that have content support embedded in them (Ball & Cohen, 1996; Schneider & Krajcik, 2002; Wang & Paine, 2003). Teachers have been found to read, understand, and then adopt particular ideas from such texts (Schnieder & Krajcik, 2002). In science and mathematics education, teachers' engagement with and use of reform-based curricular materials have supported their learning of content (Ball & Cohen, 1996; Krajcik, McNeill, Reiser, 2008; Remillard, 2000; Schneider & Krajcik, 2002). Additionally, reform-based or revised curriculum materials can influence teachers' views of reform ideas as they offer models of how reform instruction might look in practice (Remillard, 2000). Curriculum materials can also develop teachers' knowledge of how to best implement reform practices in ways that are responsive to students and that support teachers in being extemporaneous in their instruction (Brown, 2002; Davis & Krajcik, 2005; Shulman, 1987).

Even when professional development and curriculum have a positive impact on teachers' views of teaching, learning, and content, it does not always lead to durable or even immediate changes to their instructional practice. A growing body of literature (Carlone, Haun-Frank, & Kimmel, 2010; Coburn, 2004 2005; Cohen & Ball, 2001; Cohen, Moffitt, & Goldin, 2007; Spillane & Hopkins, 2013; Spillane, Reiser, & Reimer, 2002) point to the critical role that organizational contexts play in shaping teachers' views and their implementation of reform instruction. In their analysis of elementary science teachers committed to the goals of the previous National Science Education Standards (NSES; NRC, 1996), Carlone and colleagues (2010) found that discourse that promoted traditional beliefs about schooling (e.g. teacher maintaining intellectual control) acted as an obstacle to teachers reforming their instruction.

Further, as teachers engage with ideas of reform, they do so while enmeshed in their current organizational practices and routines. These practices that organize, monitor, direct, support, and organize instruction - viewed collectively as IGIs (Hopkins & Spillane, 2015) - have the ability to both support or constrain teachers' efforts to maintain and adapt instruction (Cohen & Moffett, 2009; Cohen & Spillane, 1992; Cohen, Peurach, Glazer, Gates, & Goldin, 2013; Hopkins, Spillane, Jakopovic, & Heaton, 2013). IGIs, for example, can offer teachers necessary coherence between instructional goals, assessments, and pacing guides (Cohen, et al, 2013); yet, at other times IGI incoherence can leave teachers confused as to what to implement (Allen & Penuel, 2015; Coburn, 2004; Cohen, Raudenbush, & Ball, 2003).

Understanding the process through which teachers develop views of teaching, learning, and content is integral for making substantive and lasting changes within science education, as these views shape what gets enacted in the classroom. Although both PD and curriculum play integral roles in supporting teachers' understanding of reform and their views of teaching, learning, and content, they have rarely been studied together. Few studies examine how - and within the same reform effort - teachers draw on both professional development *and* curriculum materials as resources to support their learning and implementation of reform. Further, we have limited understanding of the ways teachers negotiate the multiple and sometimes conflicting messages that come from curricular materials, PD, and other organizational practices that manage teachers' instruction and how these negotiations manifest into teacher practice.

Chapters 2 and 4 in this dissertation take up these gaps in the literature. In Chapter 2, Dr. Penuel and I examine teachers' local engagement with *The Framework for K-12 Science Education* and Next Generation Science Standards (NGSS). We conducted this analysis within a randomized-controlled trial study directed by PI Christopher Harris and co-PIs Joseph Krajcik and William Penuel, which examined the role of curricular materials and professional development in supporting teachers' learning and adoption of the *Framework* and NGSS. Specifically, we were interested in teachers' responses to ideas of science education reform as presented to them through professional development on the *Framework*, standards, and curricular materials. Utilizing concepts from organizational theories, we framed teachers' sensemaking of reform as a process of reducing the ambiguity and uncertainty caused by the suggested changes within the Framework and NGSS. Using observational data from professional development workshops and teacher interviews, we examined the cases of Marie at Central and Abby and Joan at Norman in order to explain how differences in teachers' instructional guidance infrastructures shaped their sensemaking of the reform.

In the analysis presented in Chapter 4, I examined teachers' implementation of instructional practices aligned with the *Framework* and NGSS (what I call science-practice based instruction, or, SPI) as an outcome of their organizational sensemaking. This analysis drew on a broader corpus of teacher interview data, in combination with classroom video and analyses of teacher-developed assignments from the larger project discussed in Chapter 2. Drawing on these data, I conducted a qualitative comparative analysis (QCA) to understand implementation patterns of 8 teachers across 5 schools within the same district. Specifically, I was interested in identifying the conditions of teachers' sensemaking that predicted a greater degree of reform implementation.

School-wide STEM Education Improvement Initiatives

In addition to instructional improvement, schools have taken up reform initiatives intended to improve STEM learning opportunities for students, particularly within urban areas. These school-wide efforts aim to improve STEM education through adopted models similar to Inclusive STEM High Schools (ISHS; Means et al., 2016). These models generally include integrated STEM curricula and assessments, high quality materials, rigorous teaching, a student-centered learning environment, and support from parents and the community (Means et al., 2008; NRC, 2011; Peters-Burton et al., 2014; Scott, 2012; Tofel-Grehl & Callahan, 2014). In areas serving high numbers of underrepresented students, ISHS's are thought to more equitably distribute opportunities for underrepresented students to engage in STEM. Recent literature suggests that school with characteristics of ISHSs (Lynch, Peters-Burton, & Ford, 2014; Means et al., 2016) do garner encouraging results in terms of preparing students with STEM core courses for college (Lynch et al., 2014), improving students' achievement in advanced STEM courses, and increasing numbers of underrepresented students in the STEM career pipeline (Means et al., 2016).

Although it can often be difficult for already-struggling schools to reconfigure into a STEM-focused school (Eisenhart et al., 2015; Weis et al., 2015), there is evidence that enhancing STEM learning opportunities within traditional high schools may bolster student participation in and successful completion of advanced STEM courses during high school and support underrepresented youth in pursuing STEM degrees in college (see Eisenhart et al., 2015). In their analysis of STEM-focused high schools, Eisenhart and colleagues found that traditional high schools that increased course offerings, teacher professional development, and the coherency of math course sequences offered better opportunities for underrepresented students within STEM.

Although these enhancements to traditional high schools may provide greater learning opportunities on paper, schools are still populated with historical practices that can maintain marginalization of underrepresented students in STEM (Carlone, Haun-Frank, & Webb, 2011; Fordham, 1996; Oakes, 1985). This is due in part to the historically-embedded discourses and practices that are pervasive within the educational system. For example, doing well in school can be associated with "acting White" (Fordham, 1996), and students may see being "scientific" as a White student activity

(Carlone, Haun-Frank, & Webb, 2011). Additionally, schooling practices can track students in racially-biased ways (Oakes, 1985), and students of color may be positioned from deficit points of view (e.g. lacking motivation, not trying hard). Teachers and school leaders may often be unaware of their own participation in such practices that work to maintain the status quo. As underrepresented students move through school, then, they must compete with, answer to, and address the kinds of school practices that may still favor historically advantaged and often White students and the discourses that may position them as underachieving, lacking motivation, or socially disadvantaged.

In Chapter 3, I present an examination of the experiences of students in the context of STEM education reform. This analysis was done within a project that examined the high school opportunity structures for underrepresented students to pursue interests in STEM within Denver and Buffalo (see Eisenhart et al., 2015; Weis et al., 2015). Specifically, the research team conducted a longitudinal ethnography of underrepresented high school students from their sophomore year in high school into their first two years of post-secondary education. Dr. Eisenhart and I conducted the analysis of Chapter 3 using data from two traditional urban high schools that had expressed commitment to improving education opportunities for underrepresented students at their schools. Although these schools had not taken up a STEM initiative de jure, they had engaged in many of the practices outlined in the literature as schools having successful STEM education. That is, they had increased advanced STEM course offerings, increased teacher professional development, and were intentionally aiming to align curriculum, standards, and assessments across grade levels. We used data from student, parent, and school personnel interviews, students' post-secondary surveys, and student transcript data, to analyze the ways that the national narrative of increasing opportunities for and broadening participation of young women of color in STEM was taken up locally at two schools within the same district, and how four young women (2 Latina, 2 Black) negotiated and maintained STEM-related identities in response to local discourse and practice.

CHAPTER TWO

Studying Teachers' Sensemaking to Investigate Teachers' Responses to Professional Development Focused on New Standards

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Abstract

Recent research on teacher professional development underscores the importance of the coherence of professional development with standards, curriculum, and assessment. Teachers' judgments of the coherence of professional development with larger system goals influence their decisions about what ideas and resources they appropriate from professional development. Little research, however, has examined how teachers formulate these judgments and why teachers' judgments vary within the same system and for the same reform. In this paper, we use organizational theory's concept of *sensemaking* to examine teachers' responses to professional development related to the *Next Generation Science Standards* within two schools in the United States. Our study shows that teachers' perceptions of coherence emerge from interactions within professional development, associated curriculum materials, and with colleagues and leaders in their schools. Some teachers, we found, were able to manage ambiguity, uncertainty, and perceived incoherence productively, while others foreclosed deep and sustained sensemaking. Our findings suggest the need for professional development to engage teachers in sustained sensemaking activity around issues of perceived incoherence to bolster teachers' emergent understandings of standards and improve the likelihood of implementing instructional practices aligned to standards.

Keywords: Education Policy, Professional Development, Standards, Science Education

Studying Teachers' Sensemaking to Investigate Teachers' Responses to Professional Development Focused on New Standards

Teachers' prior knowledge shapes what and how they learn from professional development. Of particular importance is teachers' *practical* knowledge, that is, the knowledge they draw upon daily to plan and organize their instruction (van Driel, Beijaard, & Verloop, 2001). Sometimes, teachers' practical knowledge helps them to interpret ideas and resources from professional development, but just as easily, such knowledge can interfere with teachers' making changes intended by leaders of professional developers (Kazemi & Hubbard, 2008).

Analyzing how teachers' practical knowledge shapes their response to professional development requires a focus on how such knowledge develops within the larger ecology of teachers' work (Connelly, Clandin, & He, 1997; Doyle & Ponder, 1977). There is evidence that teachers' own interpretations of their contexts vary widely and diverge from policymakers' interpretations (Penuel, Fishman, Gallagher, Korbak, & Lopez-Prado, 2009). In turn, these interpretations shape outcomes of professional development, particularly teachers' judgments about how well the goals and strategies of the professional development cohere with local standards, curriculum, and assessments (Garet, Porter, Desimone, Birman, & Yoon, 2001; Penuel, Fishman, Yamaguchi, & Gallagher, 2007).

To date, few studies of teacher professional development have examined the ways that organizational aspects of teachers' work shape what they take away from professional development. All too often, studies explain differences in teacher change in terms of individual learning styles, beliefs, or concerns, even when scholars take a situated perspective on teacher learning (e.g., Beijaard, Van Driel, & Verloop, 1999). In fact, within the professional development literature, there is very little focus on the organizational and institutional contexts where professional development occurs and how it shapes teacher practice (Cobb, McClain, Laumberg, & Dean, 2003). The limited focus on these broader contexts is problematic, because contemporary large-scale reforms demand coordination and coherence across multiple components of complex educational systems, including components related to professional development (Jackson & Cobb, 2013; Linn, Kali, Davis, & Horwitz, 2008). In addition, teachers' knowledge of educational contexts in which they work is an integral part of their knowledge for teaching (Shulman, 1987).

In this paper, we draw on the idea of *sensemaking* from organizational studies to interpret teachers' response to professional development linked to new science education reforms in the United States. Sensemaking, we argue, provides a useful framework for analyzing teachers' responses to professional development, because professional development activities create new and foreground existing sources of ambiguity and uncertainty for teachers in their organizational environment. Using evidence from a study of teacher professional development focused on the *Framework for K-12 Science Education* (National Research Council, 2012) and *Next Generation Science Standards* (National Research Council, 2013), we illustrate how focusing on teachers' attempts to resolve ambiguity and uncertainty provide us with a powerful lens for explaining when and how teachers' participation in professional development can influence teachers' decisions about implementing reforms.

Policy Context for the Professional Development

The professional development that is the focus of the current study took place within the United States, in a time when many states had just adopted ambitious new standards in English/Language Arts, mathematics, and science. The reforms embody perspectives on teaching and learning developed over many years of interdisciplinary research on student learning from sociocognitive and sociocultural perspectives (National Research Council, 2005, 2007). They share with other reforms being undertaken by countries in Europe and North America over the past decade that emphasize focusing instruction around a few core ideas of disciplines and promoting student engagement with disciplinary forms of reasoning (De Jong, 2007).

The professional development that is the focus of this study aimed to develop teachers' understanding of the *Next Generation Science Standards* (NGSS; National Research Council, 2013). Developed from the vision of science learning articulated in the *Framework for K-12 Science Education* (National Research Council, 2012), the *NGSS* call for disciplinary core ideas, crosscutting concepts and science practices to be integrated in science education. This integration is reflected in sets of "performance expectations" for students, which (as of summer 2014) twelve states and the District of Columbia have adopted as their new science standards.

If findings from implementation research on earlier generations of standards in mathematics and science education are a guide (Garet et al., 2001; Spillane, Reiser, & Gomez, 2006; Supovitz & Turner, 2000), providing professional development and supports for individual teachers will be a critical condition for the success of

NGSS. Such professional development is necessary to develop teachers' understanding of science content, the vision of the *Framework,* and instruction that engages students in science and engineering practices.

However, even when professional development has a positive impact on teachers' attitudes, knowledge, and skills, it does not always lead to durable or even immediate changes to their instructional practice. Prior research suggests that teachers' perceptions of incoherence among their own goals for student learning, district goals, and goals presented in professional development may, in part, explain why the impacts of PD can be limited (Garet et al., 2001; Penuel et al., 2007). At present, though "coherence" is widely accepted as an important feature of professional development, we do not have useful frameworks for guiding our understanding of how and why teachers' perceptions of coherence may vary within the same larger reform context (Penuel et al., 2009).

In the current policy context in the United States, there are many reasons to expect teachers' perceptions of coherence to vary in ways that could either support or impede adoption of practices consistent with the vision for science learning outlined in the *Framework for K-12 Science Education.* Teachers may perceive strong support from district leaders eager to adopt the vision and therefore perceive a high level of coherence. At the same time, teachers in the same district could perceive there to be a low level of coherence, because of differences in how they perceive district or school level support. Understanding and ultimately addressing teachers' concerns about coherence is critical to implementing reforms linked to the *Framework* and *Next Generation Science Standards.*

Conceptual Framework: Sensemaking

The concept of *sensemaking* offers one productive way to analyze how teachers wrestle with issues of coherence, as it considers how local actors negotiate meaning from a variety of, often conflicting, messages they encounter in their local environment. Sensemaking describes the ways that actors "structure the unknown" (Waterman, 1990, p. 41) within organizational settings such as schools (e.g., Coburn, 2001). Actors engage in sensemaking in order to resolve ambiguity and manage uncertainty within their environment and make retrospective, as well as prospective sense of change. Sources of ambiguity can include the presence of conflicting goals, contradictions or paradoxes, limited resources available to perform actions demanded of external change agents, lack of clarity with respect to roles and responsibilities, or the absence of measures for judging the success of action (Weick, 1995). Uncertainty that occasions sensemaking arises when people lack understanding of how different aspects of the system are changing, the potential impact of change on the system, or the response options that are open to them (Weick, 1995). Follett (1924) describes the sensemaking process as "confronting the activity" of one's environment, as it involves a noticing of change or difference, but includes the potential for integrating difference into one's practice.

Sensemaking processes are also influenced by the actual, imagined, or implied presence of others (Weick, 1995). Within organizations, "decisions are either made in the presence of others or with the knowledge that they will have to be implemented, or understood, or approved by others" (Burns & Stalker, 1961, p. 118). Additionally, sensemaking often occurs in discourse-rich environments

(Currie & Brown, 2003), in which people attempt to resolve ambiguity by relying on different vocabularies of meaning that draw from ideology, professional paradigms, and tradition. Further, in large organizations where the activities of many different actors must be coordinated, sensemaking also entails *sensegiving,* or efforts by leaders in organization to help guide others' sensemaking efforts toward the accomplishment of desired organizational goals (Gioia & Chittipeddi, 1991).

Education researchers have used sensemaking theory to interpret teachers' responses to new policies and programs introduced into their schools and districts. For example, Coburn (2001) examined the interactional processes teachers in a single elementary school used to make sense of new and often conflicting messages about reading instruction. In a subsequent analysis, she documented how individuals' sensemaking in relation to changes in reading policies were shaped by individuals' history of involvement with earlier reform efforts, as well as by messages in their immediate school environment (Coburn, 2004). Other policy implementation studies have documented the ways that both school leaders and interactions with colleagues exert normative pressure that in turn can have an effect on individual teachers' classroom practice (Coburn, 2005; Coburn & Russell, 2008; Penuel, Frank, & Krause, 2011; Penuel, Sun, Frank, & Gallagher, 2013).

Studies have examined teacher sensemaking in science education, primarily in the context of program implementation. In science education, teachers interpret new policies in relation to the instructional materials, framing their response on the basis of access they are able to gain to new materials and support in how best to use them (Penuel, Shear, Korbak, & Sparrow, 2005; Vesilind & Jones, 1998.) Additionally, studies of teacher understanding of science reform—such as standards-based teaching—suggest that teachers interpret new policies in light of access to curriculum materials and hands-on activities (Penuel, Shear, Korbak, & Sparrow, 2005; Vesilind & Jones, 1998).

Scholars have also begun to apply sensemaking theory to examine teachers' responses to professional development in science education. Penuel and colleagues (2009) used sensemaking theory to help explain discrepancies between policymakers' and teachers' judgments about how well particular curriculum materials aligned with standards and professional development. They found teachers' judgments about the coherence of professional development with standards influenced teachers' decisions to implement materials introduced through professional development. It mattered little that policymakers made a clear and strong effort to create systemic alignment at the policy level, suggesting a need to understand better how teachers make judgments about coherence.

We hypothesize that sensemaking offers a particularly useful framework for analyzing teachers' responses to new messages about teaching and learning encountered in professional development that are related to major reforms, such as the adoption of new standards. In the United States and elsewhere, teachers' environments are populated with numerous and changing sources of ambiguity and uncertainty, including fluctuating policies around teacher evaluation and continued pressure to demonstrate growth on external tests. Multiple reforms compete for attention and resources, and science teachers—even though they have a limited sphere of autonomy within their classrooms—are not immune to the shocks and interruptions (Weick, 1995) these competing reforms introduce. *NGSS,* for some, will be experienced as a shock or interruption from the external environment (Weick, 1995), presenting them with an occasion for individual and social sensemaking that does not just demand new knowledge but also demands meaning making.

In this study, we set out to document and analyze the ways that *NGSS*-related professional development provided opportunities for teacher sensemaking to resolve ambiguities and manage uncertainties associated with implementing messages from the workshop. Specifically, we ask:

1. *What are the key sources of ambiguity and uncertainty with which teachers wrestle, during and after professional development?*
2. *How does their sensemaking shape their decisions about their teaching practice?*

Method

This paper employs a multiple-case study methodology (Stake, 2005) to explore the ways teachers make sense of science practice-focused instruction and the *NGSS*. We look closely at two school sites over a 16-month period, and although data were collected from numerous sources (e.g. professional development fieldnotes, classroom video, teacher online logs, teacher surveys), we focus this analysis on teacher interviews and artifacts of teaching (e.g. teacher-developed assessments or instructional resources) that we viewed as products of teachers' sensemaking processes.

Research Context

The district where this study took place, Georgetown School District*, served more than 140,000 students, and had a student composition during the time of our study that was 42 percent African American, 32 percent White, 18 percent Hispanic, and 5 percent Asian. Fifty-four percent of the students in the district were eligible for free or reduced-price lunch. The teachers in schools discussed in this analysis participated in professional development on the *Framework* (Year 1) and *NGSS* (Year 2), and on the *Project-Based Inquiry Science (PBIS)* curriculum materials (described in more detail below).

***Framework* and *NGSS* professional development**. The *Framework* and *NGSS* workshops both took place during the August of the prior to the start of the school year in 2012 and 2013. Members of the research team and committee that developed the *Framework* and *NGSS* led the professional development. Professional development activities in the *Framework* and *NGSS* workshops emphasized learning about disciplinary core ideas through driving questions; science practices, with particular emphasis on modeling and explanation; and how core ideas, practices and cross-cutting concepts are integrated in performance expectations. In particular, teachers had practice developing and revising models and writing and revising scientific explanations related to material they were required to teach (per state standards). For example, during the *Framework* workshop (Year 1 of the study), teachers worked in small groups on an activity from *Investigating and Questioning our World Through Science and Technology* (Krajcik, Reiser, Sutherland, & Fortus, 2013) curriculum that focused on the

* All district, school, and teacher names throughout this paper are pseudonyms.

particulate nature of matter (one topic teachers in Georgetown were required to teach). In these small groups, teachers created models of what happens to air inside a syringe when the syringe plunger is pushed and pulled. Teachers then shared and compared those models with their colleagues – presenting their small group work with the larger group. During the *NGSS* workshop (Year 2), teachers developed and revised explanations in small groups that described energy transfer, demonstrated across multiple phenomena. Professional development facilitators also emphasized the language demands inherent in the *NGSS* practices (Lee, Quinn, & Valdés, 2013) and which of the Language Arts and math Common Core tasks overlap with the *NGSS* practices. Teachers also examined the *NGSS* performance expectations and were given an opportunity to adapt state standards into performance expectations.

Project Based Inquiry Science Professional Development. Curriculum is widely viewed as an essential resource to help teachers understand new standards and support standards-based instruction, and it has played a critical role in standards-based reform efforts in the United States throughout the past fifty years (Atkin & Black, 2003; Krajcik, McNeill, & Reiser, 2008). Teachers in this study also received professional development in the *Project-Based Inquiry Science (PBIS),* a comprehensive 3-year curriculum sold and distributed through It's About Time Publishing. The curriculum is comprised of science units in life, physical, and Earth science, spanning grades six through eight. A typical unit takes 8-10 weeks to complete. In contrast to other materials that present ready-made investigations for students to carry out, *PBIS* presents challenges to students in which they must investigate phenomena and apply concepts to answer a driving question or to achieve a design challenge.

As a curricular support to teachers' shifting their instruction toward a science-practice approach, *PBIS* is a good candidate as it has features that align with the vision of the *Framework*. The driving question or challenge typically targets a core idea in science, and the activities within each unit provide students with multiple occasions for investigating as scientists would – through observations, asking questions, designing and carrying out experiments, building and using models, reading about the science they are investigating, constructing explanations, and so forth. In this way, the *PBIS* curriculum's design emphasizes a knowledge-in-use perspective (National Research Council, 2007) and reflects in a broad sense the principles of the *Framework*. At the same time, the particular goals of *PBIS* units do not align perfectly to performance expectations as articulated in the *NGSS.* In addition, not all of the eight practices emphasized in the *Framework* are prominent within the investigations. This partial alignment is important to point out, because for the teachers in our study, the materials embodied and even served as a stand-in for the *Framework* and *NGSS.*

Teachers in the current study received professional development focused on this curriculum, in addition to the professional development they received related to the *Framework* and *NGSS.* It took place at three time points throughout each school year and ranged between 1-3 days – August, October, and January, roughly – and intended to coincide with teachers' curricular pacing (Figure 1). For example, the initial workshop was designed to introduce teachers to the curriculum and the introductory unit they would teach; the October workshop prepared teachers for the second unit (*Energy*); and the January workshop for the third (*Everchanging Earth*). Teachers had opportunities to learn about the design principles behind the curriculum. Workshop leaders emphasized connections between *NGSS* and curriculum activities and structures, with particular attention given to the role of scientific practices of constructing explanations and developing and using models within the curriculum. Teachers worked as their students might through condensed versions of the curriculum units they would teach. They were additionally given an opportunity to discuss alignment of the new curriculum with their district pacing guide within small groups and in collaboration with district personnel.

[Figure 1]

Participants and School Sites

We selected the two school sites for this analysis on the basis of multiple criteria. First, the teachers at these sites were participating in other data collection, namely a smaller video study (Moorthy, Harris, D'Angelo et al, 2014), in which teachers' recorded focal lessons for the larger research study; the weekly online logs (D'Angelo, Moorthy, Allen Bemis, & Sherwood, 2014) through which teachers noted their implementation frequency of the eight practices outlined in the *Framework*; and these teachers agreed to participate in interviews. Teachers at these sites also attended roughly the same amount of professional development days offered through the study during Year 1 (see Table 1). Although teacher attendance in PD was comparable, issues of concern (interpreted as ambiguity or uncertainty) and questions raised by these teachers during professional development (as noted in the PD workshop fieldnotes) varied significantly; and as part of an initial review of data, two different schools were selected for additional analysis because of the sharp contrasts between them with respect to sources of ambiguity and uncertainty, in order to help elaborate our initial framework such that it might explain differences in sensemaking across school contexts (Yin, 2013). These two school contexts are described in detail below.

Central Middle School

The area around Central has seen large demographic shifts over the past decade. The student population at Central is roughly 40 percent African American and 40 percent Latino, 96 percent on free or reduced-price lunch (FRL), and a large Spanish-speaking population. Central is historically a low-performing middle school, with less than 50 percent of students at grade level over the past several years. Teachers at Central are expected to keep and maintain data folders that included assessment scores for students. Building administrators--specifically, the principal and assistant principal—expected teachers to assess students daily. Over the course of the Years 1 and 2 of the study, the science department decreased by half. Three teachers – formally in the larger study – were reassigned to different discipline areas (social studies, math, and physical education), leaving the sixth grade teacher in this study, Marie, as the remaining "veteran" science teacher. At the time of this analysis, Marie was in her third year of teaching.

Norman Middle School

Norman sits toward the northern boundary of the school district and serves a population of students who are mostly white (76 percent) and affluent (23 percent

FRL). The school touts a mission to “inspire, empower, and challenge learning” in its community. In general Norman ranked high in terms of test score proficiency. Teachers at Norman were expected to maintain consistent pacing with other teachers in their same grade level and subject area. Abby and Joan were two of four sixth grade science teachers at Norman. With their classrooms positioned just across the hallway, Joan and Abby regularly visited each other’s rooms throughout the day. At the time of the study Joan had been teaching for 10 years and Abby for three.

Abby, Joan and Marie were selected for this study because of their different approaches to sensemaking and the availability of data from a broad range of sources collected as part of the study, namely participation in the video study, weekly online logs, teacher surveys and workshop attendance.

Data Collection and Sources

Data for this analysis were collected over a 16-month period. Although data sources collected were multiple (fieldnotes, teacher interviews, teacher-developed artifacts, online posts made by focal teachers, and focal teacher survey data), we focused this analysis on teacher interviews and teacher-developed artifacts. We have outlined descriptions of these data below:

Teacher Interviews. Author 1 interviewed focal teachers during the fall of Year 2 of the larger study. The interview protocol was developed using a construct-centered approach to assessment design (Wilson, 2005) that utilized both Weick’s (1995) typology for sources of ambiguity and uncertainty and our fieldnote data (see also, description of coding scheme development in Data Analysis). Interview topics included instructional management practices at teachers' schools sites –such as what teaching and classroom-organizational practices (e.g. Essential Questions or objectives posted) building administration look for, lesson planning expectations, and teacher responsibilities – and teachers' perceptions of coherence between the *NGSS*, their current instructional approaches, and state and district goals. The interviews were conducted over Skype or in person and were audio recorded and transcribed. Interview length ranged from 25-75 minutes.

Teacher artifacts. During informal conversations and interviews, our focal teachers mentioned a number of materials they had developed in order to address building or district expectations, such as particular lesson-plan sections, additional assessments or activities. We collected these artifacts from teachers as evidence of their sensemaking. Additionally, Abby and Joan were asked by IAT to conduct the *PBIS* workshop during the fall of Year 2; for this workshop the two created a CD of materials of the Energy unit for teachers attending (also in the larger study). We collected these materials and discussed them with Abby and Joan during their interviews. In particular, Author 1 asked Abby and Joan their process of developing the materials and in what ways these materials differed from *PBIS* or other curricular materials they were using for their instruction.

Data Analysis

Because we were interested in the sources of ambiguity and uncertainty that emerged for teachers within our study, we inductively defined what these sources were based on teachers' expressed concerns and questions during professional development (as documented in our field notes). We used the field notes to establish topical categories that emerged for teachers in their responses to PD messages during workshops (e.g., “assessment,” “building administration,” “pacing”). We then tested and iterated on these codes with additional data, namely teacher artifacts and interview transcriptions. Once we identified consistent topic codes, each set of field notes, each interview, and artifact was initially coded for all topics. At this point, we also identified schools where we could focus analysis, because the processes at these schools appeared to vary the most (as described above in Participant Selection). In a second round of coding, we identified what we considered sources of ambiguity evident in statements teachers made related to different topics. This second round of coding drew explicitly on Weick’s (1995) typology of sources of ambiguity in sensemaking. We then operationalized these sources through patterns that emerged in our data (as illustrated in Table 2). Sections of all three teachers’ interviews (about 30%) were coded independently by Author 1 and one additional coder. Percent agreement was 94% across all codes; Cohen’s kappa ranged from 0.72 to 0.87 with the exception of two topical codes: ‘time’ and ‘district initiatives’. Differences for codes with low reliability were resolved by discussion and consensus. Author 1 then coded an additional third of the interview data and checked codes with the co-rater.

[Table 2]

Results

The most prevalent sources of ambiguity and uncertainty for the teachers in this study were *conflicting goals*, an *absence of measures*, and *limited resources.* As we elaborate in the sections that follow, teachers’ organizational structures were integral in shaping their sensemaking in response to these areas of ambiguity and uncertainty, but the differences in how they resolved these sources of ambiguity and uncertainty bolstered differences in perceptions among teachers in how well messages from the PD cohered with goals for teaching and learning in their respective contexts.

Sources of Ambiguity and Uncertainty at Norman and Central

For the teachers in this study, *conflicting goals* emerged as the most prominent source of ambiguity and uncertainty that, depending on teachers' organizational contexts, either resulted in teachers' constrained sensemaking or served as fodder for sustained sensemaking around the PD messages. Specifically, teachers faced uncertainty around pacing and timing, as the curriculum and the school district allotted differing amounts of time to science topics. Teachers also faced conflicting goals with respect to what constituted best science teaching practice, requiring them to make sense of the multiple and sometimes competing messages from the professional development leaders, their building administration, their students, as well as their prior teaching experiences and their previous and continuing education degree programs.

Although perhaps not as disruptive as *conflicting goals*, an *absence of measures* for gauging successful implementation of science-practice instruction surfaced as a source of ambiguity and uncertainty for teachers. Because assessments of student learning available to teachers measured content and did not adequately measure science and engineering practices, teachers faced uncertainty around how to measure student learning. As will be discussed more fully in the next sections, for one of our teachers, a lack of shared views regarding what counted as valid assessment coupled with the district-mandated expectation to assess student learning on a daily basis and track student assessment data proved particularly problematic and significantly foreclosed her sensemaking process. ,

In terms of *limited resources*, the *PBIS* curriculum did not sufficiently provide teachers with the supports they needed to implement *NGSS*-aligned practices. Teachers required additional tools – such as clearer pacing guides – to support their instruction of both *NGSS* practices and their current state standards. Limited time, coupled with curriculum materials that inadequately supported the *NGSS*, made it difficult to fully implement instructional strategies for engaging students in science practices throughout the school year.

Conflicting Goals

At both Central and Norman, there were conflicting goals present that influenced teachers' implementation of practices. At Central, there were conflicts between teachers and building administration around learning goals, specifically the purpose and value of *PBIS* and whether these resources were organized in ways that promoted student learning. At Norman, these conflicts were mostly around *instructional pacing*, specifically around competing demands about how teachers should organize their instructional time and how to prioritize their time outside of the classroom. In both instances, routines and tools for monitoring instruction were occasions for surfacing conflicting goals.

Conflicting Goals at Central Middle School. At Central, there was a lack of coherence between the building administrators' views regarding the instruction and

Marie's own views about instruction. Marie valued developing students' conceptual understanding. She believed her implementation of science practices supported in *PBIS*, like constructing and using models, deepened student understanding of scientific concepts in ways that her prior instructional approaches (that placed the teachers as the primary disseminator of information) did not. She appreciated how lessons built on each other in the *PBIS* materials, allowing her to revisit their investigations to build understanding of relevant terms and concepts to students' repertoire of experiences. However, for building administrators, some *PBIS* lessons appeared to lack "rigor", as they were too aberrant from traditional instructional approaches, particularly those that came earlier in a unit series and were intended to be the first step in developing student understanding.

A classroom visit during a lesson on energy made visible the differences in these viewpoints. In this lesson, an early lesson in a sequence of lessons about types of energy, students are asked to "mess about" with various toys. The toys have springs and gadgets, and students are encouraged to make predictions about what kinds of energy are present in the toys. Later in the lesson series, students return to their predictions after a series of investigations with new conceptual resources to identify the forms of energy. However, to an observer unfamiliar with the sequence as a whole - in this case, Central's assistant principal – the earlier lesson of "messing about" appeared to lack the kind of intellectual rigor the building administration had come to expect in science classrooms. The assistant principal gave Marie a less-than favorable evaluation for the lesson, with her primary question being, “Where’s the rigor here?” Marie explained her reaction to the assistant principal’s observation this way:

> With these toys, kids are trying to figure out how these things work, describing what that type of energy is doing what. There is an end result….For her to say that there is no *rigor* in this program is a load of BS! But, how do you walk up to your principal and say, “That's a load of BS?” You can’t, and have job security.

Marie’s reaction here speaks to her belief in the value of science-practice instruction, seemingly based in her observations of student responses to this way of engaging in science practices and developing understanding of core ideas. She described this approach as being “best” for her students.

Coming to this conclusion required a process of sensemaking with conflicting messages about the importance of particular goals for instruction. At the time, Marie was working toward her master’s degree at a local university. She found there to be vast differences among what her program suggested as effective teaching practices and the messages presented at the *Framework* workshop on the one hand, and those enforced at Central on the other. She claimed, “Nothing that my administration says about rigor is what I’m learning about rigor.”

Despite her administration’s insistence otherwise, Marie believed engaging students in science practices from the start was a more appropriate goal for science instruction than goals for science learning her administrators seemed to favor. Marie interpreted her assistant principal’s view of science-practice instruction as lacking understanding of the knowledge-in-use approach to science learning as compared to the kind of teaching the school promoted. Marie explained that with the model of teaching endorsed in the school, teachers would "frontload" information and vocabulary to students, provide them with a demo, and then ask students to do something with the content. So, according to Marie, when building administration did not see lessons that followed this type of trajectory, they were confused and dismissed the approach as not providing students with the degree of challenge needed. In the *Framework* workshop, Marie had received explicit messages that such pre-teaching of vocabulary was counterproductive to deep understanding of core ideas.

Goal conflict can become an occasion for sensemaking when teachers are required to participate in other, related activities in which administrators monitor teachers' instruction. This was the case for Marie. In Year 1 of the study, Marie was able to use a lesson plan template provided by the publisher of *PBIS*. But in the second year of the study, Marie's administration began requiring teachers to use a particular template that did not align with the lesson format of the *PBIS* curriculum. Marie was also required to incorporate materials at least twice a week from the current district-adopted curriculum for science. Marie found creative ways to fill in the lesson template to meet this requirement, but she also described this step to be a "waste of time" and unnecessary. In addition, Marie did not see how both curricula could be incorporated, as she interpreted them as being too dissimilar. In explaining how she managed to meet the school's expectations, Marie explained, "I just don't do it…it's like having on the sweater and adding a scarf."

Ultimately, Marie's process of sensemaking brought her to different conclusions about the importance and value of a science-practice focused teaching approach than her building administration. The primary source Marie drew on for her sensemaking was students' responses to the knowledge-in-use approach to teaching present in the *PBIS* curriculum. She described the ways that her students "had something tangible to go back to" when answering questions about science content, and she contrasted this with other methods that simply gave students the content and asked them to memorize it. In addition, rather than try to find ways to satisfy both the study's demands and her school's administrative requirements, she chose to follow one set of guidelines that was more aligned to the demands of *NGSS*.

Conflicting Goals at Norman. At Norman, the building administration and teachers had shared ideas about the value of *PBIS* and a science-practice approach to instruction. In fact, the building principal's son was in one of the *PBIS* teachers' classrooms during Year 1 (not one of the two teachers discussed here). Having drawn from her son's experience and excitement around science, she had concluded that this approach to instruction was an effective one.

But Norman teachers still experienced goal conflict, specifically around pacing demands. The school administration expected teachers to be on pace with the other sixth grade science teachers. This meant that teachers should teach roughly the same lesson on a given day. The members of the sixth-grade science team met on a semi-regular basis to collaboratively develop an instructional plan for each lesson. To make decisions around pacing, the team – led by Abby – relied heavily on the district pacing guide and state standards. Per the request of teachers and district leaders, the publisher (IAT) had developed a pacing guide to align with the state standards to help teachers meet district expectations while still implementing the curriculum with integrity (see Table 3). The pacing guide was intended as a resource for teachers while implementing *PBIS*.

[Table 3]

The pacing suggested by IAT did not fully align with the pacing established by the district, however. As Joan explained, “The book allocates more time than what we have in the [district’s] pacing guide; so, if you were to implement the [*PBIS*] units with complete fidelity, you’d run out of time.” To address this timing conflict, Joan and Abby created an additional pacing guide, which outlined the time suggested by the district for a particular topic, time suggested by IAT and their suggestion for addressing both. Table 4 shows one small section of the map Joan and Abby created for created for the PBIS energy unit.

[Table 4]

Joan explained how they made decisions around developing this alternative pacing guide: “We had the book out, the district’s pacing guide, IAT’s suggested pacing guide, and unit plans we’d used in the past.” Abby and Joan describe their students’ “needs” as being the most vocal message in coming to decisions about how to organize instructional time. Ultimately what felt “best” to their students while still “addressing” the state’s standards guided their sensemaking the most.

For Marie, sensemaking in response to goal conflict resulted in an uptake of and focus on instructional practices that, on the surface, most readily cohered with goals of the PD itself. Marie cued in to messages about learning from her master’s program, professional development provided from the study, her student's responses, and her experiences teaching as indicators in support of science-practice instruction. She essentially chose to listen to those messages, rather than her building administrators, which resulted in conflict for her. For Joan and Abby, they were able to sit with multiple and conflicting resources, such as the various pacing guides, and consider the ways the instructional goals represented in the tools were similar or different. Additionally, they were able to produce a new instructional tool that could support them in accomplishing what – in some ways – could have been seen as competing goals.

Absence of Measures

At present, there exist only a few kinds of assessments that include multi-component tasks that assess core ideas, practices, and crosscutting concepts (Pellegrino, 2013). Some of the tasks developed specifically for the study do include such tasks, and examples are featured in a consensus volume on assessment and the *NGSS* (Pellegrino, Wilson, Koenig, & Beatty, 2014). However, neither the district nor state used measures aligned to *NGSS*, because the state had not adopted the new standards.

The absence of measures created uncertainty for teachers: it was difficult for them to know when changes to instruction resulted in improved learning. Moreover, the measures that are used in the schools and by the state present tasks for assessment of learning goals that could be viewed as inconsistent with *NGSS*. As illustrated below, administrators' insistence on teachers using these types of assessments created potential occasions for sensemaking and exacerbated goal conflicts.

Assessment expectations at Central. At Central, Marie faced a great deal of pressure to demonstrate daily assessments and corresponding data generated from multiple-choice assessments focused on factual recall. During a campus visit, Marie greeted our on-site coordinator (Joyce) and the first author with a look that expressed both humor and frustration. She announced to Joyce: “I’m in trouble again.” Hands lifted just slightly and shoulders shrugged, she exchanged glances with Joyce and shook her head. Without missing a beat Joyce asked playfully, “What did you do now?” a reference to her earlier conflict with an administrator over her feedback from the observation described above.

This time, Marie was “in trouble” for not providing her principal with a complete data folder, showing student progressions through daily assessments. She said, “We have the data. We assess students at the end of each class, it’s just not going to look like what she wants.” This particular day, Marie had been pulled out of class by her principal and “yelled at” in the hallway for not providing her data folders to building administration. This pressure did not change Marie’s commitment to teaching students through engagement in science practices, as she believed strongly that her students learned most deeply through this approach. In regard to assessment measures, Marie’s sensemaking drew most strongly on what she interpreted as her students’ engagement in class activities and students’ ability support their ideas with “tangible” evidence. In this way, messages from her building administration about what counted as good or valid assessment did not cohere with the other messages in Marie's environment (e.g. student responses and PD messages).

Assessment Expectations at Norman Middle School. At Norman, Abby and Joan felt that they had more leeway around daily assessments. They started each lesson with a "warm up" activity to assess students' understanding of material covered in the previous lesson and to generate discussion related to that day's lesson. These "check-ins" – similar to Marie's – served as adequate daily assessments for Abby and Joan from the standpoint of school administrators. Though teachers are required to keep data folders, those folders were not monitored in the way that they were at Central:

> Abby: "They harp on data, but do they really check it? I mean, we are supposed to keep a data folder."
> [Author 1]: I don't get a sense from you that you have a lot of pressure placed on you or that you're worried about this.
> Abby: The pressure I feel is more me putting on myself to make sure the students are getting what they need to get. Do I feel it from the administration? Not so much, which is a good thing.

Joan and Abby had developed more formal assessments (tests) for each learning set in *PBIS* (about 5 per unit). These assessments included multiple-choice, true-false and short answer questions. These were not strongly aligned to *NGSS*, and in many ways resembled the kinds of assessments that the school and district had been using. In the building, teachers referred to these assessments as "common assessments" in that they were shared among grade-level teams. Joan and Abby created and revised these common assessments collaboratively and were given the autonomy by administrators to do so. For example, if students did not perform well on an assessment, Joan and Abby would compare their students' performance and examine test items to try to interpret why students performed poorly without strong interference from administrators. They might not have intervened, however, had they seen the assessments the two had developed, because they did not diverge in form and content from other assessments in the school.

One reason these assessments may not have drawn attention – and which we will explore in more detail in the next section – is that Joan and Abby were given autonomy with respect to the design of assessments, and they let state standards guide their decision about what items to put on these assessments. Abby described the content (characterized by Author 1 as "choices about what to teach") and assessments as being "intertwined": The assessments "intertwine with the content – we have these standards they have to get and so these assessments are telling me whether they've [the students] got that."

Even so, Abby still felt that the assessments she and Joan had designed did not align well to the vision of the *NGSS*, stating that she preferred the style of assessment in which students wrote scientific explanations to elucidate science phenomena: "I'd like to do the whole, 'tell me about convection;' and where those explanations come along, that's the best way to assess them because I can see, oh they're relating it back to what we've done; they've got the concept." Limited time, however, left Abby (and ultimately Joan too) feeling reliant upon multiple-choice tests that could be graded quickly.

Lack of Resources

Common to both school sites was a concern that *PBIS* provided an incomplete curricular solution for them. It presented compelling models for a different kind of science instruction, but it took significant amounts of time and did not cover all the standards teachers were required to teach.

At both sites, the teachers expressed a desire to use what they termed as "*PBIS* strategies" and that we recognized as practice-focused instruction that provided students with opportunities to investigate phenomena through science practices throughout the school year. They wanted to use these strategies in the units for which curriculum materials were not provided. As Joan explained, "I hear from my students that they are talking about what we did in class when they go home. They are able to explain to their parents pretty hard concepts. I can tell they're excited about class." All three case study teachers realized providing students with such experiences would require them to adapt their existing curriculum materials that they used to cover standards not taught in *PBIS*. None felt they had the time to make such adaptations. But by Year 2, Abby had made these adaptations for one additional unit and shared that she felt "very proud" of herself, as this work took a great deal of time. Abby was able to "chunk" the task of adaptation into a smaller, manageable task focused on a single unit. And because teachers at Norman teach the same units, following the Content Lead (Abby's role during Year 2), Joan would also benefit from the additional unit Abby adapted. Marie, however, had not yet made any adaptations. She explained that she "intended to" make changes to her other units for next school year.

Role of Sensemaking in Shaping Teachers' Implementation of *NGSS*

In the previous section we detailed sources of ambiguity and uncertainty that emerged as sources for sensemaking as teachers attempted to implement science-practice instruction. In this section, we highlight the ways that teacher sensemaking informed and shaped their perception of coherence and appropriation of ideas and teaching strategies from the PD.

For the teachers in this analysis, their sensemaking led to different perceptions of coherence and appropriation of ideas from PD. In the case of Marie, the tight monitoring of instructional practice by her administration forced expedited and constrained sensemaking about practice-focused instruction, which resulted in streamlined decision making around what of and in what ways to teach the ideas presented in professional development. Marie was not able to reconcile the incoherence she perceived and experienced between goals of the PD and those of her site administrators. Joan and Abby's autonomy afforded them slightly more opportunity for productive sensemaking that resulted in the creation of instructional materials – that supported their implementation of activities to engage students in science practices. This more sustained sensemaking was due in part to principal support Joan and Abby experienced at Norman and their opportunities to collaborate with each other to reconcile conflicting goals across different artifacts guiding their instruction. The result was a kind of coherence they jointly and locally accomplished among key system components.

Sensemaking at Central. At Central, Marie's sensemaking resulted in a decision to use instructional resources from the study. As she dealt with ambiguity and uncertainty in her environment, she defaulted consistently to the *PBIS* curriculum and what she interpreted as "the study's" goals rather than turning to the compulsory goals of her administrators or finding ways to accomplish both sets of goals. For example, when describing her decision making around whether to teach the district-mandated curriculum, Marie explained: "Our principal wants us on the tech book two days a week. How can I do that and the *PBIS* curriculum when they aren't integrated?" When asked by Author 1 what was in the tech book and what Marie had used from it, if anything, she replied that she had incorporated "some chemistry stuff – we've got that on the tech book. There is some stuff on there, but it's not going to mesh well [with *PBIS*]." Marie's discussion here of the district-mandated tech book highlights her sense of ambiguity – "how can I do that and *PBIS*?" – while also indexing her truncated sensemaking. That is, rather than consider the ways the tech book might complement *PBIS*, Marie saw the two approaches as too dissimilar to be integrated and dismissed the district-mandated curriculum because she valued the goals of *PBIS* more. It was too difficult to adhere to administrators' goals, she believed, because they were constantly changing. During her interview, Marie indicated that the multiple and continuously changing instructional management practices – such as the change or lesson plan format or the new requirement to include the district-mandated curriculum each week – were too ambiguous. Further, Marie expressed concern that if she were to teach from the tech book, she might "mess with integrating a whole new way of learning," speaking of the knowledge-in-use approach of practice-focused instruction.

Although Marie's tight adherence to implementing the *PBIS* curriculum could be viewed as a "success" from the perspective of the larger research project because she was implementing instructional practices in ways we would hope for, at the same time, by not engaging in deeper thinking about how it could fit within larger school or district goals, she missed out in developing more robust understandings of how multiple kinds of materials might be employed and used in an integrated fashion to support student engagement in science practices.

Sensemaking at Norman. In contrast to Marie, Abby and Joan sought to "satisfice" (Simon, 1956) that is, reconcile the messages from both the district and the study and meet each perceived conflicting goal the best they could. They relied on publisher-created resources to help them, and when these did not work, they created their own. Importantly, Abby and Joan were able to work together to develop these; an opportunity Marie did not have. By doing so, they were able to uncover nuances and explore incoherence more deeply, particularly around assessment. In discussing these assessments, Abby explained:

> I like the questions that [the research team] gives us with those tests where they give [students] the picture and then ask them to explain. For us [teachers at Norman], we are in just a time crunch and so multiple choice is just the easiest way to do it…and where those explanations come along, that's the best way to assess them because I can see, oh they're relating it back to what we've done; they've got the concept.

Here, Abby describes her perceptions of the ways that current assessment measures do not cohere with what she and Joan created while suggesting her ideal, or "best" way to assess students that includes both science practices (developing explanations) and content. Her encounter with the model tasks she saw the research team had created generated conflict for her that occasioned sensemaking. She recognized these items as being more aligned with *NGSS*, but noted that a lack of time made it difficult for her to change her practice. Abby's description here reveals an understanding of one of the goals of science-practice instruction (connecting content with practices), the ways that organizational structures at her school cohered (or not) with this goal, and her autonomy to choose how to assess her students.

Discussion and Conclusions

The preceding results highlight key sources of ambiguity and uncertainty for teachers that shaped their implementation of ideas introduced in professional development. Teachers at both sites faced some degree of ambiguity and uncertainty around instructional goals, available accountability measures, and adequate resources. In particular, available time to adapt curriculum materials and assessments of student learning to cohere with the *NGSS* and differing views of the value and purpose of reform proved especially challenging. Teachers had to negotiate ways to meet the pacing demands of the district while maintaining fidelity to *PBIS*. Despite these similarities, teachers at each school engaged in different sensemaking processes, as they sought to resolve conflicting goals of engaging students in science practices as part of instruction with goals embodied in district pacing guides, protocols used by administrators to evaluate instruction, and local assessments. In both cases, teachers chose to shift their teaching to align with the vision of the *Framework for K-12 Science Education* and *NGSS,* but only in the school where teachers had opportunities to engage with each other in making sense of conflicting goals were teachers able to reconcile perceptions of incoherence between PD goals and goals of their local educational contexts.

Each of the three teachers discussed here shared a belied in the value of science practice and knowledge-in-use instruction; however, their school-specific instructional management practices played a crucial role in shaping teachers' sensemaking. In the case of Marie, her sensemaking was constrained by the tight monitoring of her environment and the absence of colleagues with whom to collaborate. Although she adopted instruction that incorporated science practices (as supported by the *PBIS* curriculum), she seemed focused narrowly on teaching the *PBIS* curriculum as written. In contrast, Abby and Joan were able to engage more fully in sensemaking, a process that resulted in new pacing guides, assessments, and adapted, alternative assignments. As sensemaking is a social endeavor, Abby and Joan served as sensemaking resources for one another; a resource Marie did not have.

The findings here point to the ways that certain tools and routines intended to bring about coherence at the system level can actually undermine it. Though it is widely recognized that contemporary large-scale reforms such as the implementation of new standards require coordination and coherence across multiple components of complex educational systems (National Research Council, 2012), the tools and routines increasingly common in schools as devices for "tightening" the coupling of policy and practice (Spillane, Parise, & Sherer, 2011) may actually create ambiguity for teachers. At the same time—as illustrated by the case of Abby and Joan—if afforded the opportunity to create new meanings in bringing these tools and routines into alignment, a kind of local coherence may be accomplished within the system.

An implication for professional development is that we need to provide the same kinds of “active learning” opportunities for teachers around issues of coherence that we value around science content. In other words, teachers need opportunities to engage in collaborative and sustained sensemaking to see, understand, and work through incongruities they perceive between goals and strategies promoted in PD and goals and strategies promoted in their local educational contexts. We can expect, moreover, that these contexts will vary by site, depending on whether teachers work in relative isolation and on the support they receive from their principals. Therefore, some differentiation of opportunity within PD workshops may be necessary.

More broadly, those aiming to support the implementation of new standards through professional development must take into account the kinds of goal conflicts teachers encounter, the ambiguity this creates for them, and the need for space to innovate and take risks. These are not typical concerns of many content-focused professional development providers, who focus principally on developing teachers’ science content knowledge or supporting curriculum implementation. Focusing on content is important, but workshop leaders must also directly address sources of ambiguity and conflict associated with perceptions of incoherence. As our study shows, perceptions of incoherence can lead to either productive adaptation or to foreclosure of deep sensemaking, depending on the circumstances. Successful implementation of new standards will require focused attention to teachers' sensemaking and the development of supports that help teachers make sense of ambiguous situations and manage uncertainty.

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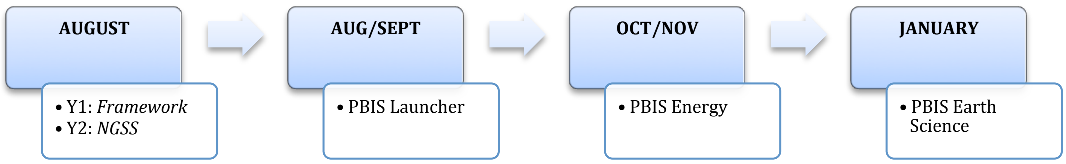

Figure 1
Professional Development Workshop Timeline

Table 1
Participants by School

School	Teacher	Framework PD*	PBIS PD	Video	Interview
Norman					
	Joan	2	4	Y	Y
	Abby	2	5	Y	Y
Central					
	Marie	1	5	Y	Y

* Number of days in Year 1

Table 2
Descriptions of Sources of Ambiguity and Uncertainty Used in Coding Teacher Sensemaking of NGSS.

Source of Ambiguity	Description
Conflicting Goals	Conflicts between district pacing demands and teaching science-practice focused lessons. District or school-level initiatives (e.g. curriculum or technology use) that interfere with instructional goals. Building evaluation guides – formal and informal – that conflict with goals. Messages from PD that teachers interpret as what they "already do."
Absence of Measures	Absence of measures aligned with NGSS that teachers can use as assessments; Lack of coherence between measures teachers are held accountable for and those aligned with NGSS; Available assessments are perceived to be misaligned with what teachers should be teaching
Limited Resources	Expressed lack of time to engage with NGSS or adapt existing curricula to align with NGSS. Lack of available material or technological resources needed to engage students in science practices. Lack of assessment items (see Absence of Measures). PBIS or other curricular assessments are misaligned with NGSS.
Role Ambivalence	Lack of clarity about how to support students' engagement in science practices, developing understanding of core ideas, or how to teach cross-cutting concepts

Table 3
PBIS-developed Pacing Guide Selection for Learning Set 2

Learning Set 2 What Affect How Much Energy an Object Has?			
2.1 Understand the Question Think About What Affects How Much Energy an Object Has?	• Scientists often work together and then share their findings. Sharing findings makes new information available and helps scientists refine their ideas and build on others' ideas. When another person's or group's idea is used, credit needs to be given. • Energy is the ability to cause change or do work. • Kinetic energy is associated with the motion of an object.	*6.P.2.2 Explain the effect of hear on the motion of atoms through a description of what happens to particles during a change in phase.* *6.P.2.3 Compare the physical properties of pure substances that are independent of the amount of matter present including density, boiling point, melting point and solubility to properties that are dependent on the amount of matter present to include volume, mass, and weight*	*30 min*

Table 4

Teacher-developed Pacing Guide Selection for Learning Set 2

Section	*Activity*	*TE page*	*Time*	*Pacing Guide Time*
Intro	*What affects how much energy an object has?*	*101*	*5 min*	*30 min*
2.1	*Think about what affects how much energy an object has*	*105*	*10 min*	
	Get started	*106*	*10 min*	
	Share your ideas	*108*	*5 min*	
	What indicates that kinetic energy is present?	*109*	*10 min*	
	Reflect	*110*	*10 min*	
	Update the project board	*112*	*5 min*	
2.2	*What factors determine the amount of kinetic energy of an object?*	*119*	*5 min*	*40 min*
	Conference	*120*	*10 min*	
	Communicate: share your ideas	*122*	*5 min*	
	Observe: what affects a cart's kinetic energy?	*122*	*10 min*	
	Procedure	*123*	*20 min*	

CHAPTER THREE

Fighting for Desired Versions of a Future Self:

Young Women's STEM-related Identity Negotiations in High School

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Abstract

In this paper, we investigate how the national narrative of increasing opportunities for and broadening participation of young women of color in STEM (science, technology, engineering and mathematics) was taken up locally at two high schools in one school district. Using ethnographic and longitudinal data, we focus on four young women of color (two at each school) as they negotiated and maintained STEM-related identities in the discursive and practice contexts of their lives at school. Using Holland and Lave's concept of history-in-person (2001), we view the young women as fighting for particular versions of a future self, while entangled in discursive and social relations that threatened to position them differently than they wished to be. Initially we interpreted the STEM-related successes of these young women as evidence of resisting the historical narrative that positions them as disinterested in or unprepared for STEM. However, as we began to look more closely at their lives over the course of high school and beyond, we discovered that their fight for future selves was not with this national narrative about STEM, but with local school narratives that negatively positioned students of color more broadly, while remaining silent on issues of gender, the intersection of gender and race, and the implications for STEM. Ironically, as these young women of color struggled with racial bias, they took on identities as good students in science and especially math that made them eligible for but not necessarily well-equipped to handle STEM in college or a career. These findings suggest a need for an explicit naming and examination of the "double bind" that young women of color experience as they move through school learning environments and for special support to prepare them for the benefits and challenges they may face in STEM-related college programs or workplaces.

Fighting for Desired Versions of a Future Self:

Young Women's STEM-related Identity Negotiations in High School

Katie sat across from me (Carrie), her face bright with enthusiasm, hands pressed against the tabletop as she leaned forward into the conversation. It was the summer after Katie's senior year in high school. We were sitting together outside a Starbucks near her home, and she was in mid-story explaining why she had decided to pursue a degree in engineering:

> [In AP Calculus] we started doing these revolutions about y and x axes. If you look at a graph, and you take a three dimensional shape - like a cone or a cup - and you want to know the volume, you can put it on a graph and you can calculate the volume from revolving it around an x or y axis…it was a really hard math concept, but it was also one of the only exciting ones…it was just so exciting for me! So I started thinking, Where can I do this [kind of math] all the time?…I started talking to my dad and he was like, "Well engineering is somewhere where you could do this…if you want to do the math all the time, then go into engineering."

As an African American female, Katie's tenor as an excited and interested young woman in pursuit of math knowledge and an engineering career tells a story that contradicts the dominant historical narrative about women of color in STEM (science, technology, engineering, and mathematics) in the United States. This narrative positions females of color (Black, Latina, and Native American) as *dis*interested, *under*prepared, and unlikely to pursue STEM or succeed in these fields (Espinosa, 2011; Ong, Wright, Espinosa, & Ortfield, 2010; Sadler, Sonnert, Hazari, & Tai, 2012). Throughout high school, however, Katie took advanced STEM courses, achieved high grades in these classes, and in college she pursued a STEM-related degree. In fact, in our five-year longitudinal, ethnographic study, we observed a trend similar to Katie's across the majority (18) of our 23 female participants. These young women expressed interest in STEM-related fields at the start of high school and maintained that interest into their first year of college.

One way we could interpret the successes of these young women is to say that they were aware of and intentionally resisting the historical narrative regarding women of color in STEM that positions them as something other than what they were or wished to be. After all, their actions and self-descriptions reflect alternatives to the ways that national narratives position them. This interpretation is in fact how we approached our analysis initially. However, as we began to look more closely at the lives of these young women throughout high school, what we found instead was that their fight was not with this national narrative, but with local school narratives that negatively positioned students of color more broadly and remained silent on issues of gender, the intersection of gender and race, and the implications for STEM.

In this article, we illustrate the local struggles these young women engaged in to construct and maintain STEM-related identities in the context of their high school lives. In particular, we focus on the local discourses and practices of the school learning environments within and against which four of the young women in the larger study engaged in STEM identity work.

Conceptual Framework

Following Holland and Lave's development of the concept of "history in person" (2001, 2009), we view the young women in our study as engaged in struggles with historical narratives about the kind of person they could or should be. That is, when young women of color construct selves and consider possible futures, their efforts can be viewed as a struggle or fight "for particular versions of the future" (Holland & Lave, 2001, p. 28), and for particular versions of a *future self*. When young women of color construct science, engineering, or math identities in school, they must do so in the presence of robust and enduring narratives and organizational practices that may define them in ways they do not wish to be. Similar to other identity work, these self- negotiations are continually contested in local practice (Calabrese Barton, Kang, Tan et al., 2012; Davidson, 1996; Holland & Lave, 2001; Holland et al., 1998; Nasir & Saxe, 2003) "as history is constituted in the space that encompasses both social participation and self-authoring" (Holland & Lave, 2001, p. 29).

As one example of a historical structure of privilege, schools "infuse and restrain local practice" (Holland & Lave, 2009, p. 5) in ways that have consequences for how students come to see themselves and author selves within STEM. In particular, research points to academic, social, and structural aspects of the school learning environment that negatively impact the experiences of women of color within STEM. For example, schooling practices can make it seem that science is the province of people who are privileged in society—upper middle class, White, and male (Bang, Warren, Rosebery, et al., 2013; Calabrese Barton, Kang, Tan et al., 2012; Carlone & Johnson, 2007; Carlone, Scott, & Lowder, 2014). School science is often treated as neutral with respect to cultural and social experiences (Bang et al., 2013), and instruction tends to focus on achieving established answers in uniform ways (Calabrese Barton et al., 2012; Carlone et al., 2014). Such practices support cultural-historical notions of the White, male scientist and work to shape students' views of *who* or *what* is "scientific" and whether they fit such depictions.

Further, how others within students' schools respond to, take up, and make legitimate (or not) students' self-authoring as someone academically capable in STEM has far-reaching influence on their views of self within school and STEM (Carlone et al., 2011; Carlone & Johnson, 2007; Holland et al., 1998; Urrieta, 2007). Gee (2000) defines identity as "being *recognized* as a certain 'kind of person' in a given context" (p. 99, emphasis added). Being recognized by teachers, peers, and family as academically capable and proficient in STEM courses emerges in the literature as a consistently integral factor supporting robust STEM identities for women of color (see Bricker & Bell, 2014; Calabrese Barton et al., 2012; Carlone & Jonhson, 2007). Additionally, relationships are key to students persisting in STEM. For example, having friends who share an interest in and commitment to STEM and having relationships with faculty, teachers, or mentors in the field can bolster students' sense of belonging in these fields (Barron & Bell, 2015; Carlone & Johnson, 2007).

As young people come to see themselves as particular types of people and begin to author versions of self that are reflective of these views, these "constellations of selves" (Bakthin, 1981) have potential to come into tension with (or further support) one another (Davidson, 1996; Carlone, Johnson, & Scott, 2015; Nasir & Saxe, 2003). One's identity as a "cool" African American may come into tension with her/his identity as a good student (Davidson, 1996); or, a young person's authoring of "female" or "girl" may come into tension with their performance of "scientific" (Carlone et al., 2015). These "tensions" derive from cultural constructions of what it means to be, act, and look like someone who is simultaneously African American, female, scientific, and a good student, and may manifest in how an individual is responded to when her/his performances of self do not align with one another or fit a particular context. Nasir and Saxe (2003), for example, describe the case of Daniel – a Black, male, medical student – who was asked by the medical school administrator (an African American woman) why he was playing dominoes--a pastime she associated with loud, boisterous, and "blue collar" Blacks and not with a serious medical student. These multiple, and at times culturally-conflicting, versions of self suggest the kind of work that individuals must engage in to negotiate meanings and intersections of multiple selves. Further, some normative ways of being – heteronormative forms of female gender performance, for example – may usurp performances of other desired selves (e.g., being scientific) (Carlone, et al., 2015).

As young women negotiate STEM identities in their schools, they can sometimes find or carve out spaces for new or different storylines (Carter, 2005; Holland et al., 1998; Nasir, Synder, Shah & Ross, 2012). In their analysis of middle school girls' identity work across multiple social contexts (such as the classroom and an after-school program), Calabrese Barton and colleagues (2012) describe the case of Chantelle, who, by the end of the study had developed a self-identity as someone who might pursue a career in science. An African American girl and someone who aspired to be a dancer and singer, Chantelle was positioned by her teacher as "a student in the middle," "easy" because of her quiet and compliant behavior in class, and as someone who "struggled" with content, particularly in math. However, her active membership in an after-school science club supported Chantelle in successfully positioning herself as someone who was "hard working" and "engaged in science," as she presented to her class what she was learning about energy efficiency in the after-school club. Further, in their analysis of the identity work of successful women of color in science, Carlone and Johnson (2007) found that undergraduate women with an "altruistic" science identity broke from the historical script of those who pursue and succeed in science. By emphasizing their commitment to serving others over more familiar characteristics of a scientist, they created spaces for constructing a different kind of science identity.

Examining students' instantiations and negotiations of STEM selves within their learning environments offers one way to theorize how to better support females of color in STEM fields and in their pursuit of STEM careers, while highlighting the work these students must engage in to answer hegemonic institutional practices and the historical narratives that allow these practices to persist. This was the initial aim in the research described below.

Method

This article employs an embedded multiple-case methodology (Yin, 2013) to explore (1) the ways that the historical narrative regarding STEM and STEM pathways gets taken up in local discourse and practices at the young women's high schools; (2) the kinds of identities these women construct over the course of high school and into college; and (3) how these young women instantiated and negotiated STEM identities in the context of their schools.

Research Context

The study described in this paper comes from a larger longitudinal and ethnographic study examining high school STEM opportunity structures and students' figured worlds of STEM (see Eisenhart et al., 2015; Weis et al., 2015) in Denver and Buffalo. The ethnographic study took place between 2010-2013 in eight public (non-charter) high schools (4 in Denver, 4 in Buffalo) that served mostly students of color and mostly students on free or reduced-price lunch. In this article, we focus on two of the Denver schools.

Near the start of the larger study, in late 2010, the research team recruited approximately 12 focal students (ages 15-16; 6 girls and 6 boys) from each of four high schools in each city. The intent was to follow closely the focal students' experiences in STEM from 10th through 12th grade. The focal students were selected from volunteers among the largely minority population of students who were in the top 20% of their high school class in math and science based on their grade point averages (GPA) and scores on state standardized proficiency tests after their first year of high school (9th grade). The research team chose high-achieving students in math and science because they seemed the most likely to be interested and to participate in STEM education opportunities offered by the high schools. In this analysis, we focus on four students, all young women of color, from two high schools in Denver. See Table 1 for demographic characteristics of the Denver schools and focal students.

[Insert Table 1: School and Focal Student Demographics]

Participants and School Sites

We selected the four students highlighted in this article through a multi-stage process aimed at identifying representative cases of young women of color who succeeded in high-level STEM courses and anticipated pursuing a STEM-related college major. First, we created a data display for all female participants in the larger study; the data display included students' demographic information as well as characteristics we identified as important to students' STEM authoring and positioning in school. These included STEM courses taken, years of STEM courses taken, grades in STEM courses, anticipated college major from 10^{th}-12^{th} grade, post-secondary plans (as of grade 12), and actual post-secondary decisions (during their first year post-high school). From this table, we identified young women who took STEM courses all four years of high school and who maintained interest in a STEM major though their senior year of high school. From this list, we then selected pairs (and in the case of one school – Capital – three) students from each school who had similar course-taking and college major pathways to serve as cases at that school, Then, from this list, we selected underrepresented students of color (Black or Latino students), excluding those who were White or Asian. This list included seven female students of color from three of the four Denver schools (roughly 40% of the 18 females in the study sample who persisted in STEM).

We then selected for comparison cases the four students from the two high schools that were most comparable in terms of graduation requirements, Advanced Placement (AP) and advanced course offerings, and strong school leadership: Capital and Southside (see Table 1). Table 2 displays the focal student characteristics and interest trajectories for all the young (non-White, non-Asian) women of color in our focal student sample at the four Denver schools.

[Insert Table 2: Female Focal Student Characteristics and Interest Trajectories at Capital and Southside]

The group of four described in this article had career interests in engineering and medicine. The four included Carla and Lorena, both Latinas attending Southside High School; and Katie and Naomi at Capital High School, both African American. Carla and Lorena planned to pursue careers in medicine; and Katie and Naomi planned to pursue careers in engineering.

Data Collection and Sources

Data for this analysis were collected over a 5-year period: students' second year of high school (grade 10, 2010-11) through their second year of college (2014-15). During the students' high school years (Years 1-3 of the study), the research team conducted face-to-face student, parent, and school personnel interviews, observed selected math and science classrooms, and collected students' high school transcripts. During the students' first two years after high school, online surveys were administered to all student participants. Both authors participated actively in collecting and analyzing these data. These data sources are described in more detail below.

Student interviews. Students in the study were interviewed five times over the course of the three-year ethnographic study: once during the spring of 2011 (Year 1), and then in the fall and spring of the following years (Years 2 & 3; 2011-2013). The Year 1 (students' 10^{th} grade year) spring interview focused on establishing a baseline of students' perceptions of their schools and themselves as students at the school. Students were asked to describe their school, their academic strengths, the courses they were taking and how they decided on those, and what they intended to study in college. During Year 2 (students' 11th grade year), interview questions asked students specifically about their views of math and science, characteristics of those who are good at math and science, and students' views of themselves in relation to these views. Although not explicitly prompted to talk about out-of-school examples of those successful in STEM or their own activities in STEM, students were encouraged to discuss these examples as they came up. In the spring of Year 2, students were additionally asked about their plans for college applications and college majors. Interviews in the final year shifted to college plans and preparation. Students were asked if they still intended to study a STEM-related major, what colleges they had applied to, and, in spring, what their final post-high school plans were. Because of their involvement in an earlier analysis, two of our participants - Carla from Southside and Naomi from Capital - additionally participated in a follow-up phone interview during the spring of their freshman year in college (Year 4 of our study). This interview was intended to clarify their decision-making about what colleges to attend and majors to pursue; we additionally asked about what courses they were taking at the time.

Student academic transcripts. The students' transcripts are official school-generated records of the courses students took freshman year (9th grade) through their senior year (12th grade), the grades students received for these courses, and students' grade point average. As evidence of students' self descriptions and characterizations, transcripts display students' grades and course-taking pathways, which can be viewed as responses to their school's course offerings and as evidence of their positioning as a particular kind of student within their school context. Further, students' courses were seen as additional contexts for identifying (or not) with STEM disciplines.

Post-high school student surveys. Students were surveyed twice, once during their first year and once during their second year post high school. Students were contacted via email and

Facebook and asked to complete an online survey; questions focused on college experiences (the college attended, courses, grades, majors, financial aid, friendships) and plans for the future. 50% of students, including the four profiled in this article, returned both surveys.

School personnel interviews. These interviews included math and science teachers, counselors, and school administrators (principals or assistant principals). Math and science teachers who taught one or more focal students at each school were interviewed once per year (Years 1-3), as were the focal students' counselors and school administrators. Interview questions asked about the recent history of the school, views of the school and its students, academic proficiency indicators, opportunities for high-achieving students, post-high school preparation, and graduation and college enrollment rates. We drew on these interviews as a way to identify and later substantiate claims about school practices, challenges, and influential discourses.

Parent interviews. In addition to school personnel interviews, we conducted interviews with at least one parent of each student participant each year of the ethnographic study. Parent interview questions asked about parents' views of the school, the students at the school, and their child's experiences at the school; additional questions focused on parents' views of how well the school was preparing students for college and work. These data served as an important additional data source regarding school practices and discourses about the school.

Data Analysis

Because we were interested in both the ways historical narratives about women of color in STEM were taken up locally at students' schools as well as students' identity authoring and negotiation within these contexts, we conducted our analysis through a multi-stage process. First, we coded student, parent, and school-personnel interviews for views of the student with regard to academics, STEM, future plans, college, how positioned socially and academically, decisions about courses to take, relationships to family, and decisions about major. Compiling these coded data and students' transcripts, we developed case summaries for each student that aimed to trace students' positioning, authoring, and interests within school and related to STEM over the course of their high school years. We then created data displays (Miles, Huberman & Saldaña, 2014) for each student of *critical moments*, *STEM/academic instantiations* (self positioning), and *college/future instantiations*, organized temporally and based on all 5 years of student data (including student surveys). These displays allowed us to identify themes regarding (1) each student's authoring of academic and STEM identities over time; and (2) the schooling practices that students engaged in. After discussing and finding agreement regarding student authoring, we then looked for the schooling practices themes that emerged in the student data within the school and parent interviews to confirm or disconfirm our emerging claims. We discussed each claim and interrogated them for alternative explanations.

Findings

Although we were initially interested in the ways that narratives about women of color in STEM were taken up in local discourse and practice at these two schools, we instead found that the school discourses emphasized broad academic disparities by race, not by gender or STEM. At Capital, a school with solid representation of Black, Latino, and White students, there was a dominant narrative that focused on "decreasing the [achievement] gap" through recruiting Black and Latino students to take more advanced courses and through motivating these students to challenge themselves more academically. At Southside, a school with a homogeneous Latino population, the narrative focused on providing opportunities-- through high expectations, rigorous courses, and college preparation--for Latino/a and first-generation students to overcome the social disadvantage they inherited as children of recent immigrants living in poverty. Although discourses at both schools reflected deficit views of students of color, Capital's discourse and practices focused on low academic achievement of Black and Latino students as a result of students missing or, at times, intentionally choosing not to pursue opportunities. At Southside, discourse and practices emphasized the school's responsibility to create opportunities for its Latino/a students. As students authored themselves as good students, those capable in STEM, and those intending to pursue STEM careers, they had to do this in direct response to and in contrast with these local discourses and practices that positioned them otherwise.

In the next section we describe the discourses and practices present at both schools. We then illustrate the ways that students both challenged and utilized these discourses and practices in their authoring of selves as good students, capable of pursuing STEM.

Capital: Motivating students of color to challenge themselves. Capital High School serves a diverse population of students (23 percent Latino/a, 45 percent White, 25 percent Black) (see Table 1) and was generally known as a "good" school within the surrounding community and the state. Students from Capital performed well, overall, on standardized exams, the school had a longstanding and successful Advanced Placement program, and many students who graduated from Capital continued on to competitive or highly selective colleges.

Although considered academically "successful" and highly ranked, Capital's narrative about students of color manifested in discourses about the "achievement gap" between students of color and White students at the school. Capital's principal stated:

> …if you look at how the kids are scoring on state standardized tests, our Latino and African American students are not testing nearly as high as our White students. And so…we want to fix the gaps here and help kids catch up and be on par with their other

> classmates…I think it's egregious that our kids…that there are those gaps. (130109_INT_Principal)

Naomi's mother (culturally Jewish with children who identify as African American) referenced the achievement "gulf" as a reason she and her husband elected to send their two older sons to a private school instead of Capital: "When we were looking at different high schools, what we kept hearing about [Capital] was that there was this gulf in achievement between the Caucasian students and the minority students" (110727_INT_Parent_Naomi). Further, when Katie was asked why she thought she was often times one of the few Black students in her advanced courses, she responded,

> Um, I think that there's definitely...we need to close the achievement gap, because it, like, it's not because [Black students] are not smart enough to be in these classes... I feel like it, it, has a bit, more to do with like, if someone is generally looking out for you. And being reminded, 'Hey, like, are you sure you [want to take the courses you're signed up for], like, why don't you just take this [advanced] class [instead]... 'Cause most [Black] kids just assume like… 'Everyone says I can't do it so I probably can't.' And they, [other Black students] don't [take advanced courses]. (121130_INT_Katie)

The gap was described by teachers, parents, and students as something "egregious," that should be "closed," and that primarily existed because of the low academic expectations students of color, and others, set for them. For example, students of color were described as not wanting to "challenge themselves" and "assuming" they "could not be successful" in advanced courses. As Katie stated in the above text, "most [Black] kids just assume…'I probably can't [take harder courses].'" And, so, they don't. As we discuss later, Katie's comment points to the important role of social supports in addressing and resisting this historical narrative regarding Black students' academic ability. This depiction of Black and Latino students not challenging themselves is further described by Capital's principal:

> [We] found that…a lot of kids, especially the minority students were saying, 'I don't want to challenge myself. I'm a B student in middle school,' you know, blah blah blah. And we said, 'you know what, in order to get these kids to try to achieve higher and try to get them in the [AP] class when they're juniors and seniors, we've got to get them to challenge themselves, go into the honors classes, find out that they can be successful and then move up. (110406_INT_Principal)

Further, Naomi's mother stated,

> I wouldn't say that the cultural norm is for there to be high achievement among [students of color at Capital]. It starts with something as simple [as] what classes they sign up for freshman year and whether [the students] are taking advantage of the honors and AP classes. (130109_INT_Parent_Naomi)

However, student course-taking patterns were not simply viewed as an individual choice. Rather, shared ideas about what courses a student should take and the kinds of students who generally take them were viewed as also shaping these decisions. As Katie suggested, students of color hear from "everyone" that they "probably can't" be successful in advanced courses. And, to Katie, students of color hear this "you-can't" message "everywhere":

> Interviewer: So "everyone" in that instance [is who]? Do you feel like it's, like a way that people talk at the school, or-?
>
> Katie: I think definitely [it's the way people talk]; it's also peers, it's…maybe even [students'] parents. It's literally everywhere. Like in my speech and debate class, it's been…tons of upper middle class [kids] and...it's been

predominantly White. And the teacher last year...she was like, “I'm sick of AP, because if you ask a lot of kids, ‘Would you wanna [take AP speech]?,’ they're like, ‘Oh, you gotta have a lot of money to do that.’” (121130_INT_Katie)

What is described here by Katie are shared ideas about the kinds of students - White, upper middle class - who take advanced or higher-level courses at the school, and the consequences this has for the Black and Latino students at the school.

In a similar manner, Naomi’s mother pointed to ways course-taking practices get “passed down” by older generations, and how White students generally benefit from these expectations:

Interviewer: And is it counselors who [place students into classes]? Or, how do students decide [what to take] freshman year?

Parent: Right, how does that division occur? I think a lot of it is kids talking to people that they know who are older and it just sort of gets passed down, like "These are the classes that you take.” And then you've got the Caucasian kids and their families going, "These are the classes that you take."

Interviewer: Do you feel like the expectation's [for what classes students should take] is a little bit higher for White students [than it is] for Black students [at Capital]?

Parent: I can't decide about that, because I don't know if it's just the lane of traffic [Black students] get into, and then it just becomes a self-fulfilling prophesy, but it does seem like over and over [my husband and I] get the schedules for the freshman boys who are in [an informal mentoring

> program they lead for black boys] and it's like, "Why are you taking a weight-lifting class? You are a varsity athlete. You're weight lifting after school. This is a throw-away right here." Like, "You could be using that [time] to take Spanish" or you know, "You're going to need several levels of language by the time you get to college." (130109_INT_Parent_Naomi)

One institutional practice that worked to maintain racial segregation at Capital while reinforcing the notion that White students were more academically capable and motivated (i.e., choosing to "challenge themselves") was what the principal called "blockers". Several years before our study, students at Capital had to receive a teacher recommendation in order to register for advanced-level courses: "I remember the first year [I worked at Capital]…the students only got into the [advanced-level] class with a teacher recommendation. Well what happens? Only White kids were getting into the honors classes and [AP] classes" (120120_INT_AP).

At the time of our study, eradicating these "blockers" and encouraging teachers to "recruit" students of color into honors and advanced placed courses had become a school-wide emphasis, at least rhetorically:

> So [because teacher recommendation resulted in only White students being in advanced courses], we [the school administration] said, "No more blockers. If you [the student] feel you are strong enough to [take an advanced course] then [do that]." And we encourage teachers: "If you see someone, especially a minority student--that you think has some potential; that you think could maybe be successful--try to encourage them to take [Advanced Placement courses]." Or encourage them to at least take an honors class. (120120_INT_AP)

And these efforts to better place students, particularly students of color, into higher-level classes had become “always part of the conversation” at the school. For example, a science teacher at the school stated:

Teacher: I would say [the academic climate is] very high [at Capital]. It has changed. I mean, there have been different focus areas, like having a conscious effort of placing students in the right class; and looking at students of color and looking at what classes they are taking and talking to them about that; and really encouraging [students of color] to push themselves rather than just taking an easy class to get the [graduation] requirement.

Interviewer: How would you say, for the minority students now in classes, are they evenly distributed?

Teacher: Actually [that’s] hard for me to say ‘cause I don't look at the data consistently, but you can look in the hallways and maybe say yes [in one class] but no [in another]. The effort [to increase participation of students of color in advanced courses] is so strong, that it's always part of conversations [at the school] now. I don't think it's where we want to be, especially at the AP level, I know it's not, but it's progressing in the direction we want to go. (120210_INT_Teacher)

And although Capital staff had been working on this issue, Naomi and Katie were still navigating an advanced-course landscape that at least appeared glaringly White. During her sophomore year, Katie stated, “There's a lot of ...well in some of my classes there are only like 5 Black kids, and I am in all honors classes except for Spanish. In my AP [Geography] class and my advanced Algebra II, I am the only Black kid" (110421_INT_Katie). During her senior year, Katie commented again about being one of the few Black students in AP courses:

> Interviewer: Are a lot of classes segregated like that [at the school]?
>
> Katie: Sadly, yeah. Like I didn't realize it so much, but I'm part of this [Black Student Union] club...And...there was a presentation [that] was talking about [how] it was like 76 [of 145] African American students out of...I think our class is like 578 […are the only ones in AP [courses]. And it gets a little bit bigger, it's like maybe like 120 [Black students] for honors. But, that's, really small compared to, a class of almost 600. (121130_INT_Katie)

Katie's comments here suggest an apparent disconnect between the discourse about Black students and their actual advanced-course taking practices. That is, the numbers that Katie provides suggest (if the numbers are correct)[1] that the percentage of Black students taking advanced courses at the school is actually quite high. When accounting for the percentage of Black students in the class of 600, roughly 52 percent of these students are in AP courses and 83 percent in honors. This could be an indicator of how the broader historical narrative that positions White students favorably while suggesting Black students have lower academic goals and ambitions was perpetuated through discourses at Capital, even if these sentiments were not reflective of students' actual participation or actions. Of course, it is likely that Katie's acceptance of the BSU statement was supported by her experience as one of the very few Blacks compared to Whites in her advanced courses at Capital.

[1] We were not able to independently verify her numbers.

Discourses at Capital about the "achievement gap" favoring White students, the shared beliefs about the kinds of students who take advanced courses and eventually attend college, and the institutional practices that tracked students of color into lower-level courses seemed to be consistent with the ways most students of color thought about and navigated academic, and particularly advanced course-taking, decisions. As we will demonstrate further, these local discourses and practices, reflective of a broader historical narrative about the personal shortcomings of students of color at Capital, played a critical role in the self-authoring Katie and Naomi engaged in.

Southside: Providing students of color with opportunities. In contrast to the student population at Capital, students at Southside were a relatively homogenous group with roughly 94 percent Latina/o. Part of the same school district as Capital, both schools were held to the same accountability mandates. Although at the time of the study Southside was making some significant and successful changes to its policies and practices (see Eisenhart, et al., 2015), students at the school had historically high drop-out rates, low performance scores on standardized exams, and a reputation for gang violence. The school was working hard to improve its reputation and community involvement.

The discourse pervasive at Southside centered on the "academic deficiencies" students had to overcome as a result of the social circumstances they faced as poor immigrant or first-generation children and non-native English speakers in the US. In contrast to the discourse at Capital that implicated students of color as lacking motivation or needing to be encouraged to challenge themselves, students at Southside were seen collectively as "behind" through no fault of their own. The school staff, then, described themselves as needing to "bring [the students] up" academically through providing the opportunities, academic rigor, and college guidance needed for students to succeed. The students' counselor stated,

> I mean our kids are just behind, many of them. It's not that they can't [go to college] or that they can't succeed by any means, but many of them have missed skills along the way…they are just missing the skills necessary to be at those advanced levels. So trying to bring them up to skill is really where we [as a school] need to improve. (120105_INT_Counselor)

Additionally, Southside's principal commented,

> We have a very good student population here. We adore our kids. We just need to get them to the next level in academics. And that is the total work we have to do because of the limited English proficiency that they bring [with them when they start 9^{th} grade]. So our focus is on academic language development here, and we keep working on it constantly so that we can get them to the next level [academically].

In large part, getting students "to the next level" involved providing students with exposure to college-going processes (such as the application process and information about what colleges look for) and providing students with academically rigorous opportunities that would allow them to "do more" and "make a better life" for themselves than their families were able to. Southside's principal the first year of our study[2] stated, "You know, I think that [parents] believe that [Southside's] going to try to prepare their kids for college, that we're going to try to give [their kids] as many opportunities to get to college as possible, and that we have high expectations [for their kids] (110419_INT_Principal)." Further, Southside's next principal (after

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[2] Southside went through a principal change during the second year of our study (the students' third/junior year of high school). The principal during Year 1 of our study had instituted the significant changes at the school. The principal who replaced him had worked at the school, including as an assistant principal, for many years and seemed to be committed to these changes.

year 1 of the study) stated, "[Emphasizing college readiness] is all we do. I mean, if you ask any student in the school, 'Why are you here?' 'What is your intention?' they would be able to relate [their purpose] to [preparing for college]. That is the mission" (121217_INT_Principal).

During the time of our study, Southside was in the process of adopting practices that afforded students these academic opportunities, supported in large part by a state-issued grant. At the time of Carla and Lorena's junior year, the school was in its first year of the grant program, which provided resources in the form of teacher professional development, AP courses, and college-readiness programs. Utilizing these resources as a springboard, the school administration made a concerted effort to place students into courses that would put upward pressure on ability level and learning needs. The principal described the school's process in this way:

> … [W]hat we have done is, starting with math…we know we have students who come [to Southside] very behind [academically]. We have a lot of sections of students who are at second grade math [as ninth graders], and we are expected [by the state] to get [these students] to ninth grade [math level] by [the time they take the state assessment at the end of the year]. Well that [would be] a miracle. So what we have done is try to help students who have already come with the knowledge [appropriate to their grade level] so that they don't get watered down curriculum, and so that [then] they get very intense curriculum [after that]. So…we look at the students we get in [each year], and place them in the proper [class], with the proper teacher so that they can keep growing. Last year, when we did the [state] testing, kids grew [by] 4 [grade levels within one year], and we want to continue [that kind of progress]. (121217_INT_Principal)

Further, getting students to take AP courses meant first building up the school's AP program:

> Right now, with the honors and AP with STEM offerings, we have AP Calculus, AP Chemistry, AP Physics, AP Biology, AP Computer Science, so we do have the classes, we just need to expand the number of kids that get into that honors track, and [because the students] don't come in [to high school at that academic level]…we have to make them go onto [this track]. (121217_INT_Principal)

In contrast to students choosing to become part (or not) of the existing, and historically White, AP structure at Capital, Southside was in the process of developing the AP program through this intentional and largely mandated course placement. Carla described getting "nudged" into taking AP courses:

> Interviewer: How were you placed into the classes? Did you choose which classes to take?
>
> Carla: Yeah, we choose them every year, and [the school] kind of gives us a choice of what we can take.
>
> Interviewer: How do they "kind of" give you a choice? What does that look like?
>
> Carla: So, like the teachers kind of push you to the class that they think you should be in.
>
> Interviewer: Oh, so they sort of suggest?
>
> Carla: [They would say] "Take this." Nudge, nudge (uses elbow to emphasize this).
>
> Interviewer: Can you think of a couple teachers that did that with you?
>
> Carla: Ya, my science teacher and my math teacher.
>
> Interviewer: What did they do specifically?

Carla: Well, my math teacher just kind of like assumed that I was going to be in Pre-Calc, 'cause I think that's where most of the students [in my class] were going…And my science teacher was like, "You should take an AP science class."

This approach of intentionally placing students in courses seemed to be working. According to the principal, the number of students in AP courses had increased and, as stated earlier by the principal, students were seeing grade level gains of up to 4 years. This at times required students to “double up” on math courses in order to take AP Calculus by students’ senior year. Additionally, for the students at grade level, being pushed to get on the “honors track,” these students were required to take advanced coursework including honors, AP, and college-level courses (offered through a partnership with a local community college). Whereas at Capital, it was up to the students to decide to take AP courses, at Southside students were required to get signed parental consent in order to opt out of taking AP courses. The principal explained:

> Many times we don't let them opt out unless their parents are coming here, and they [the parents make] the final decision. …When I talk to parents, I say yeah we are pushing your students…push them, encourage them, and they will get there. I also…said don't [feel sorry for them], let them struggle, let them push themselves… otherwise [the students] will not be able to face situations in college or in jobs things [that are challenging]. ‘Cause it is easier to give up, so easy, and I said don't let them do that. (121217_INT_Principal)

The school additionally offered multiple programs that both supported students in the college-application process and helped educate parents about the process. The school had a

College Center, which offered students support in completing applications and applying for financial aid and scholarships. Additionally, students could meet with TRIO[3] counselors for college guidance. Lorena described meeting regularly with her TRIO counselor, who "always gives me advice…and opens up doors" (110923_INT_Lorena). The school also had an AVID[4] program that Carla participated in. Like TRIO and the College Center for Lorena, Carla named AVID as a key resource in providing her with college guidance.

Additionally, the school had a program specifically designed to engage parents in the college-application process. They offered parent information sessions (in English and Spanish) throughout the year and supported parents in joining students on college visits to schools in the area. They were also developing a program organized around using computers to work on math homework at home. The principal described parents as "involved" and committed to supporting their students' academic achievement.

Despite the desire and practices to create greater opportunities and a better future for students at Southside, there seemed to be a consensus that many students would not be able to overcome their social hurdles. During her junior year, Carla stated,

> First of all [those at the school] don't expect half of the class to graduate…we had a grade-level meeting, and they said 'we expect 200 walking this year.' There are 400 students. So, they think [that half] are all going to drop out…and they will be lucky if [the rest of us] do graduate. So, I don't think they expect us to go to a huge university or anything. (121026_INT_Carla)

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[3] TRIO is a set of 8 federally-supported programs that assist low-income and disadvantaged students with academics and college readiness.

[4] Advancement Via Individual Determination (AVID) is a national program in the U.S. that was developed to prepare underrepresented and first-generation students for college through study habits and critical thinking skills. AVID is taken as a school elective.

Further, the math teacher commented,

> We [the adults at the school] say [college readiness] all the time. We say it all the time. But it doesn't feel real for many of my students. …I know their grades. I see their ACT score, and it comes back as a 14. I can see that if I gave them a 9th grade algebra test or a middle school math test, they can't pass it. But, [as a school] we talk college, college, college—and you'll see it all over the school. But…I don't think it's reality. …my thinking is, out of a freshman class of 500, I would be shocked if 20 graduate from a 4-year university. (110425_INT_Teacher)

The local discourse and practice at Southside positioned students as those who needed "bringing up" and opportunities to "have a better life." Further, discourses at the school normalized the notion that most of these Latino/a students would not complete high school or attend college, but that some could if they were provided the opportunities and were pushed to pursue these opportunities. This contrasts with the Capital's discourse that implies that students of color can succeed if they were more motivated academically.

At the two schools, addressing student underachievement required attention to increasing opportunities for or motivating students to take more rigorous coursework and get on track for college. This included advanced coursework offerings in STEM and (particularly at Southside) intentional course sequencing to get students into AP Calculus by their senior year. At neither school was the explicit objective to improve STEM outcomes per se, or to encourage more girls or students of color in STEM, but rather to address the perceived educational inequalities that existed at each site. In the next section, we demonstrate the ways in which students at both Capital and Southside drew on and contrasted themselves with these locally-embodied social constructions of students of color in their authoring of academic and STEM selves.

Authoring Identities Within and Against Locally-Embodied Historical Narratives

Capital: Authoring academically-capable selves. As Naomi and Katie, two young Black women, authored identities as "good students" and those good at math and science and capable of going into STEM fields, they did so in seeming contrast to the prevailing discourse about the underachievement of students of color and the pattern of racial segregation in advanced courses at Capital. Katie and Naomi described themselves as "good students," emphasizing their hard work, enjoyment of learning, and their ability to succeed in their courses. They took honors courses (in various subjects) throughout their four years of high school, and AP courses their junior and senior years. By their senior year they had taken AP or honors Chemistry, AP Biology, or Honors Physics and AP Calculus.

However, in constructing themselves as good students, they drew from the school's discourse about students of color. Katie, for example, authored herself as one of the few Black students to take advanced courses, and as one who was able to overcome institutional barriers and discursive practices that her peers could not. She described other Black students as "believing that they can't do things and [believing] that they aren't smart." In contrast, Katie described herself as capable and not deterred by low grades or challenging courses: "…in some of my classes, like in math, sometimes I don't get the grades that I want, but because I like it so much and really want to understand it, that's what keeps me coming in everyday to my algebra teacher asking for help (110421_INT_Katie). Although Katie characterized other students of color as those who often were not motivated in school and did not challenge themselves, she authored herself as someone who enjoyed learning, wanted to learn more, and was willing to put in the extra effort (e.g. coming in everyday for help).

Naomi similarly drew on the prevailing discourse at Capital at distinguish herself:

> In middle school, we did math minutes, and I just loved math minutes 'cause I was good at them…So, I'd finish in like 45 seconds, and I would be like, "Haha, you guys all suck," and like that type of thing. I dunno, math was just something that was fun for me. I still think it's fun, and people are like, "You have fun doing your math homework?" And I'm like, "Yes I do." People were like, "The AP Calc[ulus] test sucks so much." And I was like, "I kind of enjoyed it." I don't mind doing three hours of math. (130528_INT_Naomi)

Apparent in both Katie and Naomi's descriptions is an authoring of someone who takes pride in performing well academically and who enjoys learning in STEM, particularly math. These depictions stand in stark contrast to the characterizations of students of color at Capital as those who do not want to challenge themselves or those who take "easy classes" to graduate with higher grades.

In both cases, Katie and Naomi took up the prevailing discourse about the low achievement and motivation of students of color at their school, and they did so as a means of distinguishing themselves from others who shared their racial characteristics. They accepted the denigration of students of color and used it to single themselves out as special.

Southside: Authoring college-going selves. As Carla and Lorena, young Latinas, authored identities at Southside, they did so within and against the narrative that suggested their social circumstances may be too difficult to overcome, and that going to college and having a different life may not be attainable. Carla and Lorena authored identities of students who were special in terms of their school-level achievements and their attitudes toward school. Additionally, they authored selves who were unquestionably going to college.

Similar to Katie and Naomi, Carla and Lorena took advanced coursework (in all subjects) throughout high school, and both took AP Calculus their senior year and had taken AP Biology and AP Physics by their senior year. By her junior year, Lorena was planning to “graduate early,” meaning she planned to take all community college courses her senior year. By her senior year, however, her counselor had coached her to stay as a high school student and take dual enrollment college courses provided through the school. Carla, too, took advantage of the college courses offered through the school (English and Ethnic Studies). Both Carla and Lorena emphasized college-going behaviors, like taking more advanced courses and being those who maximized the available opportunities at the school.

Carla contrasted herself with those at the school who did not take advantage of the opportunities available at Southside. She described most students at her school as people who “don’t really try” in class, the majority of them likely not to graduate, and many not attending a 4-year college. Carla, however, would “not not” consider going to college: “I can’t not go to college…I really can’t imagine what it would do if I didn’t go to college and get an education. I don’t know what would happen. Like, I don’t really want to know” (120525_INT_Carla). Like Carla, it was not an option to Lorena not to graduate from high school or attend college:

> I really want to go [to college]. Like, it's no option for me. I know that I'm really going to go for a long time… [My parents] have really supported me a lot, and they really always tell me they dream about the day that I get my career, and that I'm successful. So, I think that all that they've done for me, I should reward them with [going to college]. It's the only way I could reward them, so [not going] would be like no option for me. (120525_INT_Lorena)

In addition to seeing college as unquestionably their next step after high school, Carla and Lorena surrounded themselves with friends who also planned to attend college, many of whom planned to pursue a major in STEM (e.g. engineering, pre-medicine). During her sophomore year interview, Carla said, “I mostly hang out with the honors people ‘cuz they’re like in more of my classes.” She also described her friends as “really wanting to be engineers” and others who want to go into “medicine” or be a “dentist.” Additionally, these peer relationships provided a community of support in working toward academic goals. Carla described intentionally taking courses with these friends because she “couldn’t [succeed] on [her] own” and that “[they] all just help each other out” (111021_INT_Carla). Lorena also described her friends this way her junior year:

> Most of them go to my classes too. And we basically work on it together and we all have the same goals and we try to do our best, and we basically all have the same grades you could say. So ya, so they are trying to get good grades so that they can go into college, because they know that the grades are like really, really important. (110923_INT_Lorena)

Additionally, Lorena and Carla described themselves as willing to put in the extra work to fully understand what course material and prepare themselves for college. Carla described struggling for the first time academically in her AP Calculus class, but working hard to improve her grade:

> Pretty much all of school I didn't really have to try to get to good grades, like it just kinda happened. And then this year and last year was kinda harder, like I actually had to like go and ask for help and like study and like…I had to work really really hard…and I had to ask my teacher for anything extra that I could do [to raise my grade], and I had to study for the final, and I had to do a lot of things. I bumped [my grade] up [to an A], but it was really hard. And so it was kind of a first-time thing where I had to try that hard. (120525_INT_Carla)

Like Katie and Naomi, Lorena and Carla authored themselves as students who did not align with and actively worked against their positioning within the discourse about students of color at their schools. However, also like Katie and Naomi, they relied on the truth of that discourse to make themselves special.

Discussion/Conclusion

Our initial frame of reference for analyzing the four cases described in this article was to view them as examples of young women of color who successfully resisted the historical discourse that positions them as disinterested in STEM or unprepared to pursue STEM in college and beyond. We found that these four young women were encouraged to pursue advanced math and science by many of their teachers, administrators, and friends; they took advantage of these advanced course opportunities; and they excelled in them. By the end of high school, all four were proud of their accomplishments and still interested in math and science and the possibility of a future in a STEM field. Three of the four chose a STEM major in college and were pursuing it at least through their second year of college.

However, from the perspective of Holland and Lave's concept of history-in-person (2001, 2009) and in light of our ethnographic data, these young people did not portray themselves as engaged in a struggle with a historical discourse about women in STEM. Unlike what has previously been reported in the literature on women of color in STEM, these young people did not find or search for alternative spaces of math or science practice to develop their prowess; nor did they produce counter-narratives that challenged taken-for-granted assumptions about people like them. Rather, their struggle was with racial discourses at school that positioned them differently than they were or wished to be. In neither school was there a discourse about encouraging young women or students of color to pursue STEM. The women's success in school, particularly in math, and their consequent positioning (qualifications, interests, identities) to go on in STEM were byproducts of their struggles and cultural productions regarding race.

Discourses of racial underachievement were pervasive, nonetheless, at both schools. As many other researchers have shown, these discourses affected the students academically and racially (e.g., Davidson, 1996; Fordham, 1996; Nasir et al. 2012; Pollock, 2004; Schaffer & Skinner, 2009). At Capital, with a relatively diverse population, students of color were positioned as underachieving in comparison to Whites: lacking motivation, doubting their academic ability, and missing the social supports needed to navigate high school successfully. Teachers, administrators, parents and students engaged in discourses about the social and academic segregation, de facto tracking, and motivational shortcomings of students of color compared to Whites. The imperative for the school to "fix the achievement gap" was pronounced, but the onus was primarily on the students of color to step up to opportunities provided at school.

At Southside, with its homogeneous population, the achievement gap was not a part of the local discourse. Rather, the narrative was about creating opportunities to "bring students up" from their unfortunate social circumstances as Mexican-American, immigrant youth. Latino/a students were described as collectively "behind" academically, but through no fault of their own. To address this problem, the school took on multiple college-preparation programs geared toward students and their parents, increased honors and AP course offerings, added intentional scheduling that considered both individual students and the broader student population, and offered additional teacher professional development and time to plan through teacher learning communities. Despite these efforts, discourse at the school continued to imply that the student body faced difficult and at times insurmountable obstacles (e.g., lack of documentation) primarily due to their racial characteristics, and that overcoming these obstacles would be something of an aberration.

In these two discursive contexts of racial underachievement, the four young women fought to define themselves as different, i.e., to author themselves as “good students” in contrast to peers who shared their racial designation. They successfully challenged their expected positioning as historically racialized subjects, and in doing so, they gained valuable academic capital. As they enacted good student identities, they simultaneously came to identify as good in math or science or both and to be identified by others as “good students” in part because of their prowess in math and science. But they successfully positioned themselves as such by accepting the validity of their schools’ (and society’s) negative representations of students of color as a group. They utilized features of the negative representation to distinguish themselves from their group—to make their racial peers the “other,” and to author themselves as better than those others.

In authoring selves in contrast to others at their schools and authoring identities as those capable of going into STEM, these young women did create opportunities for their continued pursuit of STEM. However, their authoring of identities as good students in STEM did not engage with national narratives regarding women of color in STEM or the very consequential reality of the marginalization, isolation, and, at times, outright abuse that women of color often face as they pursue STEM in higher education and careers. We worry about the limited resources these women will have to support them as they try and navigate these spaces in the future. High STEM drop-out or push-out rates among women of color may be one consequence.

The findings suggest other considerations in terms of designing for and implementing educational improvement efforts for underrepresented students in STEM. Foremost, it is evident that local histories of schools play an integral role in how improvement efforts get shaped in practice. Capital's history of academic tracking, for example, seemed to so firmly establish that advanced courses were for White students that, even when tracking practices were removed and students of color were well-represented (relative to their percentage in the school), Black students still viewed advanced course-taking as a White activity (see also Fordham, 1996). This indicates that simply "encouraging" Black students to take advanced courses is not likely to be effective in making large gains toward increasing participation of students of color in these courses. A reform effort that considered the school's local history in this context might have instead developed advanced courses and/or programs specifically tailored for students of color. Similarly, schools should consider designing improvement efforts around the particular needs of their student populations. We saw this modeled to some degree in Southside's approach to designing programs and instituting practices geared toward increasing advanced course-taking and college attendance of its students. The school administration intentionally placed students into courses that would challenge them academically, and they carefully created college-preparation programs that involved the students and parents at that school.

Further, with regard to our original aim in this analysis, these findings suggest a need to address the intersections of race, gender, and STEM more explicitly in schools. We wonder what it might have meant for young women in our study to be equipped with an awareness of the "double bind" women of color face (discrimination as a "double" minority) in STEM (Malcolm, Hall, & Brown, 1976; Williams, Phillips, & Hall, 2014); and what it might look like to equip students with strategies that enable them to challenge not just their positioning within local discourses, but to challenge the discourses themselves.

To date, most literature on young women or girls of color in STEM has emphasized the role of classroom interactions or out-of-school activities. This analysis contributes to this body of research in that it highlights the relationships between the institutional practices of the school and students' identity work in response to these practices, namely their answers to the local hegemonic narratives within their schools. Further, this paper puts forth a nuanced view of young women's identity work in high school STEM, highlighting both the ways that discourses and practices of schools are intricately woven into students' self-authoring, and demonstrating how students' active resistance to their negative positioning may reconstitute the very hegemonic practices that they were resisting. Further, this analysis suggests that young women of color, like those in this study, may benefit from special encouragement, extra support, and critical consciousness-raising about the positioning and possibilities of women, as well as people of color in general and in STEM.

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Table 1
School demographics

School	Student	Enrollment	%FRL	%Latina/o	%White	%Black	%Asian	%Multi-racial/Other	%ELA
Capital		2,383	36	23	45	25	2	5	12
	Focal		8	17	16	25	17	25	
Southside		1,649	95	94	2	>1	3	>1	74
	Focal		100	90	0	0	10	0	

Table 2

Student major trajectories, Southside and Capital, 2011-2015

School	**Student**	**Ethnicity**	**GPA math**	**GPA science**	**ACT**	**Sophomore Year**	**Junior Year**	**Senior Year**	**College: Year 1**	**College: Year 2**
Capital										
	Katie	African American	4.12	4.41	22	Engineering, computer science, biochemistry, architecture	Business, marketing, psychology	Engineering	Chemical engineering	Chemical engineering
	Naomi	African American	5.09	4.22	27	Engineering	Engineering	Engineering	Mechanical engineering	Mechanical engineering
	Gina	Chinese American	4.71	4.38	26	Engineering; music conductor	Speech pathology	Speech pathology/music		
	Wendy	African American	3.83	4.28	25	Pre-veterinary/undecided	No information	Pre-veterinary	Biology	Psychology with minor in zoology
	Amelie	Chinese American	3.86	4.28	23	Engineering	Early childhood education and sociology or social work	Social work	Human development and family studies	Early childhood education
	Ashley	African American	4.06	4.06	25	Engineering or pre-medicine	Pre-medicine or biological research	Engineering or pre-medicine	Molecular, cellular, and developmental biology	No information
Southside										
	Carla	Mexican American	5.04	5.2	29	Pediatric medicine	Pediatric medicine, teaching, psychology	Biology/pre-medicine	Biology	Biology, Nurse practitioner
	Lorena	Mexican American	3.09	3.08	22	Mathematics	Pilot, architecture	Pre-medicine	Undecided	Education and human development
	Irma	Mexican American	4.28	4.4	15	Psychology/ teaching	Psychology/ teaching	No information	Undecided	Culinary arts; still interested in math/science

CHAPTER FOUR

Conditions of Teachers' Organizational Sensemaking and Implementation of Reform in Science Education

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Abstract

Educational reforms often bring with them new demands on how teachers should teach, and the *Framework for K-12 Science Education* is no exception. Past research has linked teachers' perceptions of coherence of new messages about teaching with existing ones from local leaders and from colleagues to their implementation. In this study, I draw on the concept of sensemaking from organizational theory to interpret data from interviews, observations, and classroom artifacts and analyze patterns of eight teachers' implementation of science-practice focused instruction. Using an innovative approach to comparative case analysis, Qualitative Comparative Analysis (QCA), I find that limited ambiguity and a lack of uncertainty as to what to do, coherent messages from local guidance infrastructures, and collegial support together explain patterns of who implemented changes to their instruction. In particular, teachers with greater collegial support were able to more effectively navigate conflicting goals between their current state standards, other local evaluation practices, and the instructional goals of reform. These findings suggest the need for collaborative planning and materials development across teams of teachers. Additionally, this analysis highlights the work teachers engaged in to craft local coherence where this was lacking in their instructional guidance infrastructures.

Keywords: Science education reform; teacher learning; reform implementation; organizational sensemaking; QCA; comparative case analysis

Conditions of Teachers' Organizational Sensemaking and Implementation of Reform in Science Education

Like other reforms in education, the *Framework for K-12 Science Education* (NRC, 2012) and the Next Generation Science Standards (NGSS; NGSS Lead States, 2013), place demands on teachers to actualize the goals of ambitious improvement efforts in their daily practice. Recent literature on reform implementation has highlighted the integral role of the schooling environment in shaping both teachers' perceptions of teaching, learning, and content and teachers' decision-making about what of reforms to integrate into their instruction (Carlone, Haun-Frank, & Kimmel, 2010; Coburn, 2004 2005; Cohen & Ball, 2001; Cohen, Moffitt, & Goldin, 2007; Spillane & Hopkins, 2013; Spillane, Reiser, & Reimer, 2002). These studies have pointed to the challenging task teachers face when being asked to engage with ideas of reform while simultaneously navigating the multitude of often conflicting messages – from colleagues, school and district leaders, and prior reform efforts – about what constitutes best practice, and the numerous institutional practices that manage and monitor teachers' instruction (see Coburn, 2004).

Further, as teachers adopt ideas and practices of reform, the *instructional guidance infrastructures* (IGIs; Hopkins & Spillane, 2015) – structures and resources that organize, monitor, direct, and support teachers' and school leaders' instruction – often lack the internal coherence needed to effectively support teachers' instruction. For instance, district pacing guides suggest what science topics teachers should emphasize in their instruction and about how much time teachers should spend on each topic; the available or district-adopted textbooks may foreground slightly different topics or suggest different amounts of time, or both. Additionally, other district initiatives, student assessment expectations, or school routines can compete with teachers' efforts to reform their practice in science, rather than support it (Allen & Penuel, 2015; Cohen et al., 2013; Heredia, 2015; Spillane, Parise, & Sherer, 2011). Despite these competing agendas and incoherent messages about effective instruction, teachers can and do find ways to respond to external reform messages and implement these ideas into their practice.

Understanding the ways that teachers develop views of reform and ideas about how (or if) reform fits into their existing schooling practices is of paramount importance in reform implementation research, as these perceptions ultimately influence what of reform gets taken up in teachers' instructional practice (Coburn, 2006; Spillane, 2004; Spillane, Reiser, & Gomez, 2006; Weiss et al., 2003). Although prior literature has examined the relationship between teachers' interpretations of reform, their uptake of reform ideas, and the ways that schooling practices shape teachers' beliefs, no studies have examined the relationship among all three in science education. In this paper I examine the process through which teachers developed interpretations of the science-practice based instruction (SPI) espoused by the *Framework* and NGSS; teachers' patterns of implementation; and the ways teachers' perceptions of their organizational (school and district) practices shaped these processes and patterns.

Instructional and Epistemological Shifts Called for in Science-Practice Instruction

One reason reform implementation can be difficult is that it requires teachers to engage with ideas and instructional practices that are likely different from their current views of teaching, learning, and content (Cohen & Ball, 2001) and therefore have consequence for their current instructional approach. Like reform efforts from earlier generations, we can expect (what I am calling) "science-practice based instruction" (SPI) to present implementation challenges for teachers, as this approach calls for significant shifts with regard to teachers' instruction and their views of science teaching and student abilities (Krajcik, Codere, Dahsah, Bayer, & Mun, 2014). This form of instruction is linked to the vision of *A Framework for K-12 Science Education* (NRC, 2012), a vision that science learning should integrate science and engineering practices with disciplinary core ideas and crosscutting concepts that span scientific domains. Through this approach, students develop their understanding of content and crosscutting concepts through their engagement with science practices, and students demonstrate their understanding not through a recitation of facts but in their application of content and crosscutting concepts through science practices (called "performance expectations"). For example, a student who had an understanding of waves and wave properties might develop and use a model to describe how waves are reflected, transmitted, or absorbed through various materials (NGSS Lead States, 2013).

SPI diverges from science instruction that is common in middle and high school classrooms in a few key ways. First, teachers generally use hands-on and laboratory activities to *reinforce* content already taught through lecture or reading (Banilower, Smith, Weiss, Malzahn, et al, 2013), rather than as activities that introduce new disciplinary ideas or allow students to reason first with phenomena. Second, although teachers may be more familiar with some of the eight science and engineering practices emphasized in the *Framework* (e.g. data analysis), they are likely to be less familiar with others (e.g. developing and using models). For example, teachers generally do not incorporate models in their instruction, and when they do, these instantiations of model use are generally surface-level representations of the practice (Justi & van Driel, 2005, 2006; Windschitl, Thompson, & Braaten, 2008). Third, instruction that integrates science practices requires that teachers make instructional shifts that impact the organization and nature of classroom talk. Many of the science practices – such as constructing explanations and developing models – require that students reason with and justify their ideas through talk and writing (NRC, 2013). In order to support students in their reasoning about disciplinary core ideas, practices, and crosscutting concepts, teachers need repertoires of questioning that facilitate this process (Weiss et al, 2003). However, at present, the majority of instructional time in science is structured around whole class activity that generally does not afford students the opportunities to engage deeply with science content or understand the purpose behind an activity (Weis et al, 2003; Banilower et al, 2013).

Part of what makes these instructional shifts difficult for teachers is the underlying epistemology regarding science teaching and learning represented in SPI. To effectively engage students in science practices, teachers must shift commonly held and historically-ingrained beliefs about how students best learn and how science knowledge is structured (Windschitl, 2002). Through the *Framework*, students are positioned as needing to engage in practices to construct explanations of phenomena in terms of disciplinary core ideas. At present, however, science teachers overwhelmingly hold beliefs about science teaching that place themselves in positions of intellectual control. For example, over 70 percent of science teachers believe that they should explain an idea to students before having students reason with that idea, and that students need vocabulary definitions provided to them at the beginning of instruction on a new science idea (despite overwhelming evidence to the contrary) (Banilower et al, 2013). Instruction that aligns with ideas in the NGSS should instead begin with students exploring questions and support students in "constructing a storyline" of how science content, practices, and crosscutting concepts build on each other over time (Krajcik, Codere, Dahsah, Baver, & Mun, 2014).

Role of Organizational Contexts in Shaping Teachers' Instructional Practice

Although challenging tasks in themselves, teachers' individual efforts to shift their thinking about science instruction to align to the vision of the *Framework* may not be not enough to make changes to practice. Organizational contexts play an integral and formative role in shaping teachers' beliefs about and implementation of reform (Carlone, Haun-Frank, & Kimmel, 2010; Coburn, 2004). In their analysis of elementary science teachers committed to the goals of the previous National Science Education Standards (NSES; NRC, 1996), Carlone and colleagues (2010) found that discourse that promoted traditional beliefs about schooling (e.g. teacher maintaining intellectual control) acted as an obstacle to teachers reforming their instruction.

Further, teachers face the challenge of both engaging with reform ideas and making sense of the consequential impact these ideas have for their instruction, all while enmeshed in their current organizational practices and routines. These practices that organize, monitor, direct, support, and organize instruction - viewed collectively as IGIs (Hopkins & Spillane, 2015) - have the ability to both support or constrain teachers' efforts to maintain and adapt instruction (Cohen & Moffett, 2009; Cohen & Spillane, 1992; Cohen, Peurach, Glazer, Gates, & Goldin, 2013; Hopkins, Spillane, Jakopovic, & Heaton, 2013). IGIs, for example, can offer teachers necessary coherence between instructional goals, assessments, and pacing guides (Cohen, et al, 2013); yet, at other times IGI incoherence can leave teachers confused as to what to implement (Allen & Penuel, 2015; Coburn, 2004; Cohen, Raudenbush, & Ball, 2003).

In this analysis, I examine teachers' processes of developing an understanding of science-practice based instruction (SPI) within their local contexts, their patterns of implementation, and the ways these (both understandings and patterns of implementation) were shaped by teachers' interpretations of their organizational (school and district) practices.

Conceptual Framework: Organizational Sensemaking

In order to understand the relationship between teachers' interpretations of reform, their implementation of these ideas, and the role of their organizational contexts in this process, I utilize conceptual tools from organizational theory about the *process of sensemaking* (Weick, 1995). Within research pertaining to social psychology and education, sensemaking has varied definitions. "Sense making" can refer to a way of studying the everyday practices of actors as they interact and interpret and account for their experience of reality (Garfinkel, 1967). Additionally, in science education, "sense-making" is generally used to describe students' processes of engaging with and understanding connections between science phenomena, content, and practices (e.g. Braaten & Windschitl, 2011; Duschl et al, 2007).

In this article, I use sensemaking in a different way that is specific to how actors interpret their organizational contexts. *Sensemaking* from this perspective is a way of describing how actors make meaning of and respond to change within their environment (Maitlis, 2005; Weick, 1995; Weick, Sutcliffe, & Obstfeld, 2005); it is the process through which actors within an organization - both individually and collectively - "structure the unknown" (Waterman, 1990, p. 4). In the sections that follow, I review concepts from sensemaking that serve as tools for understanding teachers' interpretations of reform, their implementation of these ideas, and the role of their organizational contexts. I start with an overview of what occasions sensemaking, and then I ground a discussion of the process of sensemaking - including resources and structures that facilitate this process - in the context of science education reform.

Occasions for Sensemaking

Although sensemaking is an ongoing process, it is occasioned when change is introduced to an environment from an external agent (such as policy makers or professional development providers). The introduction of change is often experienced as "shocks" to those within the organization as they disrupt the practices and routines of the organization (Weick, 1995). When what is new or what "does not fit" (Weick, 1995, p. 4) is noticed, uncertainty and ambiguity can arise for those within the organization - *How does this new thing fit into my existing organization? What does this new thing mean for me and my role within my organization?* Through sensemaking, actors work to reduce ambiguity and uncertainty and to resolve the disruption caused by the introduced change. Sources of ambiguity can include the presence of conflicting goals, contradictions or paradoxes, limited resources available to perform actions demanded of external change agents, lack of clarity with respect to roles and responsibilities, or the absence of measures for judging the success of action (Weick, 1995). Uncertainty that occasions sensemaking arises when people lack understanding of how different aspects of the system are changing, the potential impact of change on the system, or the response options that are open to them (Weick, 1995).

With the introduction of SPI into districts and schools, teachers are likely to experience these ideas as "shocks" that interrupt the day-to-day routines, practices, and shared ideas regarding science education of a school and district. As teachers engage with SPI, they are likely to encounter ambiguity from conflicting goals for instruction, such as competing district initiatives; limited resources to support instruction that aligns with the standards (e.g. curriculum materials, time to plan new lessons/units); a lack of clarity with respect to roles and responsibilities with the new standards; and the absence of measures (e.g. assessments) for judging how successfully they have accomplished goals of reform. Additionally, teachers are likely to experience uncertainty around what reform means for how and in what ways the different aspects of the system are changing as a result of SPI.

Sensemaking as Collective

Sensemaking processes are collective in nature, rooted in social interaction and negotiation (Coburn, 2001). As members of an organization interact over time around ideas of reform, they negotiate its meanings and, at times, form shared interpretations of it (Coburn, 2001; Spillane et al, 2006). It often occurs in discourse-rich environments (Currie & Brown, 2003), and involves making one's ideas known to others in their organization (Weick, 1995). People's sensemaking is influenced by the actual, imagined, or implied presence of others (Weick, 1995). Within organizations, "decisions are either made in the presence of others or with the knowledge that they will have to be implemented, or understood, or approved by others" (Burns & Stalker, 1961, p. 118).

When teachers consider adopting reform, their sensemaking may be influenced by questions such as: *How will my actions be interpreted by others? What will this mean for how I am viewed as a teacher at this school? How will my administration feel about my instructional changes?* In this way, sensemaking is also concerned with maintaining or negotiating one's identity within their organization.

Resources for Sensemaking

As people engage in sensemaking, they draw on a variety of resources to do so. These resources are both formal and informal in that they can be structured by organizational tools, routines, and practices (e.g. IGIs) or through designed PD activities; or they can be informal, such as unplanned interactions with colleagues or conversations in the hallways. In this section I describe further a few of these resources salient to this analysis and how we might expect to see them utilized in the context of science education reform.

Personal and social resources. Teachers' personal and social resources influence how they make sense of new messages about teaching and address disruptions to their work practice. Personal resources that teachers' utilize during sensemaking include their conceptions of science and how students' understanding develops within science (Cohen & Ball, 1999), and their repertoire of strategies for supporting student learning in science (Harris, Phillips, & Penuel, 2012).

Teachers' social resources can include their informal collegial interactions and shared artifacts of practice. Teachers' informal interactions with colleagues are important influences on teachers' sensemaking. When there is a high level of relational trust among colleagues in a school, teachers are more likely to take risks by sharing struggles they are having with implementing reforms (Bryk & Schneider, 2002; Cohen, 2011; Printy & Marks, 2006) and to challenge their own ideas about student capabilities (Philip, 2011). Further, informal alliances can provide teachers with access to greater resources and expertise; and it can support teachers in their grappling with the multiple, and at times conflicting, messages at their schools and in their districts (Coburn, 2001). Additionally, shared artifacts and representations of practice can broaden teachers' professional vision and sense of possibilities about how to teach (Horn & Little, 2010; Kazemi & Hubbard, 2008; Sherin & van Es, 2005; van Es & Sherin, 2002).

Instructional Guidance Infrastructures. The multitude of practices and structures that organize teachers' instruction – pacing guides, curriculum, standards, instructional coaches, teacher evaluation, student assessment – are incredibly influential in shaping teachers' sensemaking and instruction. I borrow the term Instructional Guidance Infrastructure (IGI) from Hopkins and Spillane (2015) to encompass these practices. IGIs can give sense (Gioia & Chittipeddi, 1991) to messages about what to teach (Cohen, 2001; Hill, 2001; Seashore Louis, Febey, & Schroeder, 2005). Teachers often use this local and state guidance as a way to make sense of reforms, comparing that guidance to messages they receive from external professional development providers (Allen & Penuel, 2015; Furtak & Heredia, 2014). Teachers' use of that guidance as a social resource can expand teachers' sense of possibilities for their practice, but it can just as easily be assimilated into teachers' existing ideas about practice (Coburn, 2004; Heredia, 2015).

Schools' formal structures for facilitating teacher collaboration about their practice—such as intentionally designed school-based teacher workgroups or teams—

constitute another type of organizational influence on teachers' sensemaking. A cohesive network within a school provides a strong basis for collective sensemaking efforts to result in a shared vision for reform (Coburn, 2001), while a more fractured network with multiple poles of leadership can result in more splintered visions (Penuel et al., 2010). Further, embedded institutional opportunities for teachers to design lessons, plan together, and make collective sense of reform provide time to more deeply engage with ideas of reform.

Additionally, curriculum materials play an integral role in shaping teachers' sensemaking of reform. When considering the role of curriculum, I employ Remillard's (2005) definition of curriculum materials as referring "to overarching frameworks that specify what should be taught or to guides or other resources that teachers use when designing instruction and deciding what will be enacted in the classroom" (p. 213). This way of conceptualizing curriculum encompasses curricular texts, pacing guides, as well as shared artifacts from colleagues. Reform-based or revised curriculum materials can influence teachers' views of reform ideas as they offer models of how reform instruction might look in practice (Remillard, 2000). Curriculum materials can also develop teachers' knowledge of how to best implement reform practices in ways that are responsive to students and that support teachers in being adaptive in their instruction (Brown, 2002; Davis & Krajcik, 2005; Shulman, 1987).

Standards additionally influence teachers' sensemaking. In Coburn's (2001) analysis of teachers' sensemaking of reading reform, teachers considered the reform through the lens of the standards. Additionally, Allen & Penuel (2015) found that teachers' ultimately privileged standards over other things that influenced their planning and teaching, as they felt most accountable to these measures.

Finally, leadership practices can influence sensemaking. Leaders help "give sense" (Gioia & Chittipeddi, 1991) to particular policies from outside the school, mediate teachers' access to ideas from outside the school, and shape conditions for learning about those ideas (Coburn, 2001, 2005). Formal leaders shape teachers sensemaking especially with respect to what standards to emphasize in teaching, what materials to select, and how students should be assessed (Sun, Frank, Penuel, & Kim, 2013). Increasingly, because of the tightening of coupling of personnel evaluation with observations of teacher practice, formal leaders (including district leaders) are also influencing how teachers make sense of their own practice and messages about reforms (Jiang, Sporte, & Luppescu, 2015). Teachers' sensemaking of the SPI, then, is likely to be mediated by these practices.

Sensemaking and implementation of reform. One substantial outcome of teachers' sensemaking of reform (and of primary concern in this analysis) is their interpretations of how reform fits into their existing IGIs. These interpretations have a direct impact on teachers' decisions about what of reform to implement into their instruction. Prior research suggests that teachers' perceptions of reform (Coburn, 2005; Spillane, 2004; Spillane et al., 2006) and their perceptions of the ways reform coheres with existing IGIs (Penuel, Fishman, Gallagher, et al., 2009) are most influential in mediating teachers' implementation. Teachers' sensemaking processes – what forms of ambiguity or uncertainty they experience, what resources are utilized during sensemaking, and to what degree teachers have time and opportunity to engage in sensemaking – will look different depending on the teacher and the organizational context (Penuel et al., 2009; Coburn, 2001). For example, within the same district, teachers' may experience different levels of ambiguity due to their particular schools' IGIs. Penuel and colleagues (2009) found that teachers' sensemaking about particular standards alignment – regardless of the state-level policymakers' alignment – affected their decisions about implementation of an Earth science program, called GLOBE.

Further, not all sensemaking processes support teachers in learning or growing. The nature of sensemaking processes can get short circuited and lead to surface-level engagement with ideas of reform (Coburn, 2001). For example, when teachers in Coburn's (2001) study of reading reform had conversations with little connection to the classroom or in time frames that shortened in-depth discussion, teachers were unable to engage with reform messages in more than superficial ways. These conversations additionally seemed to encourage teachers to interpret ideas of reform in ways that aligned with their pre-existing views of teaching and learning. Different configurations of teachers' sensemaking are likely to be consequential for their implementation (Coburn et al, 2012).

As teachers engage with SPI, they are likely to experience these suggested changes as a shock and experience varying forms of ambiguity and uncertainty with regard to how these changes fit into their existing ideas about science, teaching, and learning and into their existing IGIs.

The Current Study

In this analysis, I aimed to better understand the processes through which teachers worked through ambiguity and uncertainty – and thus developed perceptions of SPI and made decisions about what of SPI was implementable – and incorporated these aspects of SPI into their instruction. Specifically, I asked:

(1) What sources of ambiguity and uncertainty occasioned teachers' sensemaking, and what resources did teachers draw on in their sensemaking?

(2) What conditions of sensemaking supported teachers' interpretations and implementation of SPI?

Method

To examine the relationship between teachers' organizational sensemaking and their implementation of science-practice instruction, I employed a multiple-case study methodology (Yin, 2013) drawing on multiple forms of teacher data from a two-year period. Utilizing a case methodology affords an in depth analysis of social phenomena within the context and conditions of that particular environment (Yin, 2014; Yin & Davis, 2007).

Research Context

This study takes place in the context of a larger, 5-year NSF-funded project, *Efficacy Study of Project-Based Inquiry Science*, (see Harris, Penuel, D'Angelo, DeBarger, et al, 2015) that intended to evaluate the impact of curriculum materials (called *Project-Based Inquiry Science* and explained more fully below) in supporting reform-based instruction, when combined with professional development. The research team worked with 6th grade science teachers in a large, urban school district, Georgetown School District[5], in the Southeast. At the time of the study, Georgetown

[5] All names are pseudonyms.

served more than 140,000 students, and the district's demographics resembled many urban districts in the United States with a student composition of 42 percent African American, 32 percent White, 18 percent Hispanic, and 5 percent Asian. Fifty-four percent of the students in the district were eligible for free or reduced-price lunch, and the district had a growing ELL population.

Georgetown was in a state that was one of the lead states that provided leadership for the writing of the standards; however, this state had not yet adopted NGSS. This is important to note, as current standards play a critical role in guiding teachers' sensemaking (see Coburn, 2001; Heredia, 2015). Further, teachers in this study began to see the NGSS as "far off" and so less requiring of sensemaking. Regardless of NGSS-adoption status, the district had a strong commitment to reform math and science, and was relatively stable in terms of unified efforts among district leadership toward integrating reforms. This meant that the district leaders were more likely engage in activities that would foster greater coherence between the ideas of reform and the district's IGI. The district also had strong curriculum leaders who had authority to make decisions about text adoption and who supported NGSS and PBIS. For example, the curriculum leaders helped develop a revised pacing guide that incorporated PBIS for teachers as an effort to align district practices with the text. This too suggested that there was greater potential for systemic coherence, and thus, an IGI that was supportive of teachers' efforts to align their teaching practices with reform goals.

As is the case in a district this size, student demographics, available resources, and school IGIs varied considerably depending on the school site. For example, some schools in the district were up against immense pressure to meet annual yearly progress

(AYP) per No Child Left Behind (NCLB) mandates; one faced challenges of how to support a fast-growing ELL population; and others struggled with having consistent access to functioning computers. These varied schooling contexts have consequence for teachers' sensemaking processes about the *Framework* and what of these reform ideas they felt they could implement (see Allen & Penuel, 2015).

***Framework* and NGSS professional development**. Teachers participated in PD four times throughout each of the two school years. The *Framework* and NGSS workshops both took place during the August of the prior to the start of the school year in 2012 and 2013. Members of the research team and committee that developed the *Framework* and NGSS led the workshop. PD activities in the *Framework* and NGSS workshops emphasized learning about disciplinary core ideas through driving questions; science practices, with particular emphasis on modeling and explanation; and how core ideas, practices and cross-cutting concepts are integrated in performance expectations. In particular, teachers gained practice developing and revising models and writing and revising scientific explanations related to material they were required to teach (per state standards). Professional development facilitators also emphasized the language demands inherent in the NGSS practices (Lee, Quinn, & Valdés, 2013) and which of the Language Arts and math Common Core tasks overlap with the NGSS practices. Teachers also examined the NGSS performance expectations and were given an opportunity to adapt state standards into performance expectations.

Project-Based Inquiry Science curriculum and professional development. The curricular text analyzed in the larger study and that I hypothesized would be integral in teachers' sensemaking of the *Framework*, is called Project-Based Inquiry Science

(PBIS). PBIS is comprised of science units in life, physical, and Earth science, spanning grades six through eight. A typical unit takes 8-10 weeks to complete. PBIS is a good candidate for supporting teachers' shifts toward reform instructional approaches as it has features that align with the vision of the *Framework*. The text is organized by "Learning Sets," that are guided by a driving question or a challenge that typically targets a crosscutting concept in science. The activities within each unit provide students with multiple occasions for investigating as scientists would – through observations, asking questions, designing and carrying out experiments, building and using models, reading about the science they are investigating, constructing explanations, and so forth. In this way, the PBIS curriculum's design emphasizes a knowledge-in-use perspective (National Research Council, 2007) and reflects in a broad sense the principles of the *Framework*. At the same time, the particular goals of PBIS units do not align perfectly to performance expectations as articulated in the NGSS. In addition, not all of the eight practices emphasized in the *Framework* are prominent within the investigations.

Teachers in the current study received PD focused on this curriculum, in addition to the PD they received related to the *Framework* and NGSS. It took place at three time points throughout each school year and ranged between 1 and 3 days—August, October, and January, roughly—and intended to coincide with teachers' curricular pacing. During these workshops, teachers additionally shared what were framed as "innovations" in their teaching. These included scaffolding tools, such as those that teachers had created to support students' development of explanations, other textbook or lesson adaptations, and student work as a product. The teachers additionally shared strategies they had used to address differences in pacing between the textbook and the district pacing guide and other planning tools they used.

Participants

I selected participants who share certain background characteristics that could be considered "constants" in terms of teachers' implementation outcomes (Rihoux & Ragin, 2009). These shared characteristics included (1) participation in the PD workshops on the *Framework*/NGSS and on the curriculum; (2) access to PBIS curriculum and other curricular resources provided in PD workshops; (3) teaching assignments in the same subject area, grade level, and school district; and (4) relative IGIs in terms of what was expected of teachers, including evaluation practices and degree of administrative value and support of reform instruction.

I additionally selected teachers who collectively had enough *diversity* as to serve as explanatory resources for understanding differences in implementation outcomes (Rihoux & Ragin, 2009). Areas of diversity included teaching histories, such as years teaching and years teaching science (seen as "personal resources"), varying access to social resources, such as degrees of interactions with ideas from the *Framework* outside of our study (as stated in interviews) or access to and interactions with colleagues at their school.

[Insert Table 1: Teacher Demographics]

Data Collection

Data for this analysis was collected over a two-year period (2012-2013 and 2013-2014) during which teachers were participating in professional development and were implementing aspects of the curriculum and professional development in their classrooms. Data included classroom video, teacher assignments, and teacher interviews.

Teacher interviews. Focal teachers were interviewed during fall 2013 and spring of 2014 (Year 2 of the study). The interview protocol was developed using a construct-centered (Wilson, 2005) approach to protocol design. Fall interview topics included instructional management practices at teachers' schools sites –such as what teaching and classroom-organizational practices (e.g. Essential Questions or objectives posted) building administration look for, lesson planning expectations, and teacher responsibilities – and teachers' perceptions of coherence between SPI, their current instructional approaches, and state and district goals. The spring interview focused on particular lessons in which teachers engaged students in science practices, the objectives of these lessons, any modifications teachers made, what type of student SPI seemed most effective for, and what materials teachers used in the planning and implementing of these lessons. The interviews were conducted over Skype, phone, or in person and were audio recorded and transcribed. Interview length ranged from 25-75 minutes.

Video data. Teachers were asked to record video of the same six lessons across two curricular units – Ever-changing Earth (ECE) and Energy (EN) – within *PBIS* and during both years of the study (2012-2013 and 2013-2014). The particular lessons selected were chosen because of their focus on the practice of either modeling or explanation. Included in this analysis are two of these six lessons – one from each unit. I made this decision based on teacher participation and lesson content. Specifically, these lessons include prompts for students to engage in the practices of modeling and explanation, and include prompts for teachers to engage students in reasoning about science phenomena. The videos typically ranged between 45-90 minutes in length and all were transcribed for analysis.

Teacher assignments. In addition to recording lessons, the teachers were asked to submit in-depth descriptions of lessons they taught during both years. Teachers completed a cover sheet along with the lesson description that asked them the purpose of the assignment, what practices, skills or objectives they hoped students would gain from the lesson, and the source of the assignment (teacher developed, the textbook, a colleague, etc.). I selected five assignments total for each teacher, choosing assignments that could represent the range of topics covered by the 6^{th} grade standards.

Data Analysis

I conducted my analysis for this paper through a multi-stage process, utilizing analytic techniques of coding, developing case summaries and matrices, generating memos, and conducting Qualitative Comparative Analysis (QCA). I followed Basurto and Speer's (2012) six-step method for conducting QCA, and techniques for developing case summaries and matrices based on Miles, Huberman, and Saldaña (2014).

QCA is an analytic approach designed to identify the multiple combinations of conditions that lead to a particular outcome (Rihoux & Ragin, 2009; see Kintz, Lane, Gotwals, & Cisterna, 2015; Woulfin, 2015). This makes QCA an effective strategy for examining teachers' implementation of reform instruction, as we can anticipate that teachers with the same implementation patterns (seen as outcomes) may have different aspects contributing to their process of sensemaking and their decision-making about classroom instruction (see Trujillo & Woufin, 2014; Woulfin, 2015). Using Boolean algebraic techniques, it compares the different combinations of categorical variables and develops models of the conditions associated with a particular outcome (Rihoux & Ragin, 2009). Through QCA, the researcher can construct "truth tables" that display which combinations of conditions (present or absent) were linked with a particular outcome. In this analysis, I was interested in the outcome of teachers' implementation of SPI and their conditions of organizational sensemaking. I constructed three measures of SPI that reflected the integral instructional shifts called for in the NGSS, *Framework*, and recent NRC report (2015) on implementation of the *Framework*. These outcome variables included (1) engaging students in science practices, (2) pressing students to reason about phenomena, and (3) positioning students as active participants in their science learning. I first systematically coded each teacher interview for each theorized condition (sources of and resources for sensemaking; see Appendixes A & B) of SPI implementation in Dedoose (Dedoose Version 6.1.18, 2015). I determined the order for coding randomly, using an online generator. I then developed case summaries for each teacher using a template organized by research questions and conditions categories (see Appendix C). At this time, I produced a memo on emerging themes present in the coding and case summaries and had these reviewed by one other researcher familiar with the literature and theory on teacher sensemaking within reform. I then revised my condition categories to better reflect the themes emerging as salient and present for teachers.

To calibrate membership, I first set anchor points for each condition and outcome measures (see Appendix D). I then determined initial membership scores for each of the conditions drawing on the literature on teacher sensemaking and implementation of reform (see Coburn, 2001; Trujillo & Woulfin, 2014; Woulfin, 2015), on Weick's (1995) theory of sensemaking, and based on my familiarity with the cases (Basurto & Speer, 2012; Ragin, 2008; Rihoux & Ragin, 2009). For conditions, I made membership determinations drawing on the case summaries. For the outcome measures of SPI, I made holistic judgments about implementation level by integrating data from video and teacher assignments, creating four (4) levels of implementation in the process. These judgments were based on consensus from the research team analyzing the teacher assignment documents. At this stage, I also ruled out *years teaching*, *degree level,* and *science background* as being indicators of teachers' SPI. That is, I used case summaries to explore whether implementation category was related to experience teaching and education. None of these summaries revealed a clear pattern. For example, Kate, who was in her second year of teaching during the start of our study, had higher implementation of science-practice instruction, while Joan who had a science degree, a master's degree in science education, and over 12 years of teaching science had low implementation. Marcus and Richard, who had the highest implementation, did both have master's degrees but neither had a background in science, Marcus had only been teaching science for 4 years, and Richard for over 40.

I then revisited the previously developed case summaries and generated data matrices for the first two research questions. Using the data matrices, I drafted another memo on the findings for these questions. I then assigned case membership based on the earlier anchor points. At this point, I revised the condition variables empirically, removing measures that were not mentioned, were mentioned infrequently, or that did not vary (and therefore potential explanatory power) across the cases. These condition variables included: *sensegiving, practices that support teachers' lesson planning,* and *absence of measures*. I revised the outcome variables to include only teacher assignment data to determine engaging students in science practices, as these provided adequate variation with regard to the outcome. Additionally, for the *student positioning* variable of the outcome, I excluded the code "Elaboration" because it had low inter-rater reliability among our larger team. Further, at this point, I revised the anchor points to be more accurate and better support me in differentiating between cases.

I made final determinations of teachers' condition membership based on my familiarity with each case (see Appendix E for membership assignment). In the few instances I struggled to make a membership score determination, I revisited and played back teacher interviews to support my understanding of the case. Further, because the video data were coded for teacher moves only (and not student responses) I reviewed the two lessons included in this analysis for each teacher to better understand teacher-student interactions, patterns of teachers' questioning and student-positioning moves, and the ratio between teacher and student talk within the lessons.

Finally, I ran QCA using the Fuzzy Set Qualitative Comparative Analysis (fsQCA, Version 2.0) program (Ragin et al. 2006) and created a "truth table" that included all remaining conditions and the aggregate outcome score for each teacher. After running QCA with all conditions, I ran additional analysis through the software to determine the configuration of "necessary conditions" (what conditions must be present) for SPI. QCA outputs generate consistency scores (ranging from 0 to 1, with 1 being a perfect score) that explain how much of the outcome can be explained by a particular combination of conditions. Per QCA standards (Ragin, 2006), I eliminated cases that had a consistency score of less than 75 percent. I then continued running QCA with different combinations of conditions until I garnered consistency scores between 90 and 100 percent.

Findings

My findings suggest that the majority of teachers in this study were able to engage in productive sensemaking that allowed them to see what was different, similar, or new about SPI (from their prior instruction), and they were able to make informed decisions about what aspects of SPI they wanted to implement in their classrooms. As they engaged with the ideas and practices of SPI, all teachers wrestled with ambiguity or uncertainty pertaining to coherence between SPI and the more traditional approaches of their colleagues and how to create a feeling of continuity among students as they moved from grade to grade. Additionally, all wrestled with ambiguity around how to make time for creating lessons that mapped onto the goals of SPI while also attending to the state's standards. Some teachers also dealt with uncertainty around coherence; namely, how to address the tension between the existing compartmentalized state standards and the kind of coherent approach of SPI and the NGSS specifically (e.g. emphasis on cross-cutting concepts).

Although it was important that teachers had *some* uncertainty or ambiguity present to drive their sensemaking, when there was too much ambiguity and uncertainty, coupled with limited or even average access to resources, teachers did not engage in productive sensemaking, leading to instruction less aligned with RBI goals. Most productive sensemaking (in terms of SPI implementation) included manageable ambiguity, little to no uncertainty, and access to particular individual, social, and material resources described in detail in this section.

In the sections that follow, I first describe implementation patterns across the eight teachers, including what high, middle, and low implementation of SPI looked like in practice. I then discuss the conditions of teachers' sensemaking, identifying the configurations that predict implementation outcomes. I conclude with a presentation of two contrasting cases – Marcus and Joe – to instantiate the findings as a whole.

Patterns of Science-Practice Instruction Implementation

Teachers' implementation of SPI varied across teachers for all outcome measures – positioning students as active participants, pressing students to reason, and engaging students in science practices. In general, the majority of teachers fell within a low to mid-range category of SPI implementation (outcome values of 0.33 to 0.44[6]), with three in a mid-high to high implementation (0.67 to 1). Table 2 summarizes teachers' outcome scores for each measure and their final outcome score (SPI). Teachers varied in degree of membership in the set of teachers implementing SPI.

[Table 2: Teachers' Outcome Membership Scores]

For the three teachers in this analysis with high implementation, they demonstrated regularly positioning of students as having meaningful contributions, they invited multiple voices to speak and discuss a topic or question, they placed students in conversation with one another, and they invited and took up student connections to everyday lives (seen as *Positioning Moves*). Their instruction was characterized by greater evidence of questioning patterns that pushed students to reason about phenomena and make connections across phenomena (*Reasoning Moves*), and they were more likely

[6] Membership scores for Fuzzy Set QCA range from 0 (fully out) membership to 1 (fully in). Scores below 0.5 are considered "more out than in" and scores above 0.5 are more in than out.

to ask students to develop and use models, and to generate scientific explanations that included claims, evidence, and reasoning (*Science Practices*).

For teachers in this study who had low implementation, they generally employed some of the positioning moves, but in general, the teacher held the stance of the primary intellectual authority in the classroom. Further, their questioning patterns relied heavily on low-inference, known-answer questions, and questions that pushed students to reason or make connections to other concepts or their daily lives were used infrequently. Further, when modeling and explanation practices were present in these teachers' instruction, models generally were a surface level representation or demonstration that students observed, and explanation prompts only included evidence, claim *or* reasoning, but not a combination of the three. Teachers in the middle, then, displayed some intermediary of the two; for example, their science practices assignments may have prompted for claim and evidence, but not reasoning, or they may have seesawed between maintaining intellectual control of the classroom and giving student opportunity to be intellectual drivers.

Teachers' final outcome membership scores represent an aggregate membership score of the three outcome variables. When parsing the three outcome variables, teachers' enactment of SPI generally included more reasoning moves and science practice opportunities than it did student-positioning moves. Teachers' implementation of positioning moves garnered the lowest implementation scores across teachers and least amount of variation, with only two teachers (Alice and Marcus) having a membership above 0.33. Teachers' reasoning moves had a similar pattern, with three teachers (Marcus, Richard, and Kate) having membership above 0.33. Opportunities for students to engage in science practices had slightly higher membership across the teachers, with half over 0.33.

Marcus had consistently high enactment of SPI across the three measures. One example of Marcus's SPI implementation can be observed during a lesson from the PBIS curriculum in which students' used a model of convection currents (using hot and cold water and food coloring) to make predictions and generate initial explanations about what causes the earth's mantle to move. Marcus facilitated a whole-class discussion about the activity in which he invited multiple students to share, build on each other's ideas, and justify their reasoning.

Using prompts from the curriculum materials, Marcus asked students to draw a diagram of what they observed when they conducted the modeling activity. He then showed pictures of the model from when he "learned about doing this lab" (referring to PD). Figure 1 is my own photograph of the investigation set up from taken from the PD (January 2013), which would have looked similar to what Marcus had his students interpret. He asked students: "Do you see the pattern on the top?" and after some student responses, Marcus asked students to consider, "Where else have you seen things layer in our classroom? What other labs or demonstrations have we done where things layered?" This question began a short dialogue in which multiple students brainstormed aloud other activities and Marcus prompted the students to name density as a concept that explained the kind of layering the students had observed in previous activities.

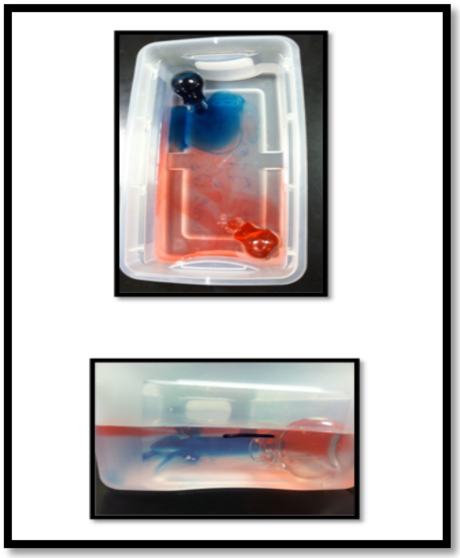

Figure 1. Mantle Convection Modeling Activity from PD

After giving students time to answer "reflect" questions (as outlined in the PBIS curriculum) Marcus then facilitated the following discussion:

Marcus: I'd like someone to share what they wrote for number two. What do you think is causing the warm water to move as it did in the simulation? If you don't know, what questions do you have? Who'd like to volunteer to share?

Student 1: I think the density of the warm water caused it to move like it did in the simulation.

Marcus: Ok. *(To others in the class)* What do you think about her answer?

Student 2: I agree with her answer. I said the hot water was less dense and the cold water more dense, so it sank in the tub. Or, rose. I agree with [Student 1].

Marcus: OK, let's talk about number three for a second. Water is a liquid that flows easily, but earth's mantle is a solid that behaves like a viscous or very thick liquid. How do you think earth's mantle might flow different than the water?

Student 3: I said I don't think that the liquid can move as fast because it's like a thicker and more dense liquid.

Marcus: Ok, now, did you hear her? thick liquid – she doesn't think a thick liquid like the mantle can move as fast as the liquid, the water in the tub. What do you think about what she said, [Student 4]?

Student 4: I agree

Marcus: Why?

This exchange between Marcus and the students continues on for the next several minutes until the end of class.

Marcus enacted important aspects of SPI leading up to and during the exchange presented in the above excerpt. First, Marcus connected the current class activity with other activities completed earlier in the year. Specifically, he aimed to remind students about the properties of density, a concept that had surfaced across topics and units and could explain the "layering" phenomena that the class was then observing. Marcus's move here attempted to connect ideas across different parts of the curriculum. Further, as Marcus engaged the class in discussion about the mantle simulation and a student raised density as an explanatory concept, the student, not Marcus, is positioned as contributing an important idea toward the class's understanding of the movement of the earth's mantle, not Marcus. Additionally, Marcus utilized the curriculum to support students in naming connections between the class activity and the phenomenon it represents (e.g.

how would water move differently than the viscous material of the mantle?), pressing students to explain why they suggested a particular answer.

Let us now look at this same post-activity discussion enacted with low SPI within Joe's classroom. Per the PBIS curriculum, and similar to Marcus, Joe instructed his students to develop a diagram in their science journals that demonstrated what they observed in their modeling activity of convection currents. He then facilitated the following discussion:

Joe: Alright guys, let's come together now. What should we have seen happen? Now after a while the food coloring scattered and spread all over the place, but what initially happened? What happened at the beginning, [Student 1]?

Student 1: Well after you put it in, it started – with your two holes, it came rushing out on the sides. The smaller beaker was acting as lava coming to this.

Joe: Okay, good, so in your science journal we need to draw a diagram of this here, and so you have your small beaker. There's two holes in it, and the first thing you should have seen happen was that it went up.

(Gives ~30 seconds for students to add this to their journals)

Joe: What was the next step? Then what did it do?

Student 2: The food coloring came out and turned the water orange.

Joe: Okay, so in terms of direction, first it went up, and then—

Student 2: It first went up and then gathered to the water.

Joe: Okay, it should have eventually went—it should eventually go to the bottom, but it did something else first, right? It at least should have.

Student 2: It dispersed and moved around.

Joe: Ya, it should have gone to the sides. Okay so you should have seen some sort of a layer of food coloring at the top, collecting at the top there. …unfortunately a lot of people weren't able to see this next step because the food coloring had dispersed, and it had gotten too mixed up, and it didn't happen, but in terms of what we know about convection currents, what should happen next?

Students: [Multiple voices] sink

Joe: Sink, yep. Why does it sink?

Student 3: Cold air sinks, and hot air rises.

Joe: The same way air works. Yeah, so what should eventually happen, and again this represents what? What is this a model of?

Student 3: The mantle. How the mantle works.

Joe then spent the final two minutes of class talking to the students about the correspondences between the model and the movement of the earth's mantle. Although we see some aspects of SPI present in Joe's enactment of this lesson, his enactment looks more like a traditional classroom in which instruction is organized around a "confirmation lab." Students were conducting the lab to confirm a particular result (what should we have seen?) and demonstrate an idea rather than discovering these ideas on their own. Students had very little opportunity to make connections themselves, and were given minimal opportunity to reason about the phenomenon they observed.

Configurations of Sensemaking that Predict Implementation Levels

Differences in implementation, such as the contrast between Marcus and Joe, can be attributed to variation in teachers' sensemaking processes. Table 3 summarizes the most common conditions of sensemaking that led to implementation of SPI. Important for all teachers' sensemaking was the presence of some, but manageable ambiguity and the absence of uncertainty. As I discuss later, the presence of uncertainty generally resulted in low implementation of SPI. Additionally, there were two personal and social resources and two institutional resources that were important conditions of sensemaking, which I describe in the paragraphs that follow.

Role of Collegial Support in Reducing Ambiguity

[Insert Table 3: Summary of Conditions for SPI]

Among the different combinations of configurations of conditions that predicted implementation level, *supportive collegial interactions* was present in all of them. Table 3 displays the combinations of conditions that led to teacher implementation of SPI. For the three teachers who had SPI membership, a combination of collegial interactions with limited ambiguity and no uncertainty explained their implementation of SPI. When adding conditions of supportive administration and teaching histories, this combination explained most (92 percent) of the outcome, but not all.

Teachers who had a colleague, or multiple colleagues, to collaborate with around instructional planning, developing or adapting materials to address SPI or generate coherence between SPI curricular materials and their local instructional guidance infrastructures tended to have a higher degree of SPI. Ambiguity associated with conflicting goals, such as the misalignment between pacing of the PBIS curriculum and state standards, could be addressed collectively when teachers had a colleague to work with. Teachers at Barton benefited from this, as the team created an adapted pacing guide to adequately address all state standards. Further, Rich and Kate at Robinson planned all weeks of instruction together and problem solved how to create more time for covering standards not addressed in the PBIS curriculum at the end of each school year.

In some cases, collegial interactions also compensated for limited resources. Abby, for example, developed a science-practice based unit on ecology that Marcus, Joan, and Alexis had access to. The PBIS materials did not include an ecology unit, even though ecology was part of the sixth grade standards. Marcus also developed a scaffold (see Figure 2) for students' writing of explanations, which was created into a poster and placed on all the 6th grade science walls until later in the year when students had had sufficient explanation-writing practice.

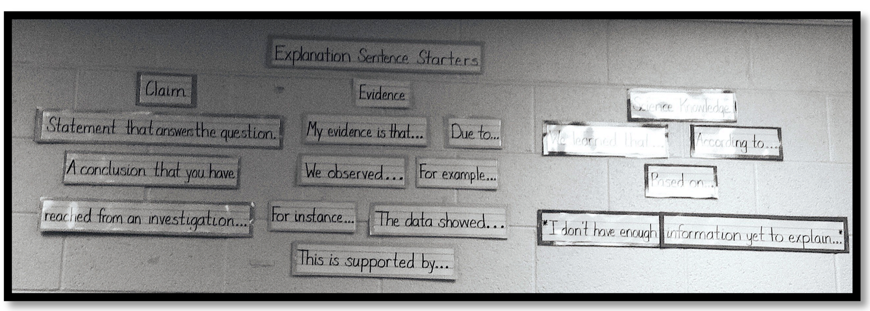

Figure 2. Explanation Scaffold, Barton

Both supportive collegial interactions and teachers' history and familiarity with their teaching assignment and expectations at their school bolstered an understanding of SPI's differences from their school's current teaching practice seemed to serve teachers in addressing ambiguity associated with the conflicting goals. These teachers found ways to reconcile what was in conflict between SPI and their local instructional guidance infrastructures and to make decisions that honored SPI goals while also meeting expectations most pertinent to their local setting. Kate and Rich talked about how their academic facilitator (science content specific administrator) had pushed them to incorporate "differentiation" into SPI-based lessons.

Rich: To them [the administration], it's like they have to see somethin'—

Kate: Written down.

Rich: - like this, this, this written down and implemented and everything, when [SPI] doesn't really a hundred percent lend [itself] to that. It's probably built in—

Kate: There' differentiation—yeah, it's built in.

Rich: Yeah, it's built in pretty much, but it's not what they really wanna see. At first they—I don't think it was really they were resistant to [SPI] or whatever. It was more that they didn't understand it. Now that they got it, they understand it better.

Although Rich and Kate are aware that SPI did not lend itself to – to use Rich's term - the evaluation "checklist" that administrators used during their walk throughs, they were able to identify the ways that SPI did address instructional aspects that were important to the school and gain administrator buy in. The administration "getting it" was an outcome of conversations with Rich and Kate.

Further, teachers' individual histories, coupled with their collegial support aided them in making decision about how to address the issue of discontinuity their students were likely to experience having engaged in SPI during 6th grade, but graduating to traditional forms of science instruction once in 7th grade. Teachers, for example, wrestled with whether they should incorporate note taking or the scientific method, as they knew students would be expected to know and do these things in 7th grade. Joan talked about how SPI was "most idealistic" in terms of what she would like to teach, but that she got "worried about getting [students] from point A to point B and getting that done well, and then [the students] trying to shift gears and going another direction when I know that the people [other teachers] next year aren't going to be continuing [with SPI]." Having both the awareness of what was different about SPI and the collegial support to plan and campaign for SPI within their grade and other grades, bolstered teachers' SPI. Abby, Joan's colleague at Barton, for example, had worked with the school leadership for approving the use science department money to get SPI supportive curricular materials for 6th grade (after the study) and at least one unit for the seventh grade to generate that across grade-level coherency for students.

Role of Curricular Materials in Supporting Implementation of SPI

One final and important condition of sensemaking that was associated with implementation of SPI was the availability of the PBIS curriculum, which they perceived to support SPI directly, and other curricular resources shared during professional development workshops. The curriculum provided examples of what SPI could look like in practice and instantiated the ways that SPI was unique. During her spring interview, Abby stated,

Abby: When they were first giving us all of that information [at the first PD], I was like, "Whatever."

Allen: What made you "like whatever"?

Abby: Well, just because, our district wasn't doing that, [our state] wasn't doing that, so it's kind of like, uh—alright I see where we're going with this, OK. But, once you start getting into the PBIS [curriculum], once we got into that second unit on Energy, it fit- it interlocked, you know? Just interlocked with all the *Framework* they were talking about, the NGSS, where it was going.

Allen: So for you, what made you kind of shift from the "Oh whatever" to the "I can kinda get behind this" was—

Abby: was the project-based *(pause)* resources, the materials. Because, [we had just been introduced to] the Common Core as well. And, I guess, that's another thing [that made me react that way]. Like, alright, they are throwing this *Framework* on us, but our school is adopting Common Core, so we gotta make sure that's in there [too].

For Abby, having the curriculum materials supported her in seeing the ways that the *Framework* could be addressed in practice. Additionally, Abby explained that, before having materials,

> It was hard to know where to start – What big question [can I ask that] covers everything [all the standards]? What big challenge would cover everything that you're trying to teach?...Now you can see, ah, that's perfect, that's a great question to ask that can cover all the content areas you need to cover.

Abby's sentiments regarding the curricular materials were shared across the teachers in this study. The resounding message from teachers was that they would have thought their instruction was more like SPI than it truly was and that they would have felt too uncertain about and lacked too much time in order to adapt lessons to be more SPI focused.

Role of Uncertainty in Foreclosing Sensemaking

The role of uncertainty, or more specifically, the *absence* of uncertainty, in teachers' sensemaking had a large impact on their implementation of SPI. Teachers who experienced uncertainty had significantly lower implementation of SPI. In Weick's view, uncertainty is caused by a *lack of resources*. Although teachers were provided with the PBIS curriculum, these materials served as an incomplete resource for supporting teacher implementation of SPI. For one, the PBIS materials did not cover all 6th grade state standards during the time of the study; nor did other teachers (e.g. the 7th and 8th grade teachers) have curriculum materials that supported the coherency of SPI as students moved onto future grades. Further, PBIS curriculum did not offer assessments that measured the kind of 3-dimensional science learning students in an SPI classroom were engaged in. served the needs of the teachers in the school district.

Considering this distinction helps to uncover why teachers who experienced uncertainty had lower implementation of SPI. Teachers' were left with inadequate resources for decision-making. Joan, for example, had collegial support, supportive leadership, and curriculum materials from PBIS, from what Abby and Marcus had developed, and had even developed SPI materials herself; however, Joan experienced prolonged uncertainty around issues of coherence that ultimately resulted in low implementation of SPI. Some of Joan's uncertainty can be seen in her spring interview:

> I guess it's hard to wrap my brain around with the NGSS stuff is, it's very much—it's such a fluid story. Particularly it fits through a—so when we think—I always

> felt like I was leaving—or that somebody [a student] leaving eighth grade should be doing. I know that's the goal of science education that's broken down at the state level. There've been a—trying to compartmentalize things for the sixth grade, seventh grade, eighth grade and [I] know that that's [the compartmentalization] going to lose some of it [the goal behind NGSS]. That can be done 60 different ways. It's hard to know when to run with [SPI] in sixth grade and when to jump off and leave the rest of the journey for seventh grade. (SPR)

Joan is trying to "wrap her brain" around how the built in coherence of the Next Generation Science Standards and of the SPI approach can be achieved within a system that is "compartmentalized." Her comment also indexes a possible challenge other teachers, schools, and district are likely to face when adopting SPI and approaches that address the NGSS: The intentional building of understanding of core ideas across grade levels of this approach conflicts with more ingrained, historical approaches that provide less coherence across grade levels.

As teachers engaged in sensemaking around the ideas of SPI and made decisions about what of SPI to implement in their classrooms, resources of collegial support, individual teaching histories, school leadership, and curricular materials were most integral in aiding teachers in this process. These resources tended to make sources of ambiguity less acute and manageable, and ward off uncertainty associated with SPI. For teachers who experienced uncertainty or multiple forms of acute ambiguity, their implementation of SPI was much lower. In the next section, I return to Marcus and Joe who were introduced earlier in this section as contrasting cases of SPI implementation to instantiate the relationship between teachers' sensemaking and their implementation of SPI.

Marcus: Multiple Resources for Productive Sensemaking and SPI Implementation

Marcus's case represents conditions teachers' organizational sensemaking that lead to implementation of SPI practices. Although Marcus was new to Barton the first year of the study, he had several years teaching within the school district and 13 years teaching at an alternative hospital school program. During the first PD session on the *Framework,* Joan and Abby were already meeting with Marcus during the lunches and breaks to discuss what of the PD they would try to integrate into their shared instructional plans. Although Marcus expressed making instructional decisions autonomously, he also expressed appreciation for the collaborative culture at Barton:

> Sometimes just the other teachers, when you're planning, some teachers think, "Well we should all do the same thing the same way." [And, I think] "No, I don't really think you have to." You do it your way, I'll do it my way. That's what I do like [about working here]. It's not competitive. It's not like, "No, you can't—I made these materials up and I'm not sharing." There's a nice culture.

Among this 6th grade team, Marcus and his colleagues had generated an adapted pacing guide that addressed both the state standards and their instructional needs, developed a scientific explanation scaffold, created end of unit assessment measures, and developed a multitude of other handouts that supplemented the curriculum. Additionally, Abby on this team had developed an ecology unit (a unit the teachers did not have PBIS curriculum for) that addressed some of the goals of SPI. Further, Marcus felt "supported" by the school administration because they were not "micromanaging" his instruction, that they were "out of our [the grade level team's] hair."

Marcus described his instruction and views of teaching and learning as having changed since the start of the research project and trying SPI practices. The PBIS curriculum and PD activities that instantiated the "just in time" pedagogy were particularly helpful resources for Marcus.

> [Before] it was like, 'Oh yeah. You have to introduce the vocabulary. You have to give these kids some background information before the lab cuz otherwise the lab won't mean anything to them.'
>
> Now my psyche has reversed on that. I really do see that you have to give them the lab. That's the experience that they're getting. Then you can help them make the connections with the vocabulary and the facts and the information after. I think, isn't that a direct result of the Next Generation Science Standards? Something they're trying to do? (Marcus_FALL)

Marcus had an understanding of the ways SPI practices differed from his prior instruction. Additionally, he talked about engaging students in practices and placing the cognitive tasks of reasoning about phenomena on the students (e.g. encouraging them to work with their peers to figure out something that stumps them). Marcus characterized SPI as,

> Giving the kids hands-on experience, investigating, answering a question, collecting data, analyzing, doing the principles of things like problem solving, inquiry. *The content is almost secondary to the process*. (FALL)

Marcus's description here demonstrates a depth of understanding of SPI, but not a fully accurate one. That is, he describes multiple practices students are engaged in: "investigating, answering a question, collecting data, analyzing data, problem solving, inquiry" and successfully related these to other ideas about teaching he has encountered in the past. Namely, he identifies a distinction between process and content, and a sense of the value of focusing on the process of learning. However, the *Framework* focuses on the *blend* of content and process, which Marcus may be missing. Further, according to Marcus, the purpose of engaging in science practices is informed by an epistemology of learning that is organized around a problem or a question and using tools to answer that,

> [SPI is] the idea of *learning a way of viewing the world and thinking about a problem* and an answer and how to gather data, how to come to a conclusion. Just the whole thing about writing an explanation. …Yeah, *the process of learning*. (FALL)

In terms of ambiguity and uncertainty, there was very little for Marcus. He described some misalignment between the curricular topics and the state's sixth grade standards, and his desire for greater coherence (and school support/time for pursuing better grade-level coherence), but this ambiguity was minimal:

> What I'd like to have more integration…we never sit down with the seventh and eighth grade science teachers, which kind of—it really shocks me. I think that would be very helpful. Cuz I know [PBIS] overlaps with their curriculum. It would be very helpful for the students. For me to be able to say [to students], "By the way, next year you're gonna build on this. Or you're gonna see this again." Or just when we come across resources that we can't use, I should know who to pass

> that on to. I do know some of that but I'd love to sit down once a month with the seventh and eighth grade. …I'd like to use that time for talking about the curriculum and vertical planning. (FALL)

Aside from the expressed desire for greater coherence and vertical planning, integrating his understanding of SPI and the curriculum materials seemed to occur with very limited and manageable ambiguity.

Marcus benefited from working with a team of colleagues both familiar with the 6th grade teaching assignment and the policies and practices at Barton. His team together generated materials that supported their implementation of SPI and these efforts seemed to reduce Marcus's ambiguity around conflicting goals and limited time and material resources.

Joe: Too Much Ambiguity and Foreclosed Sensemaking

Joe's story highlights the relationship between sources of ambiguity or uncertainty and the role of teachers' histories, collegial support, and building leadership in serving as resources for teachers' sensemaking. We could argue that, during the time of the study, too much was "new' for Joe. He was in a new teaching assignment, having moved from teaching elementary schools for several years to teaching middle school science. Although Joe had teaching experience, he was – at the time of the study – trying to familiarize himself with the building-level expectations at his new school, the state standards for 6th grade science, and a different approach to instruction (through SPI) simultaneously. In his own words, "Everything was gonna be new, anyway. It was good timing for me to start a new [approach to teaching]." However, the degree of newness and lack of supportive sensemaking resources may have foreclosed Joe's sensemaking process.

During the second year of the study, Joe shared that he was "disheartened" to see that his students from last year did not "meet growth." This meant that his students from the previous year had not demonstrated that they had adequately learned the concepts for that year, as assessed by the state exams. This was frustrating and confusing for Joe and caused a great source of uncertainty about how to address the issue. Describing this situation, Joe shared,

> One thing that we saw this year, we were a little bit, I don't know, disheartened to see that our scores were—we didn't meet growth. That was a little bit of a frustration and kind of something that we're like, "Man, we gotta figure out how to make that not happen this year," cuz it was—I feel like it was partly cuz we ran out of time. We actually hit zero [of the] ecology [concepts]. That was a problem, but it's just somethin' that I think the principals look at, too, and they're like, "Hey, where can we fix this? Where can we add some things that it's not part of PBIS? Where can we kinda add some things to make it more enhanced with everything that they need to know?"

Joe's description here is largely around his uncertainty about the process of measuring growth. He is, understandably, shocked by the results and searching for ways to address the issue so that he and his students did not have a similar experience moving forward. Although Joe had expressed that he felt supported by his school administration, he clearly was feeling pressure from his principal to "fix" the issue of low test scores.

Part of what was driving Joe's confusion and frustration was a lack of awareness about what concepts needed to be covered in 6th grade. He had understandably assumed that state standards for 6th grade would be met through the implementation of the PBIS curriculum the study provided, given the district leaders' endorsement of the curriculum:

> One of the things that I was kinda frustrated with was, last year, I just focused on PBIS's pacing guide because we were told we needed to follow this with fidelity to see how the testing comes out**.** I did that, so that's what I kinda dedicated my year to learning. Then this year, after those scores came out, I said, "Shoot. I'm gonna look at our pacing guide for our district, what the students should know after nine weeks and so on." I noticed that with the Diving In [introductory] unit, there's actually no—there's no time [based on the standards we were supposed to cover] in our curriculum set aside for [those concepts] for students. To get to know what it means to be a good scientist [the focus of the unit]. There's no time for that in our pacing guide for the county. That's like four weeks of lost time, essentially, in terms of the standards. That was a little bit frightening for me.

Whereas other teachers in this study became attuned to the discrepancies between the curriculum materials provided through the study and the expectations of the state standards early on in Year 1, Joe did not, which resulted in significant consequences for him, his grade-level team, and the school. Although there were no immediate consequences, aside from the pressure to meet growth that second year, if the team was not able to demonstrate better growth moving forward, it could affect their tenure at the school.

Joe's lack of certainty about SPI and what it meant for his instruction can be evidenced in his description of what "felt new" (my words),

> Well, I'm trying to wonder and actually trying to remember if it was already covered [in PD], if like when the science standards are actually going to be a part of everyone's curriculum, or supposed to be, expected to be. Is that—I don't know.

Whereas all other teachers in this study were able to name some aspect of SPI that appeared new or different or compelling, it is evident that Joe is not sure what to make of SPI. With all the new messages in his different teaching assignment and school, the messages of the study and of SPI, sadly, became one more message to sift through in his already-cacophonous environment. Making determinations, then, about what of these messages aligned most with his beliefs about teaching and learning, what was best for his students, or what approach best addressed the local IGIs appeared too much for Joe. Instead these determinations were bypassed by a decision to focus on addressing one new aspect and one form of accountability: SPI and the study curriculum materials (see also the case of Marie in Allen & Penuel, 2015).

When considering what conditions of sensemaking may have made these acute forms of ambiguity and uncertainty more manageable, Joe felt he lacked the experience teaching in his current assignment that could have supported his sensemaking. He was new to teaching middle school, science, and teaching at his particular school. As he stated, "I guess I didn't know…where we were coming from [those at my school] or how it's different from the current [approach]." In terms of collegial support, Joe did work with a 6th grade science team, with two other teachers; however, after the death of their more senior science teacher, Joe became the grade-level lead. Unlike the grade level teams of Rich and Kate or teachers at Barton that had a depth of experience in science teaching, Joe's team was limited in teaching history and collegial support that lead to an understanding of SPI.

Limitations

In an effort to address patterns of reform implementation and teachers' needs within these processes, this study is limited in a few ways. First, this analysis included only a small number of teachers. QCA is ideal when examining outcome patterns of a small number of participants (n=8-150; Rihoux & Ragin, 2006; Ragin, 2009); however, the n for this study (8) is at the very low end of this range. These small numbers present a challenge for making causal claims regarding the conditions of sensemaking that led to SPI. For example, only two teachers had high implementation of SPI and one had a mid-high implementation score. I grappled with whether or not, given such a small number of participants, running QCA afforded any analytic leverage that a traditional comparative case methodology alone would not have garnered. In one sense, QCA did allow me to identify systematically what conditions were contributing to teacher implementation of SPI, a task that might have been difficult to conduct for eight teachers without QCA tools. However, there is reason to doubt that these results do in fact point to a causal relationship, given the small number of participants for which these conditions and outcome were the case. The act of calibrating membership about what conditions were present or not for a particular participant, calibrating participants' outcome membership, and noticing patterns across these categories was especially productive. However, running QCA with the number of conditions (9) and this number of participants (8) did not provide similarly rich or potentially valid results. I wondered if generating case displays of conditions and outcome would have resulted in similar findings. Running QCA with less conditions (no more than 5) and a greater number of participants would have garnered more substantiated results for this analysis.

Additionally, my conceptualization of SPI is one perspective of reform efforts in science education and do not encompass all aspects of reform or changes suggested by reform. Further, teachers in this study were in a state and district that had possible intent to adopt the NGSS but had not yet, so teachers were still held to their state standards, which caused ambiguity for them. For teachers adopting SPI practices in an NGSS state, these results may differ. And, lastly, the PBIS curriculum materials provided an integral resource for teachers' understanding of SPI, but these materials are limited in their alignment to the standards. Different materials may have garnered greater support and re-visioning of science instruction for these teachers.

Discussion/Conclusion

This paper aimed to understand the relationship between conditions of teachers' organizational sensemaking and their implementation of science-practice based instruction (SPI). These findings suggest that conditions of sensemaking that predict implementation of SPI included the presence of manageable ambiguity, limited or no uncertainty and resources of collegial support, knowledge of local practices and policies, curriculum materials, and supportive school administration. Collegial support, such as collaboration related to planning and the development of curricular resources, played the most integral role in minimizing sources of ambiguity and supporting teachers' sensemaking around these sources. For teachers in this study, the prominent sources of ambiguity emerged around how to create a sense of continuity for their students between SPI and more traditional forms of instruction or more compartmentalized treatments of science learning (e.g. content standards approaches) and around limited SPI curricular resources and time to develop these. Some teachers also experienced uncertainty regarding their role in implementing SPI within local system that did not fully support or cohere with the goals of the reform.

In an analysis of just two of the teachers in the broader study (Allen & Penuel, 2015), we found the role of shared goals across teachers and building leaders was key. Although building leadership, buy in was an important condition for SPI in that study, it did not emerge as a key finding in this analysis of this broader sample of teachers. All teachers in this study felt supported by their building administration and generally felt a sense of autonomy regarding instructional decisions. That said, each teacher also expressed being aware of ways that SPI did or did not align to teacher evaluation expectations from their principals and how to address those expectations in their teaching – such as the example of Kate and Rich above. Having both collegial support and familiarity with school leaders' expectations and the requirements of evaluation aided teachers in being able to do this accommodation work. Joe's case demonstrates a lack of these personal and social resources that resulted in concern from building leadership and prolonged uncertainty for Joe during the second year of the study.

Teachers' enactment of SPI generally included more reasoning moves and science-practice opportunities than it did student-positioning moves. This pattern was likely due to the embedded questioning and science-practice supports present in the curriculum materials provided to teachers. Positioning moves, although embedded some in the curriculum as well, relied more heavily on teachers' views of teaching and learning and their extemporaneous decision-making during enactment. In general, teachers' implementation of SPI was in the lower to mid-level range, with two teachers having high implementation.

In looking at both teachers' enactment patterns and the predictive conditions of SPI, we can draw some conclusions about teachers' needs for learning within reform contexts and implementing reform practices in science. First, collegial networks were integral to teachers' implementation of SPI. For all cases of SPI implementation, collegial networks were present. Additionally, SPI implementation was linked to teachers' opportunities to co-problem solve within these networks, particularly when these networks included colleagues with familiarity of the landscape of their grade-level science expectations within the school, district, and state (see also Woulfin, 2015). Second, teachers benefited from materials and time to develop and adapt materials that incorporated goals of SPI and attended to their local instructional guidance infrastructures and measures of accountability. Collegial networks, again, supported teachers in their efforts to use, adapt, and develop materials.

Additionally, this study highlights the work teachers engaged in to craft a kind of local coherence for themselves and their students. Despite the incoherence present locally for teachers, they were still able to address these conflicting messages by either tabling these issues for later or taking action to make bigger institutional changes at their schools (e.g. adopting SPI in 7th grade too). For some teachers, issues of incoherence did create prolonged uncertainty, a lower implementation of SPI. For all teachers, having greater coherence across the various aspects of the system would undoubtedly have created time and capacity for teachers to engage deeply with the content and pedagogy of SPI where they were previously detained.

Through taking an organizational lens to considering teachers' processes of coming to an understanding and making decisions about what of reform to implement, this work builds on the work of Coburn (2001, 2005) in reading reform and of Carlone and colleagues (2010) within in science. Specifically, such an approach brings attention to the multitude of messages and practices teachers are held accountable to and must answer in their daily practice. Such lenses remind us that teachers' engagement with reform happens within complex systems and that their processes of learning and implementing reform ideas cannot be divorced from these systems.

Within the science implementation literature specifically, this analysis demonstrates what of the current reform - the *Framework* and NGSS – is likely to be challenging for teachers to implement. Prior literature on science education reform implementation has pointed to teachers' content knowledge as an important, if not integral, component of effective implementation (e.g. Henze, van Driel, & Verloop, 2006; Shulman, 1987). These findings suggest that, even with professional development and curricular materials to support teachers' content knowledge and science teaching practice, what was ultimately paramount for teachers' implementation were personal and social resources that helped them navigate the IGIs (Hopkins & Spillane, 2015) of middle school science within their schools and district. This should importantly call our attention to teacher learning designs that include consideration of teachers' IGIs, particularly with regard to how supportive materials can be adapted productively for teachers' use in their education systems while still maintaining the goals of science education reform, such as the *Framework* and NGSS.

Future work on teacher implementation of reform in science education might consider if the same conditions of sensemaking supported teacher implementation of science-practice instruction across IGIs that vary significantly. For example, do collegial networks play the same or a similar role within a school that has an administration that is uncertain about the value of science-practice instruction in science? Or, how does teacher sensemaking look different within a district-wide adoption of NGSS within all grades, rather than just one? Further, future scholarship should examine how taking an organizational lens to teacher implementation of science education reform can inform our design of teacher learning and the materials that can bolster their efforts toward more practice-based instruction.

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Table 1
Participant characteristics

Teacher	School	Years teaching	Years in current assignment	Years teaching science	Degree level	Science background
Joe	Greenfield	7	2	2	Bachelor’s	AS Integrated sciences BA Secondary science
Abby	Barton	4	2	4	Master’s	BA Secondary science
Joan	Barton	10	6	10	Master’s	BS Biology MA Secondary science
Marcus	Barton	17	2	4	Master’s	None
Alexis	Barton	2	2	2	Bachelor’s	None
Alice	Columbus	6	2	6	Master’s	None
Richard	Robinson	42	10	20	Master’s	None
Kate	Robinson	3	3	2	Bachelor’s	BS Biology

Table 2
Teacher Fuzzy-set Outcome Measure

Teacher	Positioning Moves	Reasoning Moves	Science Practices	Outcome Score: SPI
Joe	0.33	0.33	0.33	0.33
Joan	0.33	0.33	0.33	0.33
Alexis	0.33	0.33	0.33	0.33
Alice	0.67	0.33	0.33	0.44
Abby	0.33	0.33	0.67	0.44
Kate	0.33	0.67	1	0.67
Richard	0.33	1	1	0.77
Marcus	1	1	1	1

Table 3
Sensemaking Conditions that Lead to SPI

Conditions					Cases	Consistency
Collegial Interactions	x	(Limited Ambiguity, No Uncertainty)			3	100
Collegial Interactions	x	(Limited Ambiguity, No Uncertainty)	x	(Curriculum Materials, Supportive Leadership, Teaching Histories)	3	92

Appendix A

Sources of ambiguity and uncertainty

Construct	Description	Data Source: Interviews
Conflicting Goals	Conflicts between district pacing demands and teaching science-practice focused lessons. District or school-level initiatives (e.g. curriculum or technology use) that interfere with instructional goals. Building evaluation guides – formal and informal – that conflict with goals. Messages from PD that teachers interpret as what they "already do."	**Spr INT (5)**a. When [school leaders] come in while you are engaged in teaching science practices - such as explanation or using models - what do you think they see? What might your principal or other building admin be missing that's important? b. How aligned are principals' "look fors" with your own goals for students? How do you manage it when those two things are different?
Absence of Measures	Absence of measures aligned with NGSS that teachers can use as assessments; Lack of coherence between measures teachers are held accountable for and those aligned with NGSS; Available assessments are perceived to be misaligned with what teachers should be teaching	**Fall INT (4).** The Next Generation Science Standards and the North Carolina Essential Standards are two different sets of standards. a. What would you say is similar about them? What's different? b. Are there any conflicts between the two?
Limited Resources	Expressed lack of time to engage with NGSS or adapt existing curricula to align with NGSS. Lack of available material or technological resources needed to engage students in science practices. Lack of assessment items (see Absence of Measures). PBIS or other curricular assessments are misaligned with NGSS.	***Spr INT (11)** The Framework talks about building on students' interests and experiences as a way to sustain students' attraction to science. How well did the PBIS materials connect to students' interests/everyday experiences?*
Role Ambivalence	Lack of clarity about how to support students' engagement in science practices, developing understanding of core ideas, or	**Spr INT (3)** Can you tell me about one activity you did that had students engage in one or multiple science practices?

	how to teach cross-cutting concepts	e. What do you think students learned from the activity? What indicated to you that they had learned this?

Appendix B

Resources for teacher sensemaking of reform

Construct	**Description**	**Data source: Interviews**
Professional development activities		
Active, content-specific learning	Activities that served as "models" for teachers. Artifacts from other teachers to support student learning. Opportunities to engage with science practices of modeling and explanation. Opportunities to engage with the science content associated with modeling and explanation activities.	**Spr INT (7)** What aspects of the professional development…were helpful for your planning and implementing activities that engage of students in science practices?
Sensegiving activities	Formal discussions or designed activities related to alignment of pacing, standards, curriculum, and lesson activities.	**Spr INT (6)** What resources did you use to support your planning and teaching of these activities or other science-practice activities?
Personal resources		
Teaching histories, views of teaching and learning	Descriptions of teaching practice/approach. Connections to current or prior teaching practice. Comments about what "kind of teacher" someone is in response to reform. Comments about how students learn best. Views of collegial teaching environment (e.g. safety, trust).	Questions related to teaching practice, views of own teaching, how teaching has changed (or not), and how reform is different or not from prior instruction. **Fall INT (4)** What feels different/similar about [state] standards and NGSS? 4c. Do you agree with PD presenters that the NGSS is "new"? **Spr INT (2)** I'm curious to hear if you feel your teaching has changed over the course of

		this study. Do you think it has? If so, how has it changed? If not, tell me more about that. **Spr INT (11)** How well do you think science-practice instruction connects to students' everyday lives? **Spr INT (12)** Now that this year and the study are coming to an end, what are your plans for instruction next year? Do you plan to continue integrating science practices into your instruction? **Spr INT (13)** Do you predict in three years you will be doing science-practice instruction?
Social resources		
Supportive informal collegial interactions	Availability of other colleagues participating in the study and/or teaching in similar ways. Informal opportunities to share artifacts of instruction. Informal discussions related to alignment of pacing, standards, curriculum, and lessons activities.	Comments about interactions with colleagues at their school. Comments about interactions with other teachers from other schools. **Fall INT (2)** Walk me through a typical day at your school… **Fall INT (3)** What sources do you consult when you decide what to teach? a. Do you consult other colleagues?
Connections to external learning opportunities	Involvement in NSTA or other professional development opportunities related to NGSS external to the research study.	Comments about involvement in NSTA or other exposure to NGSS outside of the study. **Fall INT (4)c.** Do you agree

		with PD presenters that the NGSS is "new"?
Instructional Guidance Infrastructure		
Curriculum materials	Available and required resources for instruction. These include district pacing guides, the PBIS text, and other district-emphasized texts.	**Spr INT (6)** What resources did you use to support your planning and teaching of these activities or other science-practice activities? **Spr INT (8)** If you had just received the PD and not the materials from PBIS, what difference would this have made for your instruction?
Practices that structure teacher lesson planning	Lesson plan structures, ELA or Common Core expectations for teachers' instruction. Other district initiatives about what "should" be present in teachers' lessons. Number of subjects to "prep" for.	**Fall INT (2)** Walk me through a typical day at your school… a. When and where do you plan instruction, typically? **Fall INT (3)** What sources do you consult when you decide what to teach?
Formal collegial interactions	Structured time to plan with colleagues.	**Fall INT (2)** Walk me through a typical day at your school… a. When and where do you plan instruction, typically? **Fall INT (3)** What sources do you consult when you decide what to teach? a. Do you consult other colleagues? c. Did you develop materials? Did you develop these with a curriculum team?
Supportive school leadership	Monitoring of teacher instruction. Messages about good science teaching practice. Relationship to school principal, assistant principal, or instructional facilitator.	**Fall INT (2)** Walk me through a typical day at your school… **Fall INT (5)** What do principals or other school leaders look for when they visit your classroom?

		Fall INT (6) Have these expectations ever affected what lessons you taught/how you taught them?

Appendix C

Case Summary Template

Name:
School:

SUMMARY:

VIEWS OF REFORM-BASED INSTRUCTION

I. *Engages students in science practices*

II. *Presses students to reason with the connections between science content, practices, crosscutting concepts and phenomena*

III. *Positions students as active participants in their learning*

SOURCES OF AMBIGUITY AND UNCERTAINTY
(For each, describe nature, number and variety)

I. *Conflicting goals*

II. *Absence of measures*

III. *Limited resources*

IV. *Role ambivalence*

RESOURCES FOR SENSEMAKING
I. *Professional development*

Active, content-specific learning

Sensegiving activities

II. *Personal resources*

Years teaching science

Views of teaching and learning (past and present)

III. *Social resources*

Collegial interactions

External learning opportunities

IV. *Instructional guidance infrastructure*

Curriculum materials

Practices that structure teacher lesson planning

Formal collegial interactions

Supportive school leadership

CONNECTIONS/CONTRADICTIONS WITH IMPLEMENTATION
(Describe set membership and make claims about sensemaking-implementation relationship)

Appendix D

Teacher Implementation
Membership Calibration

Outcome: Reform-based Instruction

Outcome: Reform-based Instruction	
Measure	**Anchor points**
Engaging in science practices	**0:** Teacher has an average of <2 on exp assignments, and <2 on modeling assignments. Science practice talk moves were <X percent of teacher codes.
	0.5: Teacher has an average of >2, <4 on assignments. Science practice talk moves were >X percent of teachers' codes.
	1: Teacher has an average of 4 or >4 on assignments. Science practice codes are >X percent of teachers' codes.
Pressing for reasoning	**0:** Questioning talk moves were <X percent of teacher codes.
	0.5: Questioning talk moves were >X percent of teachers' codes.
	1: Questioning talk moves are >X percent of teachers' codes.
Positioning students as active participants	**0:** Positioning talk moves were <X percent of teacher codes
	0.5: Positioning talk moves were >X percent of teachers' codes.
	1: Positioning talk moves were >X percent of teachers' codes.

Conditions: Resources for Sensemaking

Condition: Professional development sensemaking resources	
Measure	**Anchor points**
Active, content-specific learning	**0:** PD is not mentioned or is named as unhelpful; activities are seen as what teachers "already do"
	0.5: PD activities served some role in supporting teachers' implementation of RBI and their thinking about teaching, learning, science.
	1: PD activities are named as an important or integral resource for "seeing" how RBI is done and/or for planning instruction.
Sensegiving activities	**0:** Sensegiving activities are not mentioned or had a negative role
	0.5: Sensegiving activities are mentioned and had some or a neutral role
	1: Sensegiving activities are mentioned as being important or integral

Condition: Personal and social resources	
Measure	**Anchor points**
Teaching histories, views of teaching, and learning	**0:** Teacher's prior experiences inhibit engagement with RBI
	0.5: Teacher's prior experiences are minimal or less influential in their sensemaking process
	1: Teacher prior teacher in experiences serve as integral resources for seeing differences and similarities of RBI. Ideas of "what kind of teacher" they are assists teachers in mapping onto RBI teaching stance.
Supportive informal collegial interactions	**0:** Collegial teaching environment is viewed as hostile or at odds with RBI
	0.5: There are some collegial interactions but they are limited and may lead to surface level interpretations of the RBI
	1: Teacher has informal interactions with colleagues that support their ideas for how instruction can/will fit into current practices
Connections to external learning opportunities	**0:** Teachers' have no access to external learning opportunities.
	0.5: Teachers have limited access to external learning opportunities and/or ideas outside do not cohere with RBI
	1: Teacher has opportunities to engage in external learning opportunities that support ideas of RBI

Condition: Instructional Guidance Infrastructure	
Measure	**Anchor points**
Curriculum materials	**0:** Teacher does not view curriculum materials as supportive of RBI
	0.5: Teacher view some but not all materials as supportive of RBI
	1: Teacher views available curriculum materials as being coherent with and supportive of RBI
Practices that support teachers' lesson planning	**0:** Schooling practices are viewed as a hindrance to teachers' adoption of RBI
	0.5: Schooling practices are viewed as some times conflicting with RBI, but teacher has ways to address
	1: Teacher views schooling (or district) practices as being coherent with adopting RBI practices
Supportive school leadership	**0:** Teaching RBI is not supported by school leadership
	0.5: Teaching RBI is supported by some but not all school leaders; or some but not all of RBI is supported.
	1: Teacher feels supported by school leadership to try out RBI practices

Conditions: Sources of Ambiguity and Uncertainty

Condition: Sources of ambiguity or uncertainty	
Measure	**Anchor points**
Conflicting goals	**0:** Numerous conflicting goals are present for teacher
	0.5: Multiple conflicting goals are present but not experienced acutely and/or teacher has plan for (or has) addressing them
	1: Conflicting goals are minimal and teacher is aware of how to address
Absence of measures	**0:** Expressed ambiguity about how to assess or track student progress
	0.5: Expressed ambiguity about how to assess student progress, but has plan to address
	1: Measures do not cause ambiguity for teacher
Limited resources	**0:** Does not feel that there are adequate resources (including time) for supporting RBI
	0.5: Feels limited with only having two units of PBIS; feels like there isn't enough time to develop other lessons/units that align with RBI
	1: Has begun to develop RBI-focused lessons for other units/has available time to do this
Role ambivalence	**0:** Expresses uncertainty about what RBI means for their instruction
	0.5: Expresses some but not acute uncertainty about RBI instruction
	1: Has clear idea of RBI instruction means for them

Appendix E

CASE ASSIGNMENT

Conditions

Professional Development Resources

<table>
<tr><td colspan="4">Measure: Active, content specific learning in PD</td></tr>
<tr><td>Case</td><td>Measure value</td><td>Fuzzy set value definitions</td><td>Assigned fuzzy-set value</td></tr>
<tr><td>Abby</td><td>Benefited from modified curriculum materials, interactions with colleagues</td><td rowspan="8">1: PD activities are named as an important or integral resource for "seeing" how SPI is done and/or for planning instruction.
0.67: PD activities served some role in supporting teachers' implementation of SPI and their thinking about teaching, learning, science.
0.33: PD is mentioned but obtusely. PD has not made a big impact on teacher instruction. Teacher is unsure yet of how to use PD but wants to.
0: PD is not mentioned or is named as unhelpful; activities are seen as what teachers already do</td><td>0.67</td></tr>
<tr><td>Joan</td><td>PD has not impacted her to the point of thinking, I'll incorporate NGSS</td><td>0.33</td></tr>
<tr><td>Alice</td><td>Mentioned obtusely</td><td>0.33</td></tr>
<tr><td>Richard</td><td>PD has not made a big impact on teacher instruction</td><td>0.33</td></tr>
<tr><td>Kate</td><td>Mentioned that she agreed with what was said</td><td>0.33</td></tr>
<tr><td>Marcus</td><td>PD activity played some role in supporting implementation</td><td>0.67</td></tr>
<tr><td>Joe</td><td>Not mentioned</td><td>0</td></tr>
<tr><td>Alexis</td><td>PD served some role</td><td>0.33</td></tr>
</table>

Personal and social resources

<table>
<tr><td colspan="4">Measure: Teaching histories, views of teaching, and learning</td></tr>
<tr><td>Case</td><td>Measure value</td><td>Fuzzy set value definitions</td><td>Assigned fuzzy-set value</td></tr>
<tr><td>Abby</td><td>Teacher prior experiences serve as integral resources for seeing differences and similarities of SPI.</td><td rowspan="2">1: Teacher prior experiences serve as integral resources for seeing differences and similarities of SPI. Ideas of "what kind of teacher" they are assists teachers in mapping onto SPI teaching stance.
0.67: Draw on histories and views of teaching/learning</td><td>1</td></tr>
<tr><td>Joan</td><td>Sees much of SPI as what she is already doing; able to engage with similarities or differences, but not to a large degree</td><td>0.67</td></tr>
</table>

Alice	Reflective of history and how different/similar	results in a some understanding of similarities/differences **0.33:** Teacher's prior experiences are minimal or less influential in their sensemaking process. Teachers see surface level connections to SPI – what they are already doing. **0:** Teacher's prior experiences inhibit engagement with SPI or teacher lacks experiences that are supportive	1
Richard	Prior experiences are integral; supports seeing differences/similarities		1
Kate	Less history to drawn on, less salient; sees differences from year 1 teaching		0.67
Marcus	Prior experiences are integral; supports seeing differences/similarities		1
Joe	Lack of history was source of role ambivalence. Unclear how teaching maps onto SPI.		0
Alexis	Minimal experiences but some present that are influential		0.33
Measure: Supportive informal collegial interactions			
Case	Measure value	Fuzzy set value definitions	Assigned fuzzy-set value
Abby	Regular supportive interactions	**1:** Teacher has regular informal interactions with colleagues that support their ideas for how instruction can/will fit into current practices **0.67:** Teacher has irregular informal interactions with colleagues that are supportive, or T does not draw on interactions **0.33:** There are some collegial interactions but they are limited and may lead to surface level interpretations of the SPI **0:** Collegial teaching environment is viewed as hostile or at odds with SPI	1
Joan	Provides support but does not receive very often		0.67
Alice	Some but limited		0.67
Richard	Regular supportive interactions		1
Kate	Regular supportive interactions		1
Marcus	Regular supportive interactions		1
Joe	Limited and at times support surface level interpretations		0.33
Alexis	Regular supportive interactions		1
Measure: Connections to external learning opportunities			
Case	Measure value	Fuzzy set value definitions	Assigned fuzzy-set value
Abby	National boards	**1:** Teacher has opportunities to	1

Joan	Numerous opportunities that support SPI (Attends NSTA)	engage in external learning opportunities that support ideas of SPI **0.67:** Teachers have opportunities but they only somewhat support ideas of SPI **0.33:** Teachers have limited access to external learning opportunities and/or ideas outside do not cohere with SPI **0:** Teachers' have no access to or does not mention external learning opportunities.	1
Alice	Opportunities that support RBI		1
Richard	Does not mention		0
Kate	Does not mention		0
Marcus	Does not mention		0
Joe	Participates in science Olympiad but interprets as overkill. Does not appear to be a resource.		0.33
Alexis	In master's program that is ambivalent re SPI		0.33

Instructional Guidance Infrastructure

Measure: Curriculum materials			
Case	Measure value	Fuzzy set value definitions	Assigned fuzzy-set value
Abby	Key resource	**1:** Curriculum materials serve as a key resource for teacher "seeing" SPI, supporting SP views of teaching/learning **0.67:** Curriculum materials are a key resource but inadequate in some way in supporting SPI **0.33:** Curriculum can at times be a resource, but often does not offer adequate support **0:** Teacher does not mention the curriculum or does not see it as a helpful resource	1
Joan	Mostly a resource		0.67
Alice	Curriculum provided key resource in seeing differences between past instruction and SPI; inadequate in some ways		0.67
Richard	Key source but inadequate in some ways		0.67
Kate	Key source but inadequate in some ways		0.67
Marcus	Curriculum materials did not cause ambiguity		1
Joe	Support but cause of ambiguity and often didn't offer enough support		0.33
Alexis	Key resource		1
Measure: School leadership values SPI			
Case	Measure value	Fuzzy set value definitions	Assigned fuzzy-set value
Abby	School leadership values SPI	**1:** School leadership values SPI and supports teachers' implementation	1
Joan	Feels complete		1

	autonomy; school leadership values SPI	**0.67:** Most but not all leaders value/support SPI. Leadership is ambivalent toward SPI. **0.33:** Teaching SPI is supported by some but not all school leaders; or some but not all of SPI is understood. **0:** Teaching SPI is not supported by school leadership	
Alice	Feels complete support		1
Richard	Most but not all leaders value SPI		0.67
Kate	Most but not all leaders value SPI		0.67
Marcus	School leadership values SPI		1
Joe	Leadership seems ambivalent		0.67
Alexis	School leadership values SPI; more scrutiny as a new teacher		0.67

Sources of Ambiguity and Uncertainty

Measure: Conflicting goals			
Case	Measure value	Fuzzy set value definitions	Assigned fuzzy-set value
Abby	Conflicting goals cause minimal and manageable ambiguity	**1:** Numerous conflicting goals are present for teacher; unsure of how to address **0.67:** Multiple conflicting goals cause acute ambiguity. Teacher has some ideas of how to address. **0.33:** Conflicting goals cause minimal and manageable ambiguity **0:** No conflicting goals present	0.33
Joan	Conflicting goals are acute but manageable		0.33
Alice	Conflicting goals cause minimal and manageable ambiguity		0.33
Richard	Conflicting goals are manageable		0.33
Kate	Conflicting goals are manageable		0.33
Marcus	Conflicting goals cause minimal and manageable ambiguity		0.33
Joe	Conflicting goals that severely impeded engagement with SPI		1
Alexis	Conflicting goals experience more acutely, managed		0.67
Measure: Limited resources			
Case	Measure value	Fuzzy set value definitions	Assigned fuzzy-set value

Abby	Feels limited but has made time; generated some additional resources	**1:** Does not feel that there are adequate resources (including time) for supporting SPI; does not state limited resources as a source of ambiguity **0.67:** Feels limited, like there isn't enough time to develop other lessons/units that align with RBI and address standards **0.33:** Feels limited with PBIS units, but has been able to modify lessons **0:** Does not experience limited resources of time or other materials	0.33
Joan	Expresses strong, unresolved frustration regarding non-PBIS resources; has not yet developed others		0.67
Alice	Has begun to develop other lessons; limited resources do not emerge		0.33
Richard	Has begun to develop RBI-focused lessons for other units; created time on the weekends and early mornings to address limited time		0.33
Kate	Feels limited but has generated some other resources		0.33
Marcus	Feels limited but has generated some other resources		0.33
Joe	Feels limited – no other time		1
Alexis	Feels limited outside PBIS, but does not experience this acutely		0.33
Measure: Role ambivalence			
Case	Measure value	Fuzzy set value definitions	Assigned fuzzy-set value
Abby	Does not express	**1:** Expresses numerous sources of uncertainty and feeling "stuck" or prolonged uncertainty **0.67:** Expresses acute uncertainty about role of SPI for them **0.33:** Experienced manageable role ambivalence regarding what RBI instruction means for them; from one source **0:** Does not experience uncertainty	0
Joan	Some acute uncertainty around addressing coherence		0.67
Alice	Some uncertainty before external learning		0.33
Richard	Does not express		0
Kate	Does not express		0
Marcus	Does not express		0
Joe	Acute prolonged uncertainty regarding SPI role, from numerous sources		1

Alexis	Some uncertainty		0.33

OUTCOME

Implementation of RBI

Measure: Engaging students in science practices			
Case	Measure value	Fuzzy set value definitions	Assigned fuzzy-set value
Abby	Students developed models or watched demo; Explanations used PBIS scaffold (CER)	**1:** Teacher assignments ask students to develop and use models, and prompt for scientific explanations that include claim, evidence, and reasoning. **0.67:** Teacher assignments ask students to develop but not use models, and prompt for scientific explanations that include claim and evidence or claim and reasoning only. **0.33:** Teacher assignments incorporate models but as a representation only; explanations only prompt for claims or evidence or reasoning. **0:** Teachers do not incorporate model activities or can't tell; explanation activities are not present or can't tell.	0.67
Joan	Models were often demos; used CER but not frequently		0.33
Alice	Models were often demos; did not incorporate explanations into assignments		0.33
Richard	Developed and used models; used CER		1
Kate	Developed and used models; used CER		1
Marcus	Developed and used models; used CER		1
Joe	Models were often demos; did not incorporate explanations into assignments		0.33
Alexis	Students developed models or watched demo; Explanations used PBIS scaffold (CER)		0.67
Measure: Pressing students to reason			
Case	Measure value	Fuzzy set value definitions	Assigned fuzzy-set value
Abby	Questioning patterns were irregular in pushing students to reason	**1:** Teachers' instruction is characterized by a high percentage of questioning patterns that push students to reason about phenomena and make connections across phenomena.	0.33
Joan	Questioning patterns are limited and irregular in pushing students to reason		0.33
Alice	Questioning patterns are		0.33

	limited and irregular in pushing students to reason	**0.67:** Teacher instruction is characterized by a somewhat regular percentage of questioning patterns that push students to reason and make connections. **0.33:** Teachers' questioning patterns are limited and irregular in pushing students to reason **0:** Teacher displays very little to no questioning patterns that push students to reason and make connections	
Richard	High percentage of questioning patterns that push students to reason		1
Kate	Somewhat regular questioning that pushed students to reason		0.67
Marcus	High percentage of questioning patterns that push students to reason		1
Joe	Questioning patterns are limited and irregular in pushing students to reason		0.33
Alexis	Questioning patterns are limited and irregular in pushing students to reason		0.33
Measure: Positioning students as active participants			
Case	Measure value	Fuzzy set value definitions	Assigned fuzzy-set value
Abby	Teacher employs effective student positioning moves but slightly less regularly.	**1:** Teacher regularly positions students as having meaningful contributions, invites multiple voices to speak and discuss a topic or question, places students in conversation with one another, and invites and takes up student connections to everyday lives. **0.67:** Teacher employs effective student positioning moves but slightly less regularly. **0.33:** Teacher at times employs student-positioning moves, but not regularly. Teacher often holds the stance of sole intellectual authority in the class. **0:** Teacher may employ some of these moves but generally holds the stance of sole intellectual authority in the class.	0.67
Joan	Teacher at times employs student-positioning moves, but not regularly. Teacher often holds the stance of sole intellectual authority in the class.		0.33
Alice	Teacher employs effective student positioning moves but slightly less regularly.		0.67
Richard	Teacher at times employs student-positioning moves, but not regularly. Teacher often holds the stance of sole intellectual authority in the class.		0.33
Kate	Teacher at times employs student-positioning moves, but not regularly. Teacher often holds the stance of sole intellectual authority in the class.		0.33
Marcus	Teacher regularly		1

	positions students as having meaningful contributions, invites multiple voices to speak and discuss a topic or question, places students in conversation with one another, and invites and takes up student connections to everyday lives.		
Joe	Teacher at times employs student-positioning moves, but not regularly. Teacher often holds the stance of sole intellectual authority in the class.		0.33
Alexis	Teacher may employ some of these moves but generally holds the stance of sole intellectual authority in the class		0

CONCLUSION

The three articles in this dissertation addressed the complex work of STEM education reform in practice, including the work of teachers as they learn about and implement ideas of reform in their classrooms, and the work of students as they navigate academic landscapes and try to position themselves positively with regard to STEM learning and future careers. In this chapter, I summarize the key findings for each paper and outline implications for future research and practice that these papers suggest when considered as set.

The first article (Chapter 2), "Studying Teachers' Sensemaking to Investigate Teachers' Responses to Professional Development Focused on New Standards," I utilized the concept of organizational sensemaking to examine teachers' responses to PD on the on the *Framework* and Next Generation Science Standards. In this analysis, each of the three teachers shared a belief in the value of science practice and knowledge-in-use instruction; however, their school-specific instructional management practices played a crucial role in shaping their sensemaking. Additionally, the teachers in this analysis benefited from having colleagues to engage in sensemaking and develop materials that supported their implementation of ideas from PD. This study revealed the importance of perceived systemic coherence, such as shared goals of reform between teachers and school administrators and aligned curricular materials (including texts and pacing guides) in supporting teachers' understanding of the *Framework* and science standards. Additionally, this study suggested the need for professional development activities that design for teachers' sustained engagement around sources of ambiguity and uncertainty.

In the second article (Chapter 3), "Fighting for Desired Versions of a Future Self," I analyzed the ways that the national narrative of increasing opportunities for and broadening participation of young women of color in STEM was taken up locally at two schools within the same district. I focused on how four young women (2 at each school) negotiated and maintained STEM-related identities in response to and in contrast with local discourses and practices that positioned them negatively. A key finding from this study was the prevalence of a local race-disparity discourse at the schools, but an absence of talk about gender or the intersection of gender and race as important issues within STEM education. In these local contexts, improving education in STEM meant "decreasing the gap" between White and Black students or "providing opportunities" for Latino/a students to pursue college. The young women, although challenging the national narrative about young women of color in STEM through their continued interest in and pursuit of these fields, were seemingly unaware of these broader narratives and instead focused on positioning themselves as good and capable students in STEM within their local environments. These findings point to the disconnect that can exist between national policy calls and what gets emphasized locally. Further, these findings may suggest a need for an explicit naming of the "double bind" of race and gender barriers that young women of color experience as they pursue STEM fields and for special support to prepare female youth for the kinds of challenges they may face in STEM-related college programs or workplaces.

In my final article (Chapter 4), "Conditions of Teachers' Organizational Sensemaking and Implementation of Reform in Science Education" I examined the conditions of teachers' organizational sensemaking as it relates to their implementation of science-practice based instruction. For this analysis, I drew on a broader corpus of teacher interview data, in combination with classroom video and analyses of teacher-developed assignments to conduct qualitative comparative analysis (QCA) to understand implementation patterns of 8 teachers across 5 schools within the same district. This study revealed that teachers who had collegial support tended to implement more reform practices, as their colleagues helped them to navigate conflicting instructional guidance from school and district leaders and policies. The two analyses of teachers' sensemaking point to the importance of attending to multiple potential pathways for teacher change and implementation of the *Framework* and NGSS's call for more integration of science and engineering practices into instruction.

Key Findings

Taken together, the three articles in this set suggest some key findings that support our thinking about the learning and implementation of efforts to improve equitable teaching and learning opportunities within STEM education.

Key finding 1: Attending to local history, needs of learners, and infrastructures are important conditions for the success of STEM education reform efforts.

Key findings from these papers suggest the importance of attending to the local needs, instructional guidance infrastructures, and accountability measures of reform efforts. Attending to the local history of tracking and the needs of the students of color, for example, may have better addressed underrepresentation at Capital in Chapter 3. Here we saw how the school's history of academic tracking seemed to firmly establish that advanced courses were for White students, and that, even when tracking practices were removed and students of color were well-represented (relative to their percentage in the school), Black students still viewed advanced course-taking as a White activity (see also Fordham, 1996). Simply “encouraging” Black students to take advanced courses, then, was not likely to be effective in making large gains toward increasing participation of students of color in STEM or supporting their interests in these fields. A reform effort that instead considered the school’s local history and the needs of its particular students in this context might have developed advanced courses and/or programs specifically tailored for students of color. I saw this modeled to some degree in Southside’s approach to designing programs and instituting practices geared toward increasing advanced course-taking and college attendance of its students. The school administration intentionally placed students into courses that would challenge them academically, and they carefully created college-preparation programs that involved the students and parents at that school.

Teachers’ efforts to implement goals of STEM education reform cannot be divorced from their local instructional guidance infrastructures; therefore, supportive IGIs can bolster teachers’ efforts. In the Chapter 2, we saw the different challenges that emerged for Marie as she tried implementing science reform practices at a school under strict accountability mandates. Marie’s instruction was so tightly monitored and she faced such acute conflict with her administration, that she gained limited understanding of the purpose and goals of reform, despite her efforts to implement them. Although Chapter 4 demonstrates that all teachers’ implementation of reform benefits from school administrator support, schools like Marie’s in particular need aligned goals and shared understandings of reform between teachers and school administration. This suggests that teachers and administrators would benefit from time to engage with ideas of reform together and to develop measures of teacher effectiveness that reflect reform goals and these shared understandings.

Further, materials that support teachers' instructional reform while addressing the local accountability measures (such as state standards) was a key finding of this analysis. Due to the lack of coherence between teachers' current materials, teachers' pacing guides, and their state standards, teachers in Chapters 2 and 4, developed new in order to satisfy these different instructional guides. Some teachers, however, lacked the time or collegial support to do this. For example, Joe in Chapter 4 discovered too late that the PBIS curriculum only partly aligned with the state standards and pacing goals of the district. This experience was jarring and confusing for him. Developing professional development and materials to help link external reform visions to local standards and pacing guides for teachers would likely facilitate more productive sensemaking.

Key finding 2: Collegial networks were an integral component of STEM education reform implementation.

A key finding that emerged in Chapter 4 was the role of collegial networks in supporting teachers' implementation of reform instructional practices. The importance of collegial support was also evident in the analysis presented in Chapter 2, as evidenced by the collective sensemaking Abby and Joan were able to engage in, but that Marie lacked. For teachers' instruction, collegial support was not just something the two teachers appreciated, it was the key condition that led to instruction most aligned with the goals of reform in the analysis presented in Chapter 4. Colleagues served as resources for materials development and co-problem solving around conflicts between reformed instructional approaches and existing instructional guidance infrastructures. Further, teachers in Chapter 4 expressed a desire to broaden these networks to vertical grade-level collaboration.

In Chapter 3, the networked efforts of Southside appeared beneficial in ways that were not present within Capital. At Southside, there was a clear school-wide agenda to increase students' college readiness and college attendance. As part of this effort, Southside had also adopted many of the principles associated with effective STEM schools (Peters-Burton et al., 2014) – greater coherence across math courses, additional teacher professional development, and more advanced course offerings – which seemed to be driven by a unified effort on the part of teachers, school leaders, counselors, parents, and the students themselves.

Key finding 3: Schools and teachers may struggle to identify ways their discourse and action unwittingly may be contributing to reproducing inequalities within STEM education.

Within the high schools of Chapter 3, teachers and school leaders seemed both aware of equity issues within education – their focus was on achievement and college-access gaps – but unaware of the ways they were complicit in practices that further marginalized and negatively positioned students of color. This suggests that school staff may have benefited from first need awareness and critical-conscious raising about issues of inequity that exist within school systems and to "take stock" of their local disparities and the schooling practices that may be contributing.

Further, in Chapter 4, teachers had lowest SPI implementation of the *student positioning* variable. Teachers shared, however, that the PBIS curriculum materials made them aware of the kinds of questions they could ask to push students to reason about science phenomena or to encourage student collaboration with their peers. So, although teachers' student positioning practices were on the low end, having the curriculum was providing fodder for their shift toward more equitable instructional moves. This suggests that teachers could benefit from other materials or professional development that supports them in developing repertoires of talk moves that bolster broadened participation of underrepresented students in science classroom discussions.

Key finding 4: What is emphasized locally may not reflect larger policy calls in STEM education reform.

Finally, the findings from Chapter 3 elucidate a divide between national policy calls for broadening participation in STEM and what was emphasized locally. In Chapter 3, neither high school was addressing issues of gender or the intersection of race and gender as an important issue within STEM education, despite the clear focus on the "double bind" (Malcom et al., 1976; Ong et al., 2010) emphasized in policy documents (AIG, 2012; NSF, 2008). The focus within these high schools, instead, was on race and socioeconomic disparities.

This finding is consistent with earlier findings about the role that local sensemaking plays in re-defining policy aims. That is, the perceptions teachers and school leaders have of reform and the ways reform fits into their existing structures is what shapes reform enactment (Coburn, 2001; Spillane, 2004). Understanding the process through which these interpretations are developed informs us about how to better support efforts of reform (Coburn, 2001 2005). My utilization of Qualitative Comparative Analysis to understand the conditions of reform engagement and teachers' implementation joins a growing body of literature (e.g. Coburn, Russell, Kaufman, &

Stein, 2012; Trujillo & Woulfin, 2015; Woulfin, 2015) that aims to elucidate these processes in local practice and inform our design of reform programs.

Conceptual Considerations

For this paper set, I utilized concepts from organizational theory and from social practice theory to understand the ways that STEM education reform was being understood and taken up locally. These theoretical and conceptual lenses were particularly helpful in unearthing the social and organizational practices that shape individual experiences and beliefs about STEM, learning, teaching, and who they are within these contexts.

Holland and Lave's (2001 2009) concept of history-in-person afforded a productive lens for identifying the ways historical narratives about students of color in academic STEM influenced schooling practices and students' authoring of academic and STEM-related selves. Historically-embedded stereotypes about African American students' lack of academic ambition manifested in actual or perceived underrepresentation of students of color in advanced courses and in a discourse about the ever-present "achievement gap." Additionally, historically-embedded narratives of poor Mexican-American youth cast Latino/a students as crippled by social disadvantage and possessing limited agency. Further, this lens highlighted the intimate ways that, for students, academic performance is entangled with STEM identities. Being a person who is good at a STEM discipline and someone capable of pursuing STEM as a career, required addressing the negatively-positioning academic narratives about these students first. And schools primarily emphasized improving *all* educational opportunities for students of color, with STEM being just one small aspect of this. That is, opportunities for STEM careers would organically open if other academic disparities (grades and low test scores) were attended to.

Utilizing a lens of organizational sensemaking (Weick, 1995) recasts teachers' learning and implementation of reform as a process heavily influenced by schooling practices and their reputation and responsibilities within their schools. It provided helpful tools for understanding the process through which teachers' came to interpretations of reform ideas and the ways these interpretations were present in teachers' implementation of reform. Having some ambiguity around conflicting goals, for example, was productive in that it drove teachers to engage with ideas of reform and consider how (or not) these ideas fit into their existing school practices. However, having too much ambiguity created the opposite effect, in which teachers focused narrowly on one aspect of reform or did not engage with reform at all. Additionally, teachers' sensemaking processes – what forms of ambiguity or uncertainty they experience, what resources were utilized during sensemaking, and to what degree teachers had time and opportunity to engage in sensemaking – looked different depending on the teacher and the organizational context (see also Penuel et al., 2009; Coburn, 2001), but the conditions of these processes that supported implementation of reform point to some avenues for supporting teachers in their STEM education reform efforts: collegial support networks, materials that cohere with their existing local infrastructures, and administrator understanding and support of the goals of reform.

Concluding Remarks

This dissertation looked across two distinct research contexts to examine the ways that efforts to improve equitable teaching and learning opportunities in STEM education were understood and implemented locally. These articles have demonstrated both the complicated work of reform and some of the intended and unintended outcomes that reform efforts in STEM education can garner. Specifically, I examined the work of teachers as they engaged with, made sense of, and implemented reform ideas and practices in their classrooms and schools; and I examined the identity work of four young women of color as they pursued STEM interests and careers within high schools aiming to improve educational experiences for underrepresented students. Through this collective set, I have argued that lasting STEM education reform efforts require attention to the local practices present within schools and the particular needs of the student population these institutions serve.

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