Disciplinary Literacies in STEM Integration: An Interpretive Study of Discourses within Classroom Communities of Practice

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Abstract

Recent attention to disciplinary literacy and the STEM education movement have opened doors to new visions of disciplinary learning at the high school level. As a result, there is a growing need to better understand what disciplinary integration looks like in the classroom communities of high schools, specifically, how teachers and students integrate the disciplines of STEM in their classroom practices (Wang, 2011; Williams, 2011), and the literacies that are created and practiced within new integrated contexts (Lankshear & Knobel, 2006; Unsworth, 2008). A specific focus on literacy in science classrooms makes evident the importance of spoken and written discourse in the development and use of scientific knowledge, practices, and academic language (Brown, Reyeles, & Kelly, 2005; Brown, Ryoo, & Rodrigues, 2010; Lemke, 1990; Yore, 2000). Although there are a number of studies that have explored science literacy (e.g., Wallace, 2004) and STEM literacy (e.g., Zollman, 2012), none of these studies have applied a sociocultural definition of literacy as social practice (Barton, 1991; Scribner & Cole, 1981). This study responds to these gaps in the literature by offering an analysis of classroom discourse and the broader social and discursive practices that surround it through application of social theories of learning and literacy, and critical theories of classroom discourse.

This dissertation is a presentation of results from two research studies of STEM integration discourses by breaking down the research aims into three separate manuscripts. The first essay presents the results from a yearlong investigation into two high school science teachers' efforts at STEM integration in their 9th grade physical science classrooms, in terms of the ways teachers and students positioned, negotiated, co-

constructed, and disrupted disciplines within their discourse practices. Through the use of a contrasting case design (Yin, 2009), classroom observations including video and audio recordings, semi-structured interviews with teachers, and student focus groups were collected from each classroom. Findings highlight the situated nature of disciplinary integration, including the enacted social identities and lived experiences of students and teachers, the disciplinary knowledge and expertise of teachers, and the uses of multimodal pedagogies that included explicit language instruction as a means to model disciplinary discourse.

The second manuscript presents a cross-case analysis of the two cases presented in chapter two, as a means to develop a grounded theory of a process of disciplinary integration. This investigation also presents the results of a critical discourse analysis (Fairclough, 1992) of texts selected using theoretical sampling (Corbin & Strauss, 2008; Charmaz, 2014) from the broader corpus of data (Fairclough, 1992). The findings offer a process of disciplinary integration including the re-presenting, modeling and apprenticing, disrupting, and learning of disciplines through classroom discourses and discursive practices. The presented process offers the fields of disciplinary literacy and STEM education a theory of what it means to integrate disciplines that is grounded in actual classroom discourse practices.

The final manuscript presents a single, embedded case (Yin, 2009) of one novice instructional coach, Madison, and her work with middle school science teachers in STEM integration efforts. The goal of this investigation was to explore the initial and evolving coaching knowledge, beliefs, and identities of a new instructional coach in order to

contribute to what is known about how coaches develop. Through the use of constant-comparative analysis methods (Corbin & Strauss, 2008) of audio recordings of coaching conversations, written reflection logs, and semi-structured interviews, a full case of Madison's coaching development is presented. Findings from the analyses indicate the importance of a new coach's development of a process of coaching reasoning and action, similar to Shulman's (1987) model of pedagogical content knowledge. Also, the well-established teaching and learning identities that Madison brought into her coaching work as found to play a dominant role in the establishment of coaching roles, positional authority, and content focus for the conversations. Cross-disciplinary coaching experiences such as this one will be essential to the successful integration of the STEM disciplines in K-12 STEM education reform efforts

Implications from this dissertation study reaffirmed the need for teachers to model and explicitly teach the language and discourses of the discipline, however because the practices of disciplinary integration resulted in borrowing across disciplines and undefined disciplinary communities of practice, it will be important for teachers to also draw on multiple discourses to teach disciplinary content (Lemke, 1990). These findings also add to the literature that has found the use of specific language instruction in science supports traditionally marginalized youth in learning and succeeding in science subject areas (Ciechanowski, 2009; Henrichs & Leseman, 2014; Lee & Fradd, 1998; Villanueva & Hand, 2011), however the students' uses of familiar social discourses and home languages were essential to their engagement with the science and engineering practices.

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Chapter 1:

General Introduction

Personal Experience

This study draws on my own professional experiences as a high school English teacher and literacy instructional coach to teachers in my building and district as well as current research in literacy and teacher education. As background, when I worked as a high school English teacher, I felt it was my job not only to teach the classics of literature, but also how to read and enjoy them. I modeled good reading practices and taught cognitive reading strategies to students at all grade levels, and many of my students found success. However, I was surprised to learn that most of their teachers did not explicitly teach students how to read their texts, instead assigning large sections of reading each night and expecting students to learn important information on their own. I felt this was a problem, and wondered why it was that science, math, health, music, and social studies teachers felt it was the English teachers' responsibility to teach students how to read their texts when we were unfamiliar with the texts, and ourselves disciplinary outsiders.

In 2007, I moved into several leadership positions in my school and district to work with other teachers, administrators, and community members to plan, develop, and implement a variety of instructional improvement goals, though adolescent literacy remained my passion. In 2009, I accepted a part-time position as an instructional coach, and one year later, I took on coaching full time. As I was learning to coach, I also enrolled in the reading licensure program at the University of Minnesota. As I participated in coursework in the U of MN's program I learned that the lack of literacy instruction in my building could be understood within a broader historical tradition of disciplinary instruction at the high school and college levels. My learning in the reading licensure program opened my mind to better understand high schools, academic content area teachers, and the traditions of literacy leadership that have worked to improve the literacy practices of adolescents in schools for decades. I now see my research and teaching efforts in higher education as situated within this historical community of practice, and this gives me confidence that I am not alone in imagining better high school literacy experiences for all students.

This study also has been re-conceptualized throughout my graduate degree program, informed by the conversations, courses, and coaching experiences I have had at the STEM education center over the past few years. Through my learning of STEM integration I have developed a stronger understanding of what a discipline is, why it historically has been defined the way it has, and the impact disciplinary boundaries have on education and society. I now see possibilities for education and literacy instruction that exist beyond disciplines, or are what Halliday (2003) called "transdisciplinary," and possibilities that are fully integrated into new, applied disciplines like Bybee's (2013) vision for STEM education.

Also important to the way this study was conceptualized was my learning through the first year of EngrTEAMS , the NSF-funded grant project at the University of

Minnesota's STEM Center, of which this study is a part. As teachers and instructional coaches engaged in the process of creating and implementing integrated STEM curriculum units in the first year of this project, it became apparent that pre-existing content expertise based on participant teachers' and instructional coaches' disciplinary knowledge and histories within the particular and restricted communities of their discipline, were being challenged by assumptions of collaboration and common practice within the discourse of discipline integration. As new communities of teachers, instructional coaches, and researchers were established, sustained, or disbanded according to the utility of their purposes, questions arose about how individuals learned to participate in particular communities, the role of disciplinary knowledge and discourses within those communities, and the ways members of the communities were negotiating disciplinary integration. I use the term "negotiating" because it became apparent that the disciplinary expertise an individual had played an integral role in the holding and maintaining of power and agency within the community.

Furthermore, the experiences we had integrating disciplines into a STEM curriculum unit challenged the recent conceptions of disciplinary literacy as discipline specific norms of practice for producing and communicating knowledge (Moje, 2008), deeply held assumptions and themes within the discipline (Lemke, 1990), and the argument that students should learn to "think like a scientist" and other professional enactments of disciplinary identities (Shanahan & Shanahan, 2008). A tension emerged for me between the call to model discipline-specific thinking (e.g., Moje, 2008; Shanahan & Shanahan, 2008) with the desire to disrupt the traditional boundaries between disciplines by seeking out *disciplinary commonality*. Thus, this study was born out of reflection on the first year of EngrTEAMS , and the merging of my interests in disciplinary literacy, disciplinary integration, and leadership for instructional improvement.

Rationale

National attention on the literacy practices in high school subject area classes continues to grow through reform efforts like the Common Core State Standards (CCSS). The CCSS presents three key shifts in literacy teaching, including a staircase of text complexity and academic language, text-dependent comprehension, and content-rich nonfiction. Now more than ever, subject area teachers in secondary schools must face the pressures of supporting literacy within their subject area curriculum, which will require them to make significant changes to the way they frame the content knowledge they teach. If literacy can no longer be a stand-alone curriculum in high schools, and must be integrated into the disciplines, what do those of us in the literacy education community need to understand about interdisciplinary curriculum and pedagogy? Just what exactly is disciplinary integration in K-12 education?

Parallel policy includes STEM integration efforts (NRC, 2012; NGSS Lead States, 2013) in which STEM, or science, technology, engineering, and mathematics, has been conceptualized as the integration of the disciplines of mathematics and science with engineering as the "natural integrator" (Moore et al., 2014). Integration of the disciplines becomes important to K-12 student learning only when students are engaged around the problems of our increasingly technological society, requiring integration of the disciplines of STEM to solve problems (Roehrig, Moore, Wang, & Park, 2012). But little is known of what happens when teachers actually integrate the disciplines from within their own stances, frameworks and discourse communities.

Recent attention to disciplinary literacy and the STEM education movement have opened doors to new visions of disciplinary learning at the high school level (e.g., NGSS Lead States, 2013). There is a growing need to better understand what disciplinary integration looks like in the classroom communities of high schools, specifically, how teachers and students work to integrate the disciplines of STEM (Wang, 2011; Williams, 2011), and the literacies that are created and practiced within new integrated contexts. As most of what gets learned in high school classrooms is shaped through classroom discourses (Alvermann, O'Brien, & Dillon, 1990; Lemke, 1990), the study of the classroom discourses in high school science classrooms where the disciplines of STEM are integrated offers an important contribution to the fields of STEM education and adolescent literacy education.

A specific focus on literacy in science classrooms makes evident the importance of spoken and written discourse in the development and use of scientific knowledge, practices and academic language (Brown, Reyeles, & Kelly, 2005; Yore, 2000; Brown, Ryoo, & Rodrigues, 2010; Lemke, 1990). Furthermore, how science teachers integrate scientific academic language and disciplinary discourse instruction into their content instruction is of particular importance in light of the increasing cultural and linguistic diversity of students enrolled in high school science courses (Brown & Spang, 2008). Although there are a number of studies that have explored science literacy (e.g., Wallace,

2004) and STEM literacy (e.g., Zollman, 2012), none of these studies have applied a sociocultural definition of literacy as social practice. A sociocultural view of literacy recognizes that the literacy practices of individuals are always located within social practices, and are constructed socially (Barton, 1991; Scribner & Cole, 1981), unlike a functional definition of literacy focused on reading and writing traditional texts (Levine, 1982).

This study builds on and extends the ways literacy learning within disciplinary and interdisciplinary teaching and learning has been conceptualized and studied. The use of a sociocultural view of literacy in the study of STEM integration and classroom discourses and practices has important implications for research and teaching in secondary classrooms. Also, the study of how instructional coaches develop coaching knowledge and practices to support teachers in STEM integration has implications for how teachers are supported in STEM and other future disciplinary integration efforts.

The purpose of this study was to explore the process of how science teachers integrated academic disciplines during a STEM professional development grant project, and how the instructional coaches who worked with them supported their STEM integration efforts. STEM curriculum was imagined and presented to teachers as a novel way to teach the relevant science and mathematical content required in the MN state standards, as well as an opportunity to integrate new engineering content standards into science. Specifically through this study, I sought to understand the process of disciplinary integration through the study of classroom and coaching discourses during STEM integration. Guiding research questions were:

1. What is the nature of classroom literacies and discourses when teachers integrate the disciplines of STEM **(chapter 2)**?
2. How do classroom literacies and discourses compare across classroom communities and what is a process of disciplinary integration in classroom discourses that accounts for classroom contexts **(chapter 3)**?
3. How do coaches develop the necessary knowledge and skills to support teachers in STEM integration efforts **(chapter 4)**?

Theoretical Perspectives and Conceptual Frameworks

Situated Learning

This study is grounded in a sociocultural theory of learning, specifically a theory of social practice which posits that "learning, thinking, and knowing are relations among people in activity in, with, and arising from the socially and culturally structured world" (Lave & Wenger, 1991, p. 50-51). The social practice of individuals is understood through his or her participation in the world, as a member of a sociocultural community. Situated learning is based on the Vygotskian idea (Vygotsky, 1978) that learning "awakens" internal development processes only when individuals are interacting with people in social environments (p. 40). Additionally, learning for the sociocultural person involves not only a change in participation with his or her world, but also, as Lave and Wenger explain, a change in identity:

> As an aspect of social practice, learning involves the whole person; it implies not only a relation to specific activities, but a relation to social communities—it implies becoming a full participant, a member, a kind of person. In this view, learning only partly—and often incidentally—implies becoming able to be involved in new activities, to perform new tasks and functions, to master new

understandings. Activities, tasks, functions, and understandings do not exist in isolation; they are part of broader systems of relations in which they have meaning. These systems of relations arise out of and are reproduced and developed within social communities, which are in part systems of relations among persons. The person is defined by as well as defines these relations. **Learning thus implies becoming a different person with respect to the possibilities enabled by these systems of relations**. To ignore this aspect of learning is to overlook the fact that learning involves the construction of identities" (1991, p. 53).

Although Lave and Wenger's communities of practice serve as a useful theoretical construct, it is not without critique. For example, Fuller, Hodkinsons & Unwin, 2005 determined that Lave and Wenger's theory calls attention to their assumption of the learner as a novice, neglecting the transfer of "old-timers" into new learning communities, as well as the idea the everyone's participation is peripheral in some respects. Additionally, legitimate peripheral participation, as Lave and Wenger defined it, is simply "catching up" rather than constructing, or contributing to the ways of knowing and acting at work (Fuller, Hodkinsons & Unwin 2005).

A parallel theory is that of Hyland's (2000) "discourse communities," which locates learners within particular cultural contexts in order to identify the rhetorical practices that are dependent on a community's particular purposes and audiences. However, this concept has also been critiqued (Harris, 1989; Chin, 1994; Cooper, 1989; and Prior, 1998; as cited in Hyland, 2000) as too structuralist, static, and deterministic a view of academic cultures and departments. I agree with these critics, and support the idea that communities of practice are innovative, having momentum and diversity in the variation of the roles, allegiances, and participation of their members. Also, within the discourse community there will always be marginalized and conflicting viewpoints that despite disagreement, still constitute an aspect of that community.

Sociocultural Literacies

Drawn from sociocultural theories of learning as explained in the previous section, this study uses a sociocultural definition of literacy, in which literacy is defined by the socially situated practices of individuals as they occur within social groups (Barton, 1991; Barton & Hamilton, 1998; Scribner & Cole, 1981; Street, 1995). A sociocultural definition of literacy is concerned with the production, distribution and consumption of texts as they are located within, and informed by broader social contexts (Gee, 1990, 1996). Often, this view of literacy has been called "New Literacy Studies," or NLS, which operates from a broad conceptualization of literacy as situated in a sociocultural framework, including a combination of discourses (Gee, 1999), semiotic contexts (Kress, 2003; Lemke, 1990), and the competencies of multiple literacies (Hyland, 2000; The New London Group, 1996). NLS also takes into account the impact of the increasing role of the Internet and digital technologies on literate practices and processes (Coiro et al., 2008). Although the NLS often include digital and technologically-based literate practices, literacies that are "new" can also include processes and practices found in traditionally print-based, or classroom-based modalities (Lankshear & Knobel, 2006).

In order to acquire the literacy practices necessary for today's literacy demands, students must engage in the ethos of new literacies, which includes participation, collaboration, and open sharing of ideas (Lankshear & Knobel, 2006). Additionally, students bring to school multiple literacies (Hyland, 2000) as well as their own primary and secondary discourses (Gee, 1999) and it is important those literacies and discourses are valued. NLS seeks to explore how adolescents' in-school and out-of-school literacy practices compare, specifically in terms of their literacy practices, contexts of use, texts, and participation in discourses (Xu, 2008). For example, Xu's (2004; 2008) study used the four aforementioned premises of NLS perspectives to analyze what she called a "hybrid space" in one teacher's English classroom. She found that when the teacher allowed her struggling students to rely on their out-of-school literacies, students became more engaged in the reading and learning required of in-school literacy. Hagood (2002) studied how one high school student constructed his identity in relation to the various available positions within a discourse community. She found that it was important to use interpretative frameworks of both identity and subjectivity when studying the critical literacy experiences of Timony, because the in-school literacy practices of adolescents require complex interplay as they negotiate identity and subjectivity within those practices.

The use of a sociocultural definition of literacy allows for study of the discourses and social practices that exist around literacy activities in classrooms. For example, Lankshear & Knobel (2006) studied scenario building on classroom blackboards as a new literacy practice as students, and considered how the social and discursive practices of the activity worked to co-construct texts. Lankshear and Knobel (2006) adopt the term "transdisciplinary" from Halliday (2003) to describe the expressions of literacy that move beyond discipline-specific enactments of knowledge-construction. This view of literacy has created new landscapes for literacy research, and opened space for what Unsworth (2008) called a "transdisciplinary imperative" for new literacy studies (p. 401). Heath and Street (2008) have also argued that the study of literacies should move beyond disciplinary boundaries. This study applied a sociocultural definition of literacy in order to examine literacy as it was informed by local and broader social and institutional discourses, examining these literacy practices from within and across disciplinary boundaries.

Disciplinary Literacies

The recent interest in disciplinary literacy is a result of increased attention on content-area reading of adolescents after the reporting of the 1998 NAEP reading assessment scores which stated that although 60% of adolescents could comprehend factual information from reading texts, fewer than 5% could extend or elaborate on the meanings of those same texts (Moore, Bean, Birdyshaw, & Rycik, 1999). The literacy community's response to the NAEP results called attention to the necessity for better instructional practices in secondary schools, which could better support the specific learning needs of adolescents in the content areas (Moore et al., 1999). Those needs included an increased attention to the discipline-specific literacies of adolescents, which have been explained more recently as "a matter of learning the different knowledge and ways of knowing, doing, believing, and communicating that are privileged in those areas" (Moje, 2008, p. 99) and "advanced literacy instruction embedded within content-area classes such as math, science, and social studies" (Shanahan & Shanahan, 2008, p. 40).

The advanced literacy instruction advocated by the Shanahans (2008) includes attention to the organizational properties of disciplinary texts, more sophisticated reading routines and responses, reading comprehension strategies, and an increasing adoption of discipline-specific language and reading routines. Despite its prevalence in disciplinary literacy theoretical literature, this foundational study of disciplinary literacy has been critiqued for its shaky methods and far-reaching conclusions. The small, purposeful sample of only six individuals within the Shannahans' immediate community of educators to act as "disciplinary experts" raises serious doubts about the validity of their findings. It is not clear in this report why each individual used different strategies for different texts, leaving the researchers' conclusions of the existence of reading strategies that are particular to the disciplines open to question. Although the use of verbal protocols in research has elicited some breakthrough understandings about the comprehension processes of readers, it has been recognized that prompting the participants to the reading processes of interest to the researchers, in this case, processes that were theorized to be particular to the disciplines, can threaten the validity of the study (Hilden & Pressley, 2011).

Unlike disciplinary literacy, content area reading instruction has a large empirical basis (Moore, Readance & Rickelman, 1983) and until disciplinary literacy research has been empirically validated, the claims of the Shanahans and others regarding discipline specific reading strategies should be critically received. The idea of disciplinary literacy as an "inside out" approach, and the more traditional "outside-in" approach of content area literacy efforts have been positioned in the conceptual literature as being at odds with one another, but there could viably exist a "both-and" middle-ground between the two approaches (Brozo, Moorman, Meyer, & Stewart, 2013).

Emerging alongside the literature of disciplinary literacy are approaches to discipline-specific literacies including scientific literacy, technological literacy, and STEM literacy. In these conversations, what constitutes specific academic literacies is often framed within an apprenticeship approach. For example, in a recent review of mathematic literacy, Hillman (2014) outlined two prevalent approaches to mathematic discourse in the literature as apprenticeship approaches. These included Sfard's (2007) four text features of mathematical words, narratives, visual mediators, and routines, and Kaiser and Willander's (2005) system of five levels of reasoning, which includes the five developmental levels of illiteracy, nominal literacy, functional literacy, procedural literacy, and multidimensional literacy, the last representing mastery of Mathematics as a discourse. Although apprenticeship approaches to academic literacies are useful to the teacher-student discourse of classrooms, they are not without critique as they rest on an assumption of a hierarchy of knowledge dissemination, which is inconsistent with sociocultural theories of learning that highlight the co-construction of knowledge in learning contexts (Lewis, Encisco, & Moje, 2007).

In this study, I took up the ideas of disciplinary literacies as ways of doing, knowing, believing and communicating within the broader social discourses of the disciplines (Moje, 2008). Combined with a sociocultural definition of literacy, this study examined the disciplinary literacies of students and teachers through analysis of classroom and broader social discourses as well as analysis of discursive practices that were unique or common to the disciplines of STEM.

Disciplinary Integration

There have been two main arguments for integrating the disciplines of the academy: 1) A liberal arts perspective that contests students should not be taught to think solely through a single disciplinary point of view and instead develop capacity to discover universal ideas and, 2) A social efficiency perspective that recognizes interdisciplinary approaches are necessary to solve the complex social problems of society that cannot be understood through one disciplinary perspective (ASHE, 2009). Disciplinary integration efforts seek to combine the isolated communities of the disciplines, which are defined by a shared body of knowledge and culture (Hyland, 2004). However, disciplines do not represent a single, shared outlook on a particular perspective, and instead are made up of an assortment of smaller scholarly communities within disciplines (Hyland, 2004). Theoretically, the integration of disciplines has been conceptualized as intradisciplinary, where one discipline is the focus; interdisciplinary, where two or more disciplines are taught side-by-side; and integrated, where explicit connections are made between and among multiple disciplines (Harris & Alexander, 1998; Huntley, 1998). These historical perspectives of disciplinary integration have been extended further through recent efforts in STEM education reform.

Bybee (2013) presented nine perspectives of STEM education to explain the various relationships that could exist between the academic disciplines of STEM. These perspectives of STEM include: 1) As a single-discipline, usually a science discipline like

Physics, 2) As a dual-discipline perspective, usually science and mathematics, 3) As a separate science discipline that incorporates technology, engineering and mathematics, 4) As four separate disciplines, 5) As a connection between the disciplines of science and mathematics, 6) As coordination of concepts, processes and resources of the four disciplines, 7) As combining two or three disciplines into one academic course, 8) As integrated disciplines that overlap and progress simultaneously as students progress through the disciplines and 9) as a transdisciplinary course or program that responds to broader social issues. The ways that STEM is conceived in theory and lived out in practice are multiple, with no agreed upon definition of STEM in existence. However, only a few of these perspectives achieve the liberal arts or social efficiency arguments for interdisciplinary education, and therefor not all STEM efforts are disciplinary integration efforts.

In actual classroom practice, disciplinary integration often includes a theme, such as a problem or issue to connect the disciplines (Davidson, Miller, & Metheny, 1995; Huntley, 1998) and addresses real-world contexts for problem-solving (Drake, 1998; Fogarty, 1991). Interdisciplinary curriculum often has either a content/concept specific focus or a process/skills specific focus, and the explicit teaching of strategies and skills to support student' engagement with the problem-solving activity (Berlin & White, 1995). The integration of disciplines in education has taken on many forms over the years, though most attempts to integrate the disciplines on a larger scale have failed in American public school systems (Harris & Alexander, 1998). One of the major challenges for successful integration of disciplines includes an "either/or" view of content/skill instruction vs. discovery-based learning (Harris & Graham, 1996, as cited in Harris & Alexander, 1998). In this debate, educators on one side argue that students will come to learn all they need to learn through "rich social interaction and immersion in authentic learning experiences within learning contexts," while those on the other side contend that students need explicit instruction on discipline-specific knowledge, skills and practices (Harris & Alexander, 1998, p. 120). This debate sets up a false dichotomy between constructed vs. instructed knowledge (Hiebert et al, 1996) and results in the pendulum swing of reform we so often see in education (Alexander et al., 1996).

In this study, disciplines have been defined by the academic content areas of science and mathematics in high schools, and by the broader professional disciplines of Physics, Engineering, and Science Teaching. Technology and literacy are at times referred to as "disciplines" however, there is much debate regarding the accuracy of this classification, as technology and literacy are used as tools and practices to carry out the functionality of individuals within disciplinary contexts. However, due to the lack of an accessible alternative, they remain disciplines for the purpose of this study.

Teacher Identity

In order to explore the ways teachers and coaches learned from and experienced STEM integration fully, I needed to consider the ways that individuals were shaped by contexts, and the ways who they were influenced their participation in the social activity of the classroom. Thus, a final theoretical construct from which this study draws is of teacher identity. Identity in the literature on teacher education has been conceptualized through the use of various theories of education including sociocultural theory (Olsen, 2008; Sfard & Prusak, 2005; Gee, 2000; 2001) as well as through application of theories from other disciplines, like anthropology (Holland, Lachicotte, Skinner & Cain, 1998), sociology (McLeod & Yates, 2006), philosophy (see Taylor, 1989), and psychology (Côté & Levine, 2002). When synthesizing a conception of teacher identity from such a wide array of epistemological stances, authors have difficulty articulating a clear definition of what teacher identity is (Beauchamp & Thomas, 2009). Furthermore, when talking about an individual's identity other important factors such as emotions, notions of the self, and lived experiences enter into the conversation, thus extending the complexity of a singular definition of identity (Rogers & Scott, 2008). Of particular significance to this study, I focus on studies that use sociocultural theories to consider how a teacher's contexts for teaching and their relationships with others in their professional lives contribute to the identities teachers develop and enact in schools.

Interpretations of teaching identity must be situated within the social contexts and communities teachers participate in: "Situating the shaping of a teacher's identity within the context of practice implies the necessity to be aware of the effects this context might have on the shifts and changes in a teacher's identity" (Beauchamp & Thomas, 2009, p. 184). Teachers bring themselves into their classrooms, and the formation of their identities "involves an interplay between external and internal forces" (Rogers & Scott, 2008). Additionally, the discipline a teacher chooses to teach may also affect identity (Levine, 1993; Stacey, Smith, & Barty, 2004; Pennington, 2002; Varghese, Morgan, Johnston, & Johnson, 2005). Recent studies of education have used sociocultural theories of identity to consider how teachers' previous vocational identities influence their teaching identity (Fejes & Köpsén, 2014) and how their affiliations to a variety of "communities of practice" (Lave & Wenger, 1991) influence the way teachers modulate their identities for different purposes in the workplace (Farnsworth & Higham, 2012).

Furthermore, teacher identity must be considered through examination of the relationships teachers have with others. Gee (2014) argues that relationship cuts across all aspects of identity because to have an identity means to be recognized as a certain "kind of person" engaged in particular "kinds of activity" (p. 61). Studies looking at the relational aspects of teacher identity have considered the co-construction of identity through engagement with others in cultural practices (Smagorinsky et al., 2004) and how pre-service teachers negotiate a teaching identity through their relationships with students, course instructors, and mentor teachers (Samuel & Stephens, 2000; Brodeur & Ortmann, 2014). Hargreaves (2001) studied the "emotional geographies" elementary and secondary teachers experienced, which consisted of the closeness or distances teachers felt with others in their school. These relationships were essential to the enacted and perceived identities of teachers in his study.

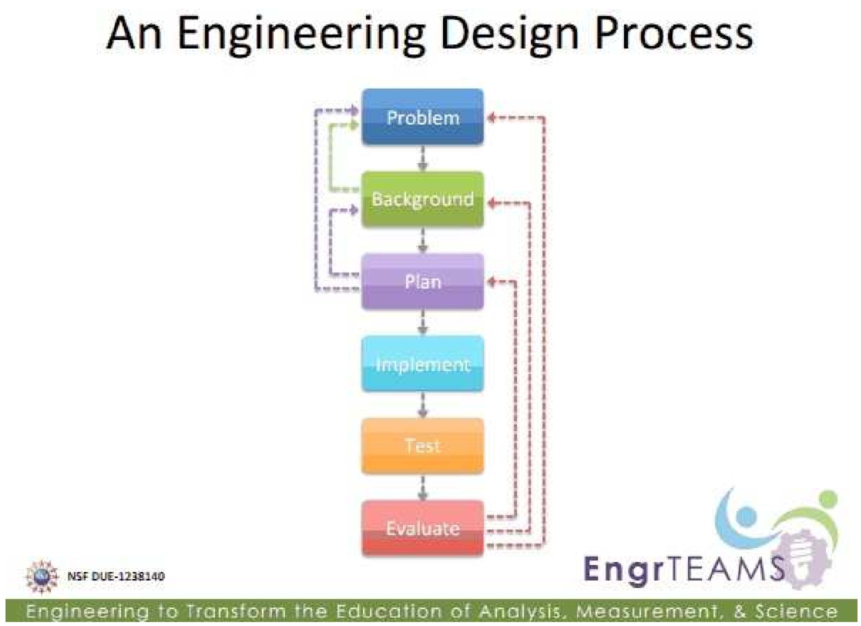
Contexts inevitably shape our notions of who we perceive ourselves to be, and how others see us. Within each community, there exists a set of norms, and it is expected that these norms will be followed by its members. Rogers and Scott (2008) argue, "Lack of awareness of these norms and pressures to assimilate, keep teachers subject to contextual forces, robbing them of agency, creativity and voice" (p. 734). Identity must be "recognized" within historical and situated affiliations within communities and the "interpretive system" that includes natural, institutional, discursive, and affinitive aspects underwrites all identity recognition (Gee, 2001). Thus, an understanding of teacher identity that includes the influences of self-perceptions, social contexts, relationships with others, broader discourse communities of practice, and disciplinary affinities is essential to this study of teachers and coaches as they integrated the disciplines of STEM in their classrooms.

The theoretical perspectives of sociocultural theories of learning combined with the specific conceptual frameworks of disciplinary literacies, disciplinary integration for STEM, and teacher identity have allowed me to study interdisciplinary teaching and learning as it was enacted and lived by the participants. A sociocultural theory of literacy and learning allowed me to examine the literacies and learning of participants through the social construction, consumption, and distribution of discourses, as well as through the enacted identities for teaching observable in those discourses. The conceptual frameworks for disciplinary literacies and disciplinary integration provided important definitions of otherwise abstract concepts and terms related to disciplines as they are broadly defined. Each of the three manuscripts draws on these perspectives and frameworks, and more specific theoretical frameworks are developed in relation to the specific research questions and methods applied in each manuscript.

Research Context: EngrTEAMS Grant Project

The context of this study is an NSF grant-funded STEM initiative (DUE-1238140) in three large schools districts in the Midwest (two urban and one suburban). In the first year, forty-eight teachers from 36 middle and elementary schools, and forty-seven teachers in the second year volunteered for a professional development opportunity to learn about STEM integration for grades K-9th grade curriculum. Each summer, the teachers participated in a three-week intensive professional development course led by university faculty and staff, where they first experienced STEM curriculum as learners, and then collaborated in interdisciplinary and inter-district teams to develop their own curricular unit. They then piloted their curriculum unit at a university summer camp. The teachers participated in group and individual coaching throughout the summer professional development with a STEM graduate student coach, then teachers implemented their specific curriculum in their own classrooms, working in partnership with the graduate student coach and their team throughout the year. EngrTEAMS professional development used a framework for K-12 STEM integration developed by the principle investigators for the project (Moore et al., 2014), which included the use of an engineering design process (see figure #). Teachers were expected to develop curriculum in line with the framework, apply the state science, mathematics, and engineering standards, and use the engineering design process.

Figure 1.1 An Engineering Design Process



Study Participants

The participants from this study were purposefully selected from the broader group of participants for specific reasons (outlined in subsequent chapters). The two 9^{th} grade physical science teacher participants included in the studies (and presented in chapters two and three) worked together in a team during the 2014-15 academic school year. The teachers worked together with me as their coach to co-develop a unit on forces and motion, specifically Newton's first three laws of motion. In this co-developed unit, the two teachers addressed state science, mathematics, and engineering standards for 9^{th} grade Physical Science through an engineering design challenge where the students needed to design, develop, and test a container that could hold and transport chemical waste. The teachers developed a series of lessons together, and implemented the unit in their own classrooms in different school districts.

A graduate student coach—Madison-- and teacher participants featured in the study (and described in chapter four of this dissertation) worked together throughout the 2013-14 academic school year, which was the first year of the EngrTEAMS project. The graduate student coach, a doctoral student in STEM education, participated in a summer training and monthly coaching class during the year to learn about coaching using a blended cognitive and instructional coaching model. The teachers she coached were middle school science teachers who were participating in the EngrTEAMS project for the first time. Although they shared the same instructional coach, the teachers were a part of different teacher teams and did not work together in any way on the project.

Researcher Role

The extent of a researcher's participation is a continuum that varies from "complete immersion in the setting as full participant to complete separation from the setting as spectator" (Patton, 2002, p. 265). The ideal is to negotiate the degree of participation that will yield the most meaningful data for the study (p. 267). For this study, I was an observer as participant, which Merriam (2009) explains as the relationship when the researcher's observer activities are known to the group being studied, and participation in the group is secondary to that of an observer. I tried to keep my influence on the participants to a minimum; however, because I was also an instructional coach and instructor for the coaching class, my role in the study was constantly being negotiated.

My role as a coach to the two teachers (named Andrea Davidson and Heidi Fischer) required me to facilitate collaboration among the two teachers, encourage their curriculum development efforts, and support their curriculum implementation during the school year by providing materials and helping set up and take down labs. I also supported their instruction by facilitating reflective conversations after each observed lesson, and at times leading testing stations or answering student questions during lab group times. During data collection, I intentionally did not influence or direct teacher or student responses or conversations because I hoped to observe the classroom discourses in their natural state.

Additionally, I was one of three instructors for the coaching class in which the graduate student coach and study participant, Madison, was a student. In this class, Madison and the other coaches were learning coaching theories and practices for the first time, and this course was designed to support their learning through an introduction to coaching as reflective practice and facilitative dialogue with teachers. My role required me to develop coaching curriculum and design and lead the class sessions. I also met with students 1-1 in small reflective conversations, which were at times audio recorded to be included in this study. Additionally, students' written assignments were used as data sources, however I did not ascribe a grade to any of the students or student assignments. The other instructors for the course —one university professor participating as a consultant on the project, and one university professor/Co-PI on the project--were responsible for all evaluative and grading tasks so as not to confound the researcher role any further.

For these reasons, I recognize that there is a possibility for researcher bias in my study because of my close interactions with the participants. Although I did proceed with great caution and used reflexive memoing, member-checking, and outside readers whenever possible, I realize the possibility for researcher bias. However, I considered my professional relationships with the teachers and coaches I worked with to be an invaluable asset to my research because an established, professional relationship provided the basis for professional dialogue and honest communication that I believe strengthened the validity of the research data.

Organization of the Dissertation

This dissertation is structured as three separate manuscripts under the umbrella of the same research context and guiding questions about the process of disciplinary integration for classroom teachers and the coaches who work with them. It is presented in a nontraditional dissertation format that includes an introduction chapter that overviews the dissertation study including theoretical perspectives and rationale, followed by the three manuscripts, and ending with a conclusions chapter that discusses themes and implications across all three manuscripts, summarizes key points, and offers future directions. A summary of each of the three manuscripts is presented below.

Chapter 2: Exploring disciplinary integration in science classroom discourses

The first manuscript presents case studies of two secondary physical science teachers who participated in the EngrTEAMS professional development program to co-design and implement a STEM integrated curriculum in their 9th grade physical science classrooms during the 2014-15 academic school year. The primary goal for this investigation was to explore the nature of STEM integration as evident in the classroom discourses of teachers and students by examining the ways students and teachers positioned, negotiated, co-constructed, and disrupted disciplines within their discourse practices. Through the use of a contrasting case design (Yin, 2009), classroom observations including video and audio recordings, semi-structured interviews with the teachers, and student focus groups were collected from each classroom. The findings presented in this manuscript highlight the situated nature of disciplinary integration, including the enacted social identities and lived experiences of students and teachers, the disciplinary knowledge and expertise of teachers, and the use of multimodal pedagogies and explicit language instruction for modeling disciplinary discourse.

Chapter 3: A process of disciplinary integration in science classroom discourse: A cross-case analysis

The second manuscript presents a cross-case analysis of the two cases presented in chapter two, as a means to develop a grounded theory of a process of disciplinary integration practice as was evident in classroom discourses across cases. This investigation also presents the results of critical discourse analysis (Fairclough, 1992) of texts selected using theoretical sampling (Corbin & Strauss, 2008; Charmaz, 2014) from the broader corpus of data (Fairclough, 1992). The findings offer a process of disciplinary integration including the re-presenting, modeling and apprenticing, disrupting, and learning of disciplines through classroom discourses and discursive practices. This process offers the fields of disciplinary literacy and STEM education a theory of what it means to integrate disciplines that is grounded in actual classroom practices.

Chapter 4: How One Novice Coach Became a Partner to Teachers in STEM Curricular Reform

The final manuscript presents a single, embedded case (Yin, 2009) of one novice instructional coach, Madison, and her work with middle school science teachers in STEM integration efforts. The goal of this investigation was to explore the initial and evolving coaching knowledge, beliefs, and identities of a new instructional coach in order to contribute to what is known about how coaches develop. Through the use of constant-comparative analysis methods (Corbin & Strauss, 2008) of audio recordings of coaching conversations, written reflection logs, and semi-structured interviews, a full case of Madison's coaching development is presented. Findings from the analyses indicate the importance of a new coach's development of a process of coaching reasoning and action, similar to Shulman's (1987) model of pedagogical content knowledge. Future directions for coaching research and practice with novice coaches is considered within this manuscript, and extended further in the final concluding chapter.

Chapter 2:

Exploring Disciplinary Integration in Science Classroom Discourses

Introduction

This chapter presents the cases of two 9th grade physical science teachers as they implemented a co-developed STEM integrated unit on Newton's laws of motion. The teaching standards that were addressed in this unit included 9th grade physical science standards regarding forces and motion, as well as the nature of science and engineering. The unit required students to design a container for transporting chemical waste out of local residential neighborhoods through applying the engineering design process, build and test a prototype of their design, and evaluate the strengths and weaknesses of their design in a final class presentation.

These two cases present analysis of classroom discourse data as a means of studying the nature of disciplinary integration and literacies in two contrasting school and classroom contexts. This chapter outlines the study and participants, and presents the full cases of Andrea Davidson and Heidi Fischer. The presentation of a theoretical framework for studying disciplinary integration through classroom discourses is presented in chapter three, along with a discussion across cases using further analysis from this study. Additionally, the results of an application of critical discourse analysis

(CDA) are applied within the cases, and the results of this analysis are discussed further in chapter three.

Rationale

The conversations students and teachers have in science classrooms play an integral role in shaping the disciplinary content students learn (Alvermann, O'Brien, & Dillon, 1990). These conversations are a part of classroom discourses which can be understood as multimodal social practices, reflecting and constructing the social world through many different sign systems (Rogers, 2011). Furthermore, these "little d" discourses are shaped and informed by broader societal and historical "big D" Discourses that include situated meanings, practices, identities, beliefs, etc. of individuals, institutions, and societies (Gee, 2000). Education researchers have been interested in the study of classroom discourses for decades because the basic function of school is carried out through communication (Cazden, 1988). The study of discourse provides a momentary window into student learning and teachers' instructional decision-making (Alvermann, O'Brien, & Dillon, 1990), as well as a way of capturing classroom interactions within sociocultural theories of literacy (Lewis, Enciso, & Moje, 2007).

In science education, discourse identity, as defined by Gee (2001; 2005) and Nasir & Saxe (2003), has offered researchers a way to examine how students choose to participate in the discourses of their science classrooms across a variety of classroom contexts and student populations (Brown, Reyeles, & Kelly, 2005). The focus on literacy in science classrooms makes evident the importance of spoken and written discourse in the development and use of scientific knowledge, practices and academic language

(Brown, Reyeles, & Kelly, 2005; Yore, 2000; Brown, Ryoo, & Rodrigues, 2010). Furthermore, how science teachers integrate scientific academic language and disciplinary discourse instruction into their content instruction is of particular importance in light of the increasing cultural and linguistic diversity of students enrolled in high school science courses (Brown & Spang, 2008), and recent educational policy documents that have called attention to the disciplinary and academic literacies inherent within the core subject areas (National Governors Association for Best Practices & Council of Chief State School Officers, 2010; NRC, 2012; NGSS Lead States, 2013).

Historically, approaches to science education have excluded explicit instruction in academic languages and discourses, which have in turn marginalized large groups of students from finding success in secondary schools (Gee, 2005). Recent approaches of a socially-oriented science literacy (Lang, Drake & Olson, 2006) and disciplinary literacy instruction in science (Wilson, Smith, & Householder, 2014) have offered opportunities to include historically marginalized youth into science classroom discourses, and provided teachers with applicable frameworks for language and literacy instruction in science teaching contexts (Brown & Spang, 2008).

The most recent turn in national science education discourse toward STEM, or science, technology, engineering, and math, has been conceptualized as the integration of the disciplines of mathematics and science with engineering as the "natural integrator" (Moore et al., 2014). Integration of the disciplines is important to K-12 student learning when students are engaged around the problems of an increasingly technological society that requires the integration of the disciplines of STEM to solve (Roehrig, Moore, Wang,

& Park, 2012). Although STEM integration approaches are extremely varied across the nation, most of these approaches include an integration of at least two academic disciplines (Bybee, 2013). But little is known of what happens when teachers actually attempt to integrate the disciplines from within their own stances, frameworks and discourse communities. As K-12 science teachers begin to integrate the disciplines of STEM into their classrooms, new opportunities for the study of classroom discourses and literacies in science arise. What happens to classroom discourses and literacies when science is no longer the exclusive discipline of study in a classroom? What is the nature of the knowledge that gets constructed within classroom spaces when disciplinary boundaries are crossed, and what does this mean for academic literacy instruction?

The purpose of this study is to develop a grounded understanding of the nature of classroom discourses and academic literacies when teachers integrate the disciplines of STEM. Therefore, the following research questions were addressed:

1. How do teachers and students position and negotiate disciplinary knowledge within classroom discourses during STEM integration and what does this reveal about broader disciplinary Discourses?
2. How do teachers and students disrupt the authority of discipline divisions during a STEM unit and how does that impact the co-constructed learning and situated identities of participants?
3. How do the evident classroom and disciplinary Discourses compare across two classroom communities using the same STEM unit, and what might account for any differences?

Literature Review

Science Literacy and Literacy in Science

Research in science education has identified ways that language mediates interaction and knowledge acquisition in science (Halliday & Martin, 1993; Lemke, 1990). The discipline of science represents an academic social language that epitomizes the sorts of representation systems and practices that are not only at the heart of higher levels of school success, but also integral to living in and engaging critically with modern society (Melville, 2008). The process of becoming an informed citizen and participating in the public debate about science, technology, and the environment suggests that there are specific sets of scientific literacies required of a reflective citizen. Science is not a "culture-free" enterprise, nor a consistent body of knowledge: Scientific concepts, discursive genres, and assessment practices common to U.S. schools are infused with specific cultural and linguistic knowledge that is not equally accessible to all groups of students (Luykx, Lee, Hart, & Deaktor, 2007). The academic departments of science teachers and faculty serve as communities of practice in which meanings, identities, and practices are negotiated in subject-specific discourses (Hodkinson & Hodkinson, 2002), thus the ways teachers conceptualize the world, their roles within it, and the nature of science knowledge, teaching, and learning are key factors in science education (Melville, 2008). Villanueva and Hand (2011) suggest a "science for all" approach, in which all students, including students with special needs and English language learners, should engage in opportunities to understand the practice and discourse of science. According to Bybee (1997) and DeBoer (2000), science literacy, or the use of a distinct, scientific academic discourse, is and always has been the intrinsic goal of science education, however; historically, language instruction has been moved to the background or ignored, while thinking and doing have been foregrounded as if isolated from the use of language (Gee, 2005).

According to Wallace (2004), scientific literacy is comprised of the abilities to think metacognitively, to read and write scientific texts, and to apply the elements of a scientific argument. Students need opportunities to use scientific language in everyday situations, negotiate readily among the many discourse genres of science, and collaborate with teachers and peers on the meaning of scientific language (Wallace, 2004). Because a component of science literacy involves the relationship between scientific definitions and vernacular ways of understanding them (Arons, 1983), teaching science explicitly as a “second language” in urban classrooms can support students in translating their understandings into scientific language (Brown & Spang, 2008). Teaching science in this way requires teachers to draw on students’ everyday discourses, connect those everyday discourses to scientific modes of thinking, and help students negotiate among these disparate discourses for scientific sense-making (Moje, Cozallo, Carillo, & Marx, 2001).

Studies of language practices and discourses in science have found teachers use a hybrid method of language, combining vernacular and scientific language in what Brown and Spang (2008) called “double talk.” They found that when teachers used “double talk” they provided students with an understanding of the scientific and vernacular ways of describing phenomena, and supported students in rooting their operational definitions of scientific concepts in shared classroom experiences. Weinstein (2006) contends that a “scientific multiliteracy” exists in the scientific discourse use of groups of professionals who engage in science, but are not scientists. Specifically in his study of professional human research subjects and science fiction writers he found a more nuanced, ambivalent, and socially engaged use of science and everyday discourses than the conceptualizations of scientific literacy within national policy documents like the Common Core State Standards. A study conducted by Mohan and Slater (2006) in a high school science class found that the teacher, Mr. Peterson, moved students from “everyday meaning” to “technical meaning” by consciously attending to the morphology of scientific terms. He also unconsciously extended the linguistic and semiotic relationships inherent within discipline-specific concepts during what he deemed as his content-specific instructional practices, thus language and science content were inextricably linked.

The use of specific language instruction in science has also supported traditionally marginalized youth in learning and succeeding in science subject areas (Ciechanowski, 2009; Villanueva & Hand, 2011; Henrichs & Leseman, 2014; Lee & Fradd, 1998). Studies of language instructional interventions have been shown to support students of diverse backgrounds in appropriating the language, culture, practice, and dispositions of science (Villanueva & Hand, 2011), improve students’ critical thinking and standardized test scores (Villanueva & Hand, 2011), support children in “code-switching” as they move across settings and purposes in their lives and school (Honig, 2010), and encourage increased participation in classroom discourses (Lee & Buxton, 2013). Studies have also found that students’ prior linguistic and cultural knowledge mediated their engagement with scientific information and learning of science (Luykx, Lee, Hart & Deaktor, 2007). While there is some evidence that "talking to learn," "reading to learn," and "writing to learn" techniques support the derived sense of science literacy, more research is needed that investigates the classroom environment, instructional context, teaching strategies and science achievement of students in science literacy approaches (Yore et al., 2003)

STEM Integration

The field of STEM education is a relatively new field, with origins in policy reports like those of the National Research Council (2012, 2013) the *Next Generation Science Standards*, and reports from professional organizations like the International Technology and Engineering Association (ITEEA, 2009). STEM is defined in a myriad of ways, and the meaning of STEM is not clear or distinct (Bybee, 2013). It has spanned in definitions from "the integration of Science, Technology, Engineering, and Mathematics into a new transdisciplinary subject in schools" (ITEEA, 2009, p. 1) to an educational approach that fosters the connection between engineering and science to help better prepare students to meet the challenges of an increasingly technological society (NRC, 2012). The wider project in which this study is situated assumes that the integration of the STEM disciplines at the K-12 level offers students an opportunity to experience learning in real-world, multidisciplinary contexts; thus the goal is to increase student learning of science and mathematics by using an engineering design-based approach for integrated learning of mathematics and science. The definition used for the project comes from Moore et al. (2014) framework for STEM integration in which engineering naturally integrates the disciplines of mathematics and science through the engagement of real-world problems. In this framework, it is proposed that successful STEM integration requires six components: 1) a motivating and engaging engineering context 2) the inclusion of mathematics and/or science content 3) student-centered pedagogies 4) an engineering design or redesign challenge 5) the opportunity for students to learn from failure and 6) an emphasis on teamwork and communication to solve real-world problems (Moore et al., 2014). This framework assumes the broader social, political and economic goals of K-12 STEM education as defined by Bybee (2013) to prepare professionally and economically successful future citizens. This is an important broader Discourse of STEM education that influences the way literacy has been conceptualized in STEM.

Most definitions of STEM literacy cover the social and economic needs of literacy taken up by the Common Core State Standards, but overlook the social and personal purposes of literacy for adolescents (Zollman, 2012). Zollman argued that STEM literacy should not be viewed as a separate academic subject area, but it needs to be deictic, composed of skills, abilities, factual knowledge, procedures, concepts, and metacognitive capacities of an individual. Similarly, Bybee (2013) summarized the broader goals of STEM education as contributing to a STEM-literate society, a general workforce with 21st century competencies, and an advanced research and development workforce focused on innovation (p. x). He defined STEM literacy as referring to the following aspects:

- Knowledge, attitudes, and skills to identify questions and problems in life situations, explain the natural and designed world, and draw evidence-based conclusions about STEM-related issues;

- Understanding of the characteristic features of STEM disciplines as forms of human knowledge, inquiry, and design;
- Awareness of how STEM disciplines shape our material, intellectual, and cultural environments; and
- Willingness to engage in STEM-related issues and with the ideas of science, technology, engineering, and mathematics as a constructive concerned and reflective citizen (p. xi)

If we consider the nouns within this definition of STEM literacy, we can see that it is a body of knowledge, a set of attitudes and skills, a point of view, a disposition, and an identity, or way of being in society. This multifaceted definition of STEM literacy mirrors the sociocultural definitions of literacy that moved away from individual, psychological and cognitive processes of literacy, to literacy as socially situated practices and processes (Heath, 1983; Street, 1995; Luke, 1995; Gee, 1990). However, there exist almost no studies that explore applications of a sociocultural view of literacy to STEM learning contexts. Most of the disciplinary literacy studies have applied a "fundamental literacy" definition (Norris & Phillips, 2003) that asserts that literacy practices in the classroom can be winnowed down to the comprehension and production of print-based texts (e. g., Wilson, Smith & Householder, 2014). Also, there are almost no empirical studies that examine STEM literacy, as has been conceptualized by Bybee (2013) and Zollman (2012), in K-12 science classroom contexts. There are a few studies that apply notions of science literacy or technological literacy to STEM learning contexts (eg., Rodriguez et al., 2012; Brickman et al., 2012), however these studies lack clear frameworks for the study of literacies, in terms of the literacy processes, strategies, practices or discourses of students and teachers in K-12 classrooms. There is clearly a need to merge the trends in the current fields of literacy education research and STEM education research to arrive at a more robust and grounded notion of K-12 integrated STEM literacy.

Theoretical Framework

Sociocultural Academic Literacies

This study uses a sociocultural theory of literacy, in which literacy is socially situated within broader social contexts, practices, and ideologies (Barton & Hamilton, 1998; Street, 1995). A sociocultural theory of literacy is concerned with the production, distribution and consumption of texts as it is located within and informing broader social contexts (Gee, 1990, 1996). In addition, this study applies the sociocultural literacy model to a study of academic literacies. Traditionally, academic literacies have been studied to answer questions about how literacy and learning in academic content areas intersect (e.g., Alvermann & Moore, 1991; Moje, 2008; Shanahan & Shanahan, 2008; 2012). The application of sociocultural theories of literacy to studies of literacy in academic contexts offers an opportunity to examine the broader social discourses and practices of the classroom communities that vary between contexts, genres and cultures (Barton & Hamilton, 1998). The literacy practices of academic disciplines can be viewed as "varied social practices associated with different communities," which Heath and Street (2008) call an "academic socialization model." This model recognizes that subject areas and disciplines use different genres and discourses to construct knowledge in specific ways. They argue that the study of academic literacies moves beyond discipline-specific communities of practice, as literacy is also informed by broader social and institutional discourses, like government policy, for example. Thus, the use of a sociocultural theory of academic literacies is essential to this study of classroom literacies and discourse.

Recent critiques of sociocultural theories of literacy have argued for the examination of power within literacy studies (Lewis, Enciso, & Moje, 2007). Critical literacy is an approach that addresses how students engage with the inherent power dynamics in producing and consuming texts according to their discursive properties and uses within social discourse communities (Appleman, 2009). These scholars apply critical discourse theories and analysis methods to the study of texts, social practices, and the broader political/institutional discourses that exist in literacy teaching and learning contexts (Gee, 1999, 2012; Fairclough, 1992; Hodge & Kress, 1988; Foucault, 1982; Kress & Van Leeuwen, 2001). Studies that are critical have introduced new ways of examining historical contexts as well as multiple discourses within single interactions, and ways to connect the social world with the linguistic expressions of teaching and learning. Although most studies grounded in critical literacy frameworks are concerned with visions of literacy that connect the examination of societal power structures within texts to personal and social transformation and justice, some literacy scholars have applied critical literacy frameworks in studies of how to support the access to academic literacy of traditionally marginalized adolescents. Other critically oriented studies have examined the inherent power structures within academic classroom communities where literacy is practiced. This study applies critical approaches to a sociocultural theory of literacy as it exists in academic disciplines of school.

A Critical Social Theory of Discourse

This study draws from multiple theories of discourse, specifically, James Paul Gee's (1999, 2012) theory of discourse comes from a critical, social linguistic framework in which he argues that Discourse is language plus all of the cultural practices, attitudes, motivations, limitations etc. that are a part of communication within cultural groups. Discourses involve situated identities, ways of performing identities and activities, ways of coordinating tools and symbols, and ways of "acting-interacting-feeling-emoting-valuing-gesturing-posturing-dressing-thinking-believing-knowing-speaking-listening (and in some Discourses, reading and writing as well)" (Gee, 1999, p. 38). Participation in a Discourse requires "recognition" by the other participants of that Discourse; you must be able to combine language, action, values, symbols etc. in such a way that others can see you as a "particular type of *who* (identity) engaged in a particular type of *what* (activity)" (1999, p. 18).

Lave and Wenger's (1991) "communities of practice" and Hyland's (2000) "discourse communities," both situate the work of groups around shared, locally defined activities that are shaped by a history of knowledge and practice. Although Hyland's (2000) "discourse community" assumes a universal connectivity across global cultures, which seems to be particular to the university, the variation of disciplinary discourse within schools and classrooms is likely to be more aligned with the situated identities of its participants (Gee, 2000) than it is to be aligned with an academic ideal. Hyland contests that whatever term we use to describe the social groups that work together to produce, fund, and interpret knowledge, the important thing is that we recognize that disciplinary producers are members of social groups and not operating independently (p. 10). For this reason I use the terms interchangeably.

Gee explains that our "primary discourse" is the way of being an "everyday person" we learned early in life. It gives us our enduring sense of self, our everyday vernacular, and although we could become divorced from our primary Discourse, it likely becomes what Gee calls our "lifeworld Discourse" (2012, p. 154). Secondary Discourses are adopted through negotiation with new membership into social groups, though some families raise their children with a secondary Discourse (he gives the example of religion) into their home Discourse. He emphatically argues that the purpose of indoctrinating children into secondary Discourses is not to give them skills, but rather values, beliefs, attitudes and ways of interacting so that they can become "real members" of the secondary Discourse community later in life (2012, p. 155). This point of view is not taken up in the recent conceptions of disciplinary literacies evident in the Common Core State Standard (CCSS) and Next Generation Science Standard (NGSS) initiatives.

Students need to find ways to see their discourse practices as opportunities, not limitations on their disciplinary learning. In acquiring disciplinary knowledge and skills, students encounter a "new and dominant literacy," finding their own writing practices to be criticized by their teachers as they attempt to imitate a discourse (Hyland, 2000, p. 146). Hyland argued that academic writing is socially shaped by the discipline, but is also producing the discipline as disciplinary discourse has evolved as a means of funding, constructing, evaluating, sharing, etc. knowledge within social groups. Institutional forces are managing the discourse of a discipline, though the discourse is ever evolving since what constitutes as appropriate knowledge and representation within a discipline changes in response to shifts in societal practices or conventions.

A social theory of discourse (Fairclough, 1992) also requires a critical approach. Fairclough explains, "Critical approaches differ from non-critical approaches in not just describing discursive practices, but also showing how discourse is shaped by relations of power and ideologies, and the constructive effects discourse has upon social identities, social relations and systems of knowledge and belief, neither of which is normally apparent to discourse participants" (p. 12). A critical approach requires examining the relationships between discursive, social, and cultural change by showing connections that are hidden (p. 9). He offers a three-dimensional conception of discourse, where the text is featured at the center, with discursive practice (explained as the production, distribution, and consumption of the text) around it, and social practice circled around them both. The analysis of discourse then, takes into account all three of these dimensions of discourse. Additionally, in his theory, texts are both "intertextual," which he explains as the property texts have of being related to other texts, never existing in isolation from others, and are "historic," referring to the connections texts have to texts of the past (p. 84). Interpretation of the apparent discourse from Fairclough's social theory of discourse offers opportunities for examining historical as well as multiple discourses, connecting the social with the linguistic.

Methodology

In order to answer the research questions, I used a case study design to organize the data by specific cases for in-depth study and comparison (Yin, 2009). For Yin, the analysis is the most important aspect of case study research as it must attend to all the evidence, address all major rival interpretations, address the most significant aspect of the case study and use the expert knowledge of the researcher in interpretation. This study presents contrasting cases (Yin, 2009) of two 9th grade, Physical Science teachers in two different high schools and districts in the metro area. In this design, "if the subsequent findings support the hypothesized contrast, the results represent a strong start toward theoretical replication" (Yin, 2009, p. 61).

Because theory of STEM literacy is in its infancy stage of empirical development, I intend to contribute to theory with this study by using grounded theory as an analytic approach. Glasser and Strauss (1967) were the first to articulate analytical strategies and advocate developing theories from research grounded in qualitative data, rather than deducing hypotheses from existing theories. The defining components of grounded theory practice for Glasser and Strauss (1967) included: simultaneous data collection and analysis, open-coding, constant comparison method, on-going theory advancement throughout the research process, memo-writing, theoretical sampling procedures, and conducting the literature review after the analysis. Additionally, this study used a constructivist approach to grounded theory (Charmaz, 2014), which acknowledges subjectivity and the researcher's involvement in the construction and interpretation of data. Thus, the results of this study were derived from a pragmatic approach to grounded theory and analysis.

Methods

Participants. Conventional grounded theory studies use theoretical sampling procedures to determine cases of interest (Glaser & Strauss, 1967), however for the purposes of this study I have selected the two cases of interest based on convenience. Due to the voluntary nature of participation on EngrTEAMS (see chapter 1 for details on the EngrTEAMS project), these two individuals were the only high school science teachers who participated; the majority of participants were either elementary or middle school science teachers. Both teachers were voluntary participants on EngrTEAMS for the 2014-15 academic year, partnering together to develop and implement a three-week STEM curricular unit for their classrooms. The teachers attended a four-week summer professional development institute hosted by the STEM education center faculty and grant project coordinators. There they learned the EngrTEAMS conceptualization of integrated STEM curriculum and pedagogy, developed a curriculum based on the MN state standards for science, engineering and mathematics, and piloted their curriculum at a university STEM camp to aid in the development process.

These teachers were also deliberately selected because they offered parallel, yet contrasting school and community contexts. The first case describes the classroom community of Andrea Davidson (all names are pseudonyms), a physical science teacher at a large, urban public high school. This study took place in her 9^{th} grade co-taught level II English language and physical science class. The students in this class were all English language learners, and refugee students from Southeast Asia. For the first time during this study, this class was co-taught with an ELL teacher, Susan Godfrey, and had an extended class period to support this student community in science academic achievement. The second case describes the classroom community of Heidi Fischer, a physical science and Physics teacher at a large, suburban public high school. This study took place in her only 9th grade physical science class. The students in this class were predominantly white, middle-class students with a small percentage of African American, Asian and Latino students. Only one student was an English Language Learner, and another student was on an IEP. Both of these classroom communities reflected the demographics of the wider communities in the schools, districts, and residents of the community.

The student participants in this study included all students in the classes who consented to participate, approximately 20 students from each classroom, or 86% of the students in each classroom. In addition, a few student groups within each class who were selected using theoretical sampling procedures also participated in audio recordings of lab group conversations. From this group, a smaller group of 4-5 students from each classroom were asked to participate in a focus group interview at the end of the unit, which were also audio-recorded and transcribed. Students who did not consent to participate in the study were still participants in the classroom community, although they were not video or audio recorded for research purposes.

STEM curriculum. The curriculum that the teachers developed was created to address the 9th grade physical science standards for Forces and Motion, specifically Newton's laws of motion. The engineering design challenge required students to design a container that could successfully and safely carry chemical waste out of residential neighborhoods. In order to design a solution to this problem, students needed to design and build a prototype of a chemical cargo carrier (CCC) on a small scale, using common household materials like popsicle sticks, cardboard, and glue. The "chemical" that students needed to transport safely was a raw egg. The challenge was to protect the egg during increasingly higher impact forces from a collision down a ramp. Students needed to use data collection and data analysis methods consistent with the 9th grade physical science standards, and needed to perform basic calculations of acceleration and force to determine the success of their design. This process of design went through two iterations—an initial design phase and a redesign phase. At the end of the unit, students gave presentations to the class using powerpoint or other online presentation software to "pitch" their CCC design to a chemical company.

Data Collection. Data collection and analysis were simultaneous processes throughout this study, with the initial analysis informing future data collection procedures (Charmaz, 2014). Observations and field notes were collected throughout the duration of each teacher's STEM unit. I observed each of the two classrooms every day, throughout the duration of the unit (approximately 4 weeks for each teacher or a total of 20 class sessions for each teacher). Each class period was also video recorded and referenced during memo writing and note taking during data collection. Field notes and memos were coded using the constant comparative method for grounded theory as a way to inform future data collection. Specifically, this process informed the selection of student lab group audio recordings during the times students were working in lab groups, which was almost every day.

Audio recordings of semi-structured interviews with the teachers happened throughout the unit, and a final focus group interview with pre-selected student participants was audio recorded and held after class in a separate room to collect student perceptions of their learning in STEM (see Appendix A). Theoretical sampling procedures (Corbin & Strauss, 2008) were also used to collect classroom texts that represented the discourse practices of STEM in each classroom. These texts included student-produced written texts, pictures of diagrams and models, co-produced teacher/student texts, teacher-texts, disciplinary texts, and other physical objects that students used and created during the unit to represent meaning or learning.

Data Analysis

Grounded Theory. The analysis happened in a number of stages, and writing, analysis, and data collection was ongoing and iterative throughout the study. All data was initially analyzed using the constant-comparative analysis methods for grounded theory (Corbin & Strauss, 2008; Charmaz, 2014) during the data collection period to determine theoretical relevance of the data, which guided data collection decisions in the field. After data collection, all data was reviewed, audio and video data was transformed into smaller segments of theoretical relevance to the study, transcribed using a modification of the Jefferson transcription conventions (see Appendix C), summarized in a brief paragraph, and reorganized into a data matrix (Miles & Hubermann, 1993) for each case. These segments were then labeled by data type and unit of analysis to make sorting and grouping of data possible, without loosing the origin of the data source.

The next stage of analysis included emergent, initial coding of all data segments by case. Through the use of grounded theory coding, I attempted to move beyond concrete statements and categorical coding, to make analytic sense of the stories that I was observing. As Charmaz (2014) explains, "We aim to make an interpretive rendering that begins with coding and illuminates studied life. If you concentrate on taking fragments of data apart and asking what meanings you glean from these fragments, you will move into analysis" (p. 111). During the initial phase, each segment of the data was coded with a phrase or gerund that focused on the activity or processes evident in the data. Through this phase, I sought to define actions, look for tacit assumptions about disciplines and disciplinary knowledge, explicate actions and meanings, "crystalized the significance" (Charmaz, 2014, p. 125) in the data, and compare data segments with other data segments within each case. These initial codes helped provide an analytic direction for the next stage of focused coding.

During focused coding, I first grouped the data segments by initial codes, and compared each incident with other similar incidents to expand and condense codes. Similar codes were re-coded using stronger theoretical language that accounted for more of the data. For example, the initial codes of "using bodies to demonstrate academic vocabulary" and "using multiple modes to introduce new science content" became one focused code of "disrupting traditional discourses with multimodal pedagogy." These focused codes were then analyzed across cases to develop broader, theoretical categories that would account for a process of integrating disciplines within classroom discourses. The descriptive categories that organize this write up represent the final analytical heuristic that was developed from the focused coding and category development in this stage.

Critical Discourse Analysis. After each case was developed, I applied critical discourse analysis (Gee, 2014; Fairclough, 1992) to a small set of the transcriptions in order to introduce a critical framework to account for issues of power within disciplinary discourse communities. The texts for this analysis were determined using theoretical sampling procedures from the larger corpus of data (Fairclough, 1992). The chosen texts represented discourse patterns that were found to be typical in the classroom, and provided further insight into generated categories and codes. Analysis of these selected texts applied Fairclough's (1992) three dimensions of analysis which are; 1) Analysis of texts and a micro analysis of discursive practices, 2) Analysis of discourse at a macro level including the intertextuality and interdiscursivity of texts and 3) Analysis of social practices of which the discourse is a part. Specifically within these three levels, I applied the analysis strategies outlined by Fairclough (1992) that offered greatest insight into the data in answering the research question. For example, in analyzing the disciplinary discourses from a macro level, I chose to focus specifically on the features of intertextuality, which Fairclough explains as the way texts are linked to other texts, constituting elements of other texts often "giving the sense of multiple discourse types trying uneasily to coexist in the text, rather than being more fully integrated" (p. 117). These features of intertextuality are helpful to questions of power evident in discourses because they help us to see how multiple discourses are living together in a text, and we can then explore where those discourses came from and why a speaker might choose to use them. The results of the CDA analysis will be used throughout this chapter sporadically to support the descriptive categories in presenting each case, however the more detailed presentation of this analysis will follow in chapter three during the presentation of the theory of disciplinary integration in classroom discourses.

Case 1: Andrea Davidson

Andrea came to the EngrTEAMS project with a strong desire to learn about how she might include STEM and engineering activities in her 9^{th} grade physical science curriculum. She had been teaching physical science at Wilson Technology Academy, a public high school in a large urban district, for several years and had attended previous STEM professional development opportunities with university faculty on the project. From those experiences, she had started to develop an understanding of engineering, but felt she had a lot to learn about implementing STEM successfully in her classroom (Interview, June 23, 2014). Throughout the year of professional development experiences, Andrea engaged with STEM curriculum and instruction as part of a curriculum development team with Heidi and I, and through reflection on her implementation in her classroom. Andrea's case highlights the situated nature of curriculum and instruction as it was grounded in the communities, relationships, and individuals within the classroom space. The situated dependency of disciplinary knowledge and representation of that knowledge in classroom and broader discourses was evident in the classroom activities and their purposes, the co-teaching collaboration, the lived experiences of the students, and the learning stances Andrea assumed as a learner of STEM integration. Together, these descriptive categories provide a story of

STEM integration in an inner-city classroom where the goals of science education and English language education merged in important ways.

Instructional Purposes of the STEM Unit

Bringing in engineering. For Andrea, the development and implementation of the STEM unit was an exciting opportunity for her to learn about integrating the disciplines of STEM, and to find new ways to "bring in engineering," something she did not feel confident in knowing how to do. She also came into the project hoping to develop an engineering curriculum that would better serve her student population. Although the students at Wilson Technology Academy where Andrea taught constituted a diverse range of language and literacy needs, she explicitly wanted this curriculum to work in the 9th grade physical science class for English Language Learners, which was to be co-taught for the first time with Susan Godfrey, an English Language teacher at the school. Because of this context, Andrea had an explicit goal to "teach the language of science."

For Andrea, teaching the language of science meant scaffolding the academic vocabulary for students, and with the integration of multiple disciplines, the academic vocabulary grew considerably from previous science units (Davidson, Interview, March 6, 2015). Within her introduction to the engineering design process alone, Andrea defined the six terms of the engineering design process, as well as the terms "constraints," "design," and "prototype" multiple times, and in multiple different ways throughout the 40 minute lesson. For example, the term "prototype" was defined on a slide as "a model of an engineer's design that can be tested" while verbally she explained it as “your first design” and when holding up the physical objects of the car base, wood block, and various building materials she said, “This is your prototype and you will have to test it to see if it breaks” (Day 6 video, 45:00). Teaching academic language was an important component of Andrea’s teaching, and it required her to plan and teach multiple representations of new vocabulary, to repeat instruction, and to model and scaffold disciplinary discourse all while she was also aiming to reach the science and engineering content standards for 9th grade physical science. It became very challenging for her to identify the “right” vocabulary to teach; at times she felt she neglected to teach the vocabulary and background knowledge that students needed, and wasted her time teaching words that they did not need to know in order to be successful on the unit (Interview, May 6, 2015).

Bringing in the engineering also meant providing a broader context in which students could apply their science and mathematics content knowledge. As students were learning Newton’s laws of motion, as expressed in the standards, Andrea would encourage them to apply what they were seeing in laboratory activities, teacher demonstrations, and video warm-up activities to the engineering challenge. The final presentations of the STEM unit required students to “use Newton’s laws to explain the success and limitations of the design,” something that was practiced over and over again throughout the unit in a variety of learning contexts. In the final presentations students used text, tables, graphs, video, images, and verbal expression to explain what they learned about Newton’s laws of motion and other physical science knowledge they developed in the context of this engineering design challenge.

During the unit, Andrea also included advanced levels of mathematics content as analytic tools that could assist students in evaluating the success of their prototype. The most prevalent example of this was the success criteria for the second iteration of the design to reach a "small mass to acceleration ratio," which she explained would be an indicator of the students' design successfully withstanding a high impact force with minimal materials used. In order to collect this data, students attached force sensors to the front of a vehicle that held their designed "cargo carrier" as a means to collect impact force upon collision into a barrier at the end of a ramp. Once students collected a series of impact forces, they needed to do basic calculations to arrive at acceleration, and then determine the ratio at which their egg broke. This number was then compared across groups, so the students could see how mass, acceleration, and force were related mathematically, as well as conceptually.

Working for an engaging purpose. Andrea introduced the STEM unit as an opportunity for students to engage in an engineering design challenge that would mimic the kinds of "real world problems" that engineers work to solve. She presented a powerpoint that showcased the various types of real world problems that engineers address, and explained the differences between mechanical, electrical, civil, and chemical engineers, thus situating the discipline of engineering as an application of science for the purpose of solving problems in a professional field. The engineering context of the unit was to prevent chemical spills in residential areas by designing a chemical cargo carrier (CCC) that could transport chemical waste safely out of the city on the bed of a truck. To build a stronger reason for working toward solving this problem, Andrea presented an image of an upturned oil truck on the side of the road with a puddle of red ooze all around it, and shared a YouTube video of a truck carrying chemicals crashing on the highway and exploding into giant fireballs. These images conveyed the danger of transporting chemicals, provided an exciting context for the engineering design challenge, and were explained as real possible disasters that engineers work hard to prevent in their designs. She explained, “Now YOU will be the engineers and prevent THIS (gesturing to the spilled red ooze image) from happening in your neighborhood!” (Day 6 video, 10:00).

Engineering was also used as the answer to the student question, “why do we have to do this?” When students became disengaged, the teachers would go back to the engineering purpose to give credibility to their pedagogical decisions. For example, at the end of the unit students were working on creating the powerpoint “pitch” of their design to the hypothetical chemical company, and Susan reminded students, “Remember, you are an engineer, so you are presenting this to your boss, right? You want to get the job, so you want this presentation to be clear. You could also use the new word of the day in your presentation—compression” (Day 12 video, 32:00). In this way the teachers attempted to motivate students to comply with their directions by connecting the activity back to “what engineers do.”

Co-teaching with an English Language Teacher

Collaborating on instruction. Andrea (Ms. Davidson) and Susan (Ms. Godfrey) were in their first year of co-teaching this course, which was designed specifically for the population of East Asian refugee students that had been clustered together since their arrival to the district when they were in elementary school. The school and district administrators determined that because of the difficulty of the 9th grade physical science curriculum, these students would need extra support of a co-taught science/EL section, and an extended class period for science. The primary language of the students was Karen, a language originating in the Karen State of Burma with some presence in Thailand. The students from this group were at various levels of literacy and English language proficiency, mostly dependent on their attendance at western school while living in the refugee camps of Thailand. While at the camps, some students chose to attend school, while other students did not, instead working on various jobs to earn money, helping out with the needs of the camp community, or spending time with friends (Yoon Wei, Interview, March 30, 2015). Thus, some of the students in the class were very proficient in oral and written English, while others had the English literacy equivalent of a 2nd or 3rd grade reading level.

For Ms. Godfrey, this group constituted her level 2 EL students, and were divided into two groups (Purple day and Gold day), with approximately 25 students in each group. She and Ms. Davidson alternated groups for "extend day" every other day. This meant that if a student had 5th hour science on Purple days, they would stay in science class for 6th hour. During EL support, Ms. Godfrey worked with students on the academic learning tasks from their content area classes, as well as English language and literacy learning goals. This model allowed the teachers to collaborate on their instructional goals for science class and extended day, provide just-in-time instruction when students were not understanding, and maintain a flexible schedule so students could access other resources as needed during the school day. Although there were varying degrees of success of this co-teaching partnership, it was a contributing factor in the ways the disciplines were presented, and in the classroom and broader discourses during the integrated STEM unit.

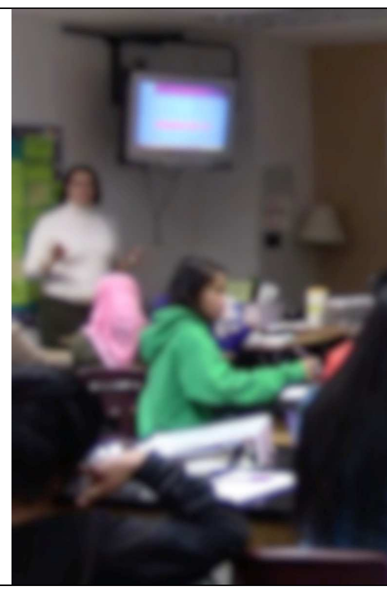
Co-teaching between Ms. Davidson and Ms. Godfrey included meeting once a week during PLC time to look at the needs of students, assessment results, and behavior reports to reflect on the week before, and also plan for instruction for the week ahead. However, this time was so limited that the planning conversation very rarely made it beyond planning for the upcoming day, which left the remainder of the class periods under the jurisdiction of Ms. Davidson, a common point of frustration for her. She expressed her desire to make the co-teaching relationship work, but after so many years of teaching on her own she had a way of doing things and because Susan often did not know a lot of the science content that Andrea was planning, she would need a lot of time to get to a place where they could co-plan together (Davidson, Interview, November 26, 2014). The co-teaching during science class often consisted of Ms. Davidson leading the class, with Ms. Godfrey interrupting the science instruction to clarify language use and expectations of students, ask questions to model attentive student behavior, or ask Ms. Davidson to explain a new concept a different way. The results of these interruptions were to either arrive at a much clearer use of academic language and explanation, or to derail the focus of instruction as the two teachers would get into a back and forth exclusive conversation (see table 2.1). In the second instance, Ms. Godfrey's interruption led to a quick back and forth between the two teachers, without including the students in the thinking that they were both doing. Rather than extend student thinking on the concepts of engineering that Ms. Davidson was trying to review, Ms. Godfrey's interruption confused the focus of the instruction.

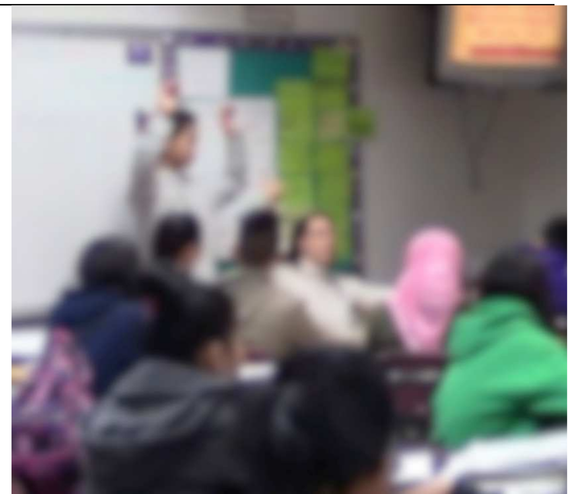
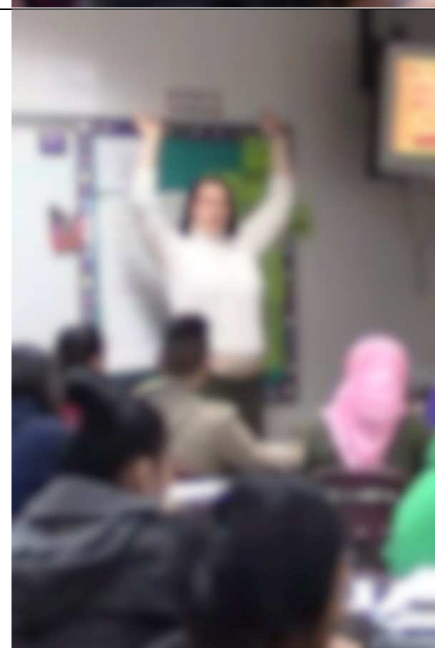
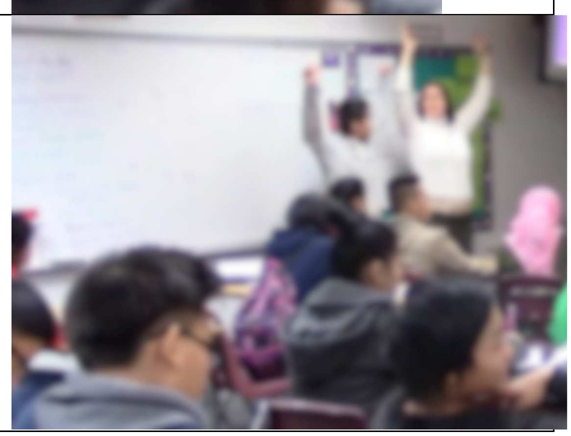
Table 2.1 Ms. Godfrey's Interruptions

	Instance #1 Day 6 video (2) 39:40-45:00	Instance #2 Day 12 video, 21:00-25:00
Science Activity	Defined *constraints*, *budget*, and *criteria* on a powerpoint slide. Paused for students to write down the definitions from the slide.	Warm-up activity was to engineer a super-suit that would protect Ms. Davidson's bones if she fell on the ice. She provided a list of possible materials including a pillow, a brick, a balloon, and a piece of paper.
Language Instruction	MG: Provided examples of *constraint*, and asked students to share their own additional ideas. MG: Money of course, and size. For instance, if a company hires you to take away their hazardous chemicals they're not going to be ok if you say, <u>'Well, we did not have enough room so we left some of it here,'</u> they're not going to be okay with that.	MG: You know what, Ms. Davidson? Maybe <u>if it was a big piece of paper and you crumpled it up, it might actually work better than the blown up paper bag.</u> MD: Yeah, depending on how big the piece of paper was (laughter). <u>Because you know I do have a mass of 100 kg (sarcasm).</u> MG: And, it might be lighter than the pillow to walk around with. MD: You're right, it could be a lot lighter than the pillow. <u>Okay. Okay, so.</u>
Outcome	Students have discussion about these terms and come up with their own examples of constraints.	No resolution to this conversation between the teachers, Ms. Davidson moves on to the lesson.

Multimodal pedagogy. Both teachers used multimodal representations when teaching disciplinary content knowledge, though it was primarily Ms. Godfrey who would initiate the uses of multiple modes. While Ms. Davidson would rely on the academic discourse of physics and visualizations on the board to explain concepts verbally, Ms. Godfrey would introduce stories and analogies; draw visual sketches on the board; hold up and manipulate physical objects; use gesturing, physical demonstrations and other embodiments of her verbalizations; songs; and engage students in physical activities that served as models for broader concepts. In one such example, Ms. Godfrey introduced the new words of the day. She wrote the words “inverse” and “directly proportional” on the white board at the side of the room, and then asked a student to help her demonstrate these new concepts (see table 2.2).

Table 2.2 Ms. Godfrey Transcript Day 4 video, 08:24-09:40

1	*We have two new words today, inverse and directly proportional. Inverse. Guess what? It starts with the word ‘in’* (moves to the white board). *Moshay, will you help me with the word inverse? Come over here… please look at Moshay and I.*	

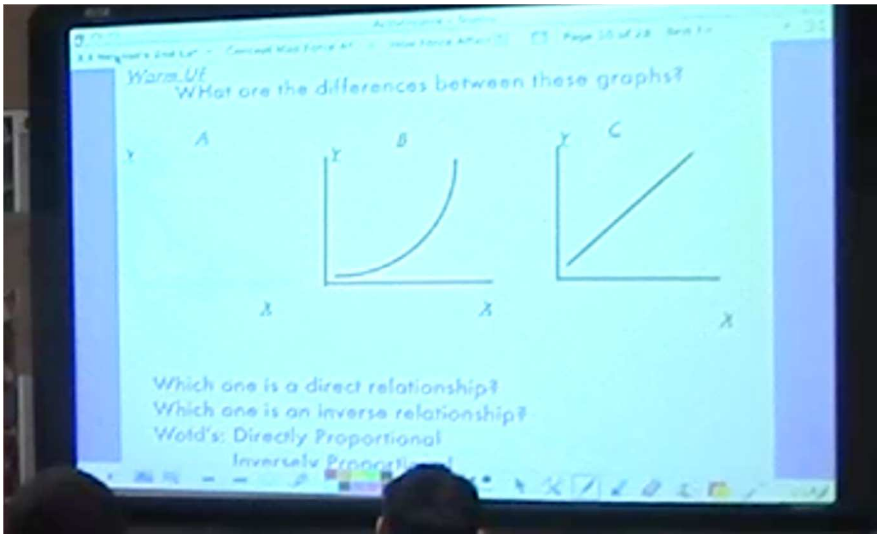
2	*Moshay and I are going to work as a team to show you inverse.* (to Moshay) *Are you ready? On your mark, get set, go. Here's inverse, when he goes up I get (.) smaller.*	
3	*Now we're going to go opposite, ready?* (gestures to him to go down) *Okay? That is inverse. Where they go in opposite directions. When x gets bigger, y gets (.) smaller.*	
4	*Directly proportional is the next one. This is when y gets bigger, x gets bigger.* (To Moshay) *So now we both put our hands up at the same time, ready? So this is directly proportional when we're both doing the same thing.*	

In another example, Ms. Davidson was at the front board explaining Newton's second law, at which point Ms. Godfrey stood up and started chanting, "F equals m a! F equal m a!" and did a conga line dance across the front of the room to help students remember Newton's second law (Day 4, 08:24). On another day, before watching the MARS Rover to do a warm up activity she interrupted Ms. Davidson by leading the students in a chant of Newton's 1st law:

> Ok, quick before we do that! Newton's first law of motion! 1, 2, goodluck, go! (In unison with students) Things at rest, stay at rest, rest rest, Things in motion continue moving. Constant (clap, clap) speed (clap, clap). Constant (clap, clap) direction (clap, clap). Unless unless unless, acted on by an unbalanced force (Day 8 video (1), 02:50-03:15).

The success of this multimodal and embodied pedagogy was evident in the silent writing that followed each of these demonstrations. Students turned directly to their notebooks and wrote down notes to themselves to help them remember. Often after these demonstrations, students were so silently focused on the writing task that the teachers would stand perfectly still so as not to disturb the silence. At this point, Ms. Davidson would take over again and rephrase the same concepts that the students just learned into the academic vocabulary of physics. She would extend the examples into more traditional examples found in science class, like baseball, car crashes, and the pushing and pulling of heavy objects. For example, Ms. Davidson's instruction directly following the inverse and directly proportional word of the day warm-up turned students' attention to the mathematical representations of these concepts. The slide on the board projected three graphical representations and students were asked to label each graph as showing either inverse or directly proportional (see figure 2.1).

Figure 2.1 Graphical Representations

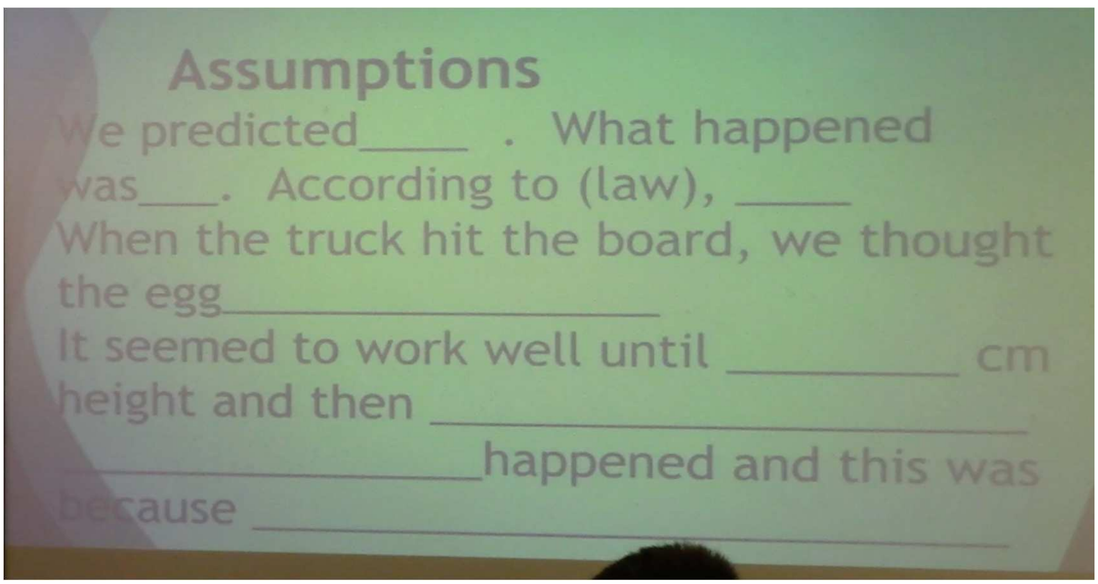


Scaffolding with language instruction. The other predominant pedagogical outcome of co-teaching was the language scaffolds that the teachers provided to support student writing and verbal reporting tasks. These scaffolds usually took the form of a slide presented at the front of the room, or a physical handout that students would glue into their science notebooks. In one lesson, Ms. Davidson used more than one scaffold as a means to support the students' ability to write an argument to "justify the redesign" before she would approve their proposal. First she projected a slide of a graphic organizer that was a modification of one presented during the summer institute to support students' argumentation skills (see figure 2.2). After explaining the "problem" box, she had a new slide with further scaffolding for the "assumptions" box (see figure 2.3). She explained that the purpose of the sentence starters was to help them with writing the argument for their "new idea."

Figure 2.2 Argumentation Scaffold

Problem	
Assumptions	
Claim/idea/solution (CIS) Claim = NEW best solution (REDESIGN)	Evidence

Figure 2.3 Assumptions Scaffold



During instruction, Ms. Davidson explained the assumptions box as "the things you came up with in your group before your test" and then read through the sentence stems. Ms. Godfrey then stepped in and added the following instruction:

> One thing I want to say about this is, students. If anyone says, 'we predicted the egg would crack,' no! We're predicting the *motion* of the egg, I will cry if anyone says 'cracked' with just one word here (points to blank space on board). You can't say it with just one word. 'We predicted that when the truck hit the *hmmm*

> the egg would ____' and then you have to say the motion of the egg. Right, this is based on Newton's 1st law or 3rd law (Day 11 video, 00:00-02:38).

Ms. Godfrey's focus during instruction was on the use of language, particularly on students' use of writing in complete sentences. For her, this language scaffold supported students' academic writing. Ms. Davidson's instructional goals were on the use of scientific argumentation, which follows a structure of claim-evidence-solution and fulfilled her goals for students to "use Newton's laws" to explain their scientific observations. However, because she was using a scaffold that originated from the EngrTEAMS project, which was an engineering interpretation of argumentation, there were competing discourses at work within this activity.

Sometimes the scaffolds were only delivered through verbal direction, and when this happened it was Ms. Godfrey who would interrupt the science instruction to clarify the expectations with a language scaffold. Likely the interruptions were due to the lack of co-planning between the teachers and happened when students were confused by a task. For example, at the beginning of one class period, Ms. Davidson had a warm-up slide on the board that was meant to be a quick activity but turned into a 15-20 minute activity (see figure 2.4).

Figure 2.4 Warm-Up Slide Text

Warm-Up: think-pair-share-write 1. How did you plan your design/how did it hold up? Describe the movement of your egg while undergoing travel and impact in your CCC… using Newton's 1st law. 2. Using Newton's 2nd law describe the above. 3. Using Newton's 3rd law describe the above.

Ms. Davidson put the slide on the screen and expected students to get to work independently while she took care of the beginning of class business like attendance and handing back papers. These warm-up routines were a familiar part of class, and students knew that a conversation with the teacher would follow their independent and partner work time. Although students were quiet and respectful, it was clear to Ms. Godfrey by the conversations she was having at their tables that students did not understand the task, and so she stepped in with more instruction. Ms. Godfrey moved to the front of the room and took over the whole-class instruction. During her instruction, Ms. Godfrey created language scaffolds on the spot by breaking these larger goals down into smaller, more concrete questions that took the form of "fill-in-the-blank" questions. In the following transcript you can see the places where she paused by the representations of these pauses with a _____.

Ms. Godfrey: Ok, here's what we're looking for. In your presentations you're going to explain why you designed it that way… We're asking why in terms of Newton's first law. According to Newton's first law, what do you know? If the egg is moving down the ramp _____.

Student: It will keep going.

Ms. Godfrey: It will continue moving. Unless ______?

Student: unbalanced force.

Ms. Godfrey: Unless acted on by an unbalanced force. So, if you wanted to, there's that wooden back of the truck part (holds up a wooden block)? That could be your unbalanced force, but then (smacks her hand into the wooden block) what's gonna happen? It's gonna break, right? So you had to create an unbalanced force that wasn't going to break the egg, that was kind of your job, right? So in your presentation (gestures to screen) you're going to have to say, 'well, I knew from Newton's first law that the egg was going to _____? continue ______?

Student: moving?

Ms. Godfrey: moving. So, we decided to use _______ (gestures hand up)?

Student: the cup?

Ms. Godfrey: the cup, the bubble wrap, the tin foil, the string, the rubberband, whatever it was that you used and what were you trying to do with that (Day 9 video, 04:15-07:09).

Although this instruction did clarify the task for students, it also presented new levels of confusion. When she explained the physical objects as an "unbalanced force" it was different from how Ms. Davidson had been explaining unbalanced forces. In her instruction, forces were not physical objects, but rather the physical objects were used to "absorb the force of impact" and "decrease the acceleration" as a way to protect the egg. This nuanced use of language is the difference between a disciplinary insider and outsider interpretation of the physical science content being taught. As the science disciplinary outsider, when Ms. Godfrey explained physical science concepts she was in fact disrupting the modeling of disciplinary discourse. She attempted to use the same vocabulary as Ms. Davidson, but her understanding of the concepts were less developed, resulting for students in conflicting information.

The co-teaching relationship facilitated multiple pedagogical representations of the disciplinary content knowledge being taught during the STEM unit. Although Ms. Davidson and Ms. Godfrey may not have planned to include different interpretations of Newton's laws of motion and the mathematical representations of those laws, the outcome was that there were multiple representations, in multiple modalities, that presented to students a multimodal and multidisciplinary experience of STEM integration. Because of the co-teaching, engineering was also presented to students as an academic content area that had its own set of vocabulary and practices to learn, existing within the space of science and language class.

Student Experiences of Learning STEM

Experiencing the disciplines through lived experiences. To develop the context for the engineering challenge of the unit, Ms. Davidson created a powerpoint about pollution. In this lecture, she talked about the types of engineered responses to cleaning up "hazardous waste pollution." She used a video of a news report of a train derailment that spilled hazardous gas in a residential area to show an example of the dangers of transporting hazardous waste. She then asked students to turn and talk with a partner about examples of hazardous waste pollution that they had heard about or experienced in their lives. The responses from students showed a variety of experiences and understandings of pollution. After a funny conversation about the difference between waste from the school bathroom and pollution, one student talked about a gas explosion that he saw happen in Japan, another student told a story about the trash and human waste in the refugee camp where he lived in Thailand, another student asked if the Tsunami of southeast Asia in 2012 counted, which led Bayani to ask if a volcano eruption could cause pollution (Day 6 video, 05:00-15:00). Ms. Davidson fumbled to incorporate these examples into her own definition of pollution, and in an interview afterwards she expressed her realization that she needed to spend more time on developing students' background knowledge of pollution (Davidson, Interview, January 6, 2015). The experiences that students shared did provide a rich discussion of the various types of pollution that occur, and helped them to connect with the engineering context.

It also gave students a chance to wonder and ask questions about the reality of the physical world they live in. One particular student, Htoo Pobzeb, was typically disengaged from class. He had very low literacy and English proficiency levels, and did not perform successfully in the traditional setting of school. Ms. Godfrey shared that he came to the United States a few years later than his peers, and that he had not attended school while in the refugee camps. However, during this conversation he moved his chair up to the front table, signaling his interest in the material to his teachers, and also his involvement in the lesson to his peers. When Ms. Davidson shared an image of people working to clean up the oil from the 2010 BP oil spill, Htoo Pobzeb asked, "Where did the oil come from, Miss?" to which Ms. Davidson replied, "There was a big oil spill a couple of years back where the oil was being transported on the ship and something happened to the ship, and all the oil spilled out." She then explained about a pipeline that broke, and that sometimes the pipe that goes through the ocean that carries oil from one place to another breaks, spilling oil into the ocean. Htoo Pobzeb asked, "What is a pipe? What kind of pipe?" and she explained it as "a long tube that is big and metal. It goes through the ocean, sometimes from one country to another." Then Htoo Pobzeb asked, "with oil inside?" and she said yes, it is being moved through the pipe through the ocean and then it burst and released the oil into the water. She also explained that this was a bad thing because the oil hurt and killed many animals. Htoo Pobzeb then asked, "Is it in there right now? In the ocean?" and at this point Ms. Davidson moved into a discussion of the different ways people have worked to clean up the oil, but that unfortunately they have not been able to clean all of it up. This was alarming to Htoo Pobzeb and his classmates, and he wondered aloud if the oil could move across the world because "all the water is connected." It was clear that many of them had not heard these stories before, and as Htoo Pobzeb integrated this story with the others he knew he found it upsetting to discover that the water of our world was in danger (Day 6 video, 22:18-25:00).

In his engineering group, Htoo Pobzeb's participation was inconsistent. He often missed class or chose to put his head down and disengage from science altogether. When he did participate, it was usually on the days when students were working hands-on with materials, building or testing a prototype. He was most successful when in a leadership role, directing his group members to accomplish various tasks. As a leader, Htoo Pobzeb was directive, but also unbiased in who he worked with, often making sure that all students in his group had a job to do. His tutor and the translator for this study, Yoon Wei, shared with me a backstory that Htoo Pobzeb was a successful leader in his community at the refugee camp where he lived in Thailand. Although he did not attend school, he worked with elders in the community to improve the quality of the physical resources available to camp citizens. He shared that Htoo Pobzeb had actually worked to engineer and maintain a rainwater collection and purification system at the camp. Yoon Wei's impression of Htoo Pobzeb was that he was having difficulty in school because he was not enjoying the leadership status and high level of contribution to society that he had experienced in Thailand. The physical work of the engineering activity was a familiar social practice for Htoo Pobzeb, and he felt confident and successful when he could participate as a leader. On these days he was also not limited by the use of English and academic language because he was able to communicate with his peers in Karen. When the nature of the task shifted to require academic language and scientific discourse, he was reminded of his struggles, and his social status in the peer group went down considerably.

Using functional discourse, primary language, and academic discourse. Htoo Pobzeb was not the only student who benefited from opportunities to speak in their primary language. The most prevalent use of discourse in student groups were "functional" conversations about the task and procedures for completing the task, and these conversations were held almost exclusively in Karen. At this school, the practice of providing ample opportunities for students to converse together in their primary languages was not only a common practice, but a tenet of the school's instructional policy. Teachers had been trained in the importance of primary language use in learning additional languages, as well as how to model and apprentice students into the academic language of their disciplines. When working in groups, the conversations also tended to be on-task and focused on the activity they were engaged in, or asking one another questions about how to complete a task. Students typically had the expectation of themselves that they would finish the task before talking about other things.

When working on their final presentation, one group spent almost the entire 45 minutes of their work time in conversation about the assignment, with a short three minute side conversation about their teacher's recent name change (Day 8 small group audio). The nature of the discourse in this group was a back and forth between two of the group members about "how to do" different components of writing the presentation. Sally (she was one of the few students who chose to go by an American name) and VamMeej had frequent, short debates about how to do different parts of the assignment, like changing the color of a slide, inserting a table, finding the acceleration using mass and force data, and what to put on the slides. VamMeej often said, "I've never done this before" and "I'm not a writer!" Sally would then get frustrated with him while she was showing him how to do something, saying, "I'm just showing you how to do this!" but they were highly productive and generally kind to one another (Day 8 small group audio). They also switched back and forth between English and Karen, with more time spent speaking in English. This was different from when they were in their lab groups, where the more physical activities of building and testing their designs allowed for functional conversations in Karen. The nature of the academic writing they were doing here facilitated the use of English, but it did not facilitate the use of "the language of science" as the teachers had hoped. Their conversations were still almost exclusively functional—focused on how to complete a task.

When students did use the academic language of science, it was within a broader apprenticing discourse where the students were trying out academic language and receiving feedback from their teachers. This was evident in student writing, during informal check-in conversations with the teacher during work time, and in the final presentations where students either did or did not take up the academic language of science. Sally and VamMeej practiced the use of academic discourse when they were writing their presentation, trying out various ways to describe the success of their design and then asking either one of the teachers if they "got it right." VamMeej asked Sally to help him understand the acceleration calculations so that he could explain it, and then asked Ms. Davidson if they had the calculations right (Small group audio, day 8). During the presentation, he explained the data table very clearly, evidence of his having practiced his words:

> As you can see, these are our data (points to the table) for uh, rolling the car. We got to 140, but there's not much space so we did to 120. And our greatest acceleration was 211 and our lowest was 18.6 (Day 15 video (2), 03:50-04:20).

Although his use of the academic discourse was very clear, his knowledge of the science concepts behind these words was less clear. Ms. Davidson pointed out his mistake:

> Ms. Davidson: I think something must have happened to that last measurement. Maybe the car went to the side and it didn't get a good read.
> VamMeej: I don't actually know. But the little black box that's all it says. It said 18.6 something.
> Ms. Davidson: Okay (Day 15 video (2), 03:50-04:20).

Not only did he not understand the acceleration calculations and what it represented, he misunderstood the purpose of the force sensor, which was to give a number for impact force, not for acceleration. Students actually did some calculations to determine acceleration, but it is likely that he was not the group member who did this calculation. In this example, although his use of an academic discourse was successful, gaps in his content knowledge of science prevented him from reaching the high level of engagement within the disciplinary discourse of science that his teachers hoped students would achieve.

Andrea as a STEM learner

Teaching the other disciplines. Andrea's position as a learner of STEM integration and teaching the other disciplines of mathematics, engineering, and technology was an important part of the classroom experiences and classroom discourses during the unit. Andrea *used* the other disciplines in order to help her teach the science content she felt responsible for teaching. For example, the context of engineering as an application of the science disciplines was her predominant understanding and positioning of that discipline in her instruction. In one warm up activity, she shared a video simulation of the MARS Rover landing on Mars from 2012 and asked students to observe what happened to the rover at various points and to explain what law of motion was at work at each of those points. As is evident in the transcript (table 2.3), she directed students' attention almost exclusively to the science content, and did not consider the principles of engineering or the types of mathematical reasoning that went into this incredible NASA feat. Also evident was the nature of the discourse she used when explaining the principles of science applied in an example from the physical world. She pointed out the visible examples of air resistance, acceleration, and unbalanced forces, but struggled to explain how to observe the second law of motion.

Table 2.3 MARS Rover Warm-Up, Day 8 video, 10:45-12:45

1	Ms. Davidson	(Keeps the video going) Ok, acceleration is happening right? And look there is a parachute, what is that causing? Unbalanced force, right?
2	Ms. Godfrey	Do we see a little **air resistance** there? (referring to jet streams)
3	Ms. Davidson	Yes, a little **air resistance** there.
4	Ms. Davidson	(Pauses the video) Ok, so the acceleration due to Mars gravity is 3.87m/s/s so what law is at work there? (gestures right hand on top of left)
5	student	1^{st} law?
6	Ms. Davidson	(looks up to the right, breathes in, opens right palm on top of left)
7	student	Second law, second law.
8	Ms. Davidson	Second law, right? So **acceleration** (.) of a **mass** (..) what does that mean for itself right here? (points to the image on the screen). Why did they want that to happen, what is M times A?

		(.) Mass times acceleration gives you…. **Force!** (in unison with some students). Oh! Okaaay (.) So there's gonna be a force? Uh uh uh upon impact there's gonna be a **force** on the **rover** isn't there? So what did they put balloons all around it for?
9	student	((inaudible)) (gestures with hands)
10	Ms. Davidson	Helps with the, the undergoing force, right? So it doesn't crack up the rover. Ok, so notice that (points to screen) happened right before impact? The law's at work there, the parachute was an **unbalanced force** to slow it down. They had two things to protect the rover from the laws of motion, right?
11	Ms. Davidson	So um, what were those things that they were using to protect the rover and why, **what laws of motion** were at work? (pauses and looks down at her desk. Remains silent while students write).

The second law of motion requires an abstraction from observations of the physical world to a mathematical representation. The challenges of teaching the levels of abstraction is something that teachers of mathematics know well (Hazzan & Zazkis, 2005, p. 102), but something that a teacher of science who is just learning STEM integration theories and practices is likely less aware of. Later in this lesson, she returned to the second law of motion in her instruction, focusing on how to convert between units of measurement so that students' calculations for acceleration would be expressed accurately. The bolded phrases emphasize the language of mathematics.

> We have to **divide the gram mass by what** to get kilograms? **What does kilo mean?** (a student says 1,000). **1,000 right?** A kilogram is about the mass of one of those purple books (points to science text book). But a gram is the mass of a paper clip. So if we want to get the mass into the terms of kilograms, **we have to divide by 1,000.** ok? clear? **Take the total mass in grams and then divide by 1,000 and that's what you're going to use for your acceleration equals force divided by mass calculation**, got it? (Day 8 video (3), 03:00).

Here she chose to focus on the procedural understanding of mathematics in her instruction, and did not engage students in mathematical reasoning which would support the need to express Newton's second law as a mathematical representation. This is an important aspect of the discipline of mathematics, but one that Andrea was ill equipped to support in her instruction. Instead, she used the discipline of mathematics as a way to understand a concept of science.

Skipping the other disciplines. In some cases where Andrea had planned to do more instruction outside of her traditional science content, she ended up skipping it altogether. In these cases, Andrea chose to skip instruction because she did not feel the students needed it, or that the science content was more important for her to teach them. In the activity of the lesson on inverse and proportional relationships in graphical representations of acceleration data, she asked students to label the relationship represented by each of the three projected graphs. After they spent a few minutes talking with their partner, she brought them back together to discuss. Through this discussion, students asked questions to get a better understanding of the concepts behind the three graphs. Ms. Davidson attempted to answer their questions, however she let them know that she was aware that students in this class had not had Algebra 2 yet, so she held back from fully explaining the concepts, instead reiterating, "I just want you to know that as X gets bigger, y gets really small" (Day 4 video, 24:57). The mathematics instruction provided an introduction to the mathematical reasoning process behind these graphic representations, however she chose not to go in depth with her instruction on these concepts because this deeper level of disciplinary understanding was out of sequence from the students' course schedule.

The other mathematics concept that Ms. Davidson used for the first time in her STEM unit was proportionality of mass and acceleration. This was to be expressed as a ratio, and intended to be an evaluative measure of the engineering design. She thought that if the students spent less money on materials, then the mass of their vehicle would be lower. Also, if the vehicle was able to withstand high impact forces, than the acceleration would be greater, therefore they could aim to achieve above a set mass to acceleration ratio. The instruction around this concept was pared down until there was only a minimal amount of directions given to students to collect the data and find the ratio. They were not clear on what the ratio meant, even in the last days of the unit when Ms. Godfrey needed to step in to clarify the use of the term ratio.

> Ms. Davidson: So you wanna **give your max acceleration to mass ratio**, ok. You guys know what ratio means, yes?
> Student: No.
> Ms. Davidson: So, that means like **you're gonna have the greatest acceleration to the lowest mass**. Alright? Or, if you were to **divide 1, divide by mass**, right? This one would be the **biggest number** and this would be **1.** You guys know what a ratio is? Proportion?
> Student: Proportion?
> Ms. Davidson: Have you used that in mathematics yet? Proportion or ratio? That's what you're going to do. You're going to **make it an acceleration to mass ratio.** OK?
> Ms. Godfrey: Ok, ratio. Let's pretend I own a bicycle factory. How many seats do I need for each wheel? Is it a 1 to 1 ratio?
> Students: No! Two to one. Two to one.
> Ms. Godfrey: No, it's two to one. So if I order fifty seats, how many wheels do I need?
> Students: 100! (Day 12 video (1), 33:37)

A few days later, Ms. Davidson was still trying to get students to understand the mass to acceleration ratio, but this time in terms of having students fill out a google form with their highest acceleration data and the mass of their vehicle. She asked them why they wanted the highest mass and the lowest acceleration, but students could not answer. She then explained it was because it meant the design was cheaper, but still had high performance at high acceleration, "Your boss probably thinks it's good to have less materials because it means less costs. You're an engineer so you want to save money too as well as have good science" (Day 14 video, 18:00). The instruction in the mathematics concepts behind this ratio was minimal, and just in time for students to complete a task or assignment like this google form and the final presentations. Although Andrea had bigger goals to integrate more mathematics instruction into her unit, in the end it was left out and replaced with quick explanations to move students along in their assignments.

Responding to technology challenges. Another significant aspect of Andrea's position as a STEM learner was her inclusion of new technology into her instruction, and the way she handled her own learning of new technology. Overall, Andrea had a difficult time with some of the new technology, particularly the use and sharing of digitally collected/created texts. Students used ipads, netbooks, and their own smart phone devices at various points in the unit to collect images and videos of their engineering process. The biggest hurdle in using these devices was getting past the licensing requirements for individually owned applications and software so that students could then share their data with their group members and teachers. A significant amount of instructional time was spent on teaching students how to use the various technologies in the unit. At one point, Ms. Davidson told students to just email the files to themselves so that they could access them later, but was surprised to learn that students did not know how to send an attachment in their email. She ended up teaching an entire lesson on the use of school email and the google drive resources their school account gave them access to (Day 10 video, 30:00-45:00). At another point, she realized students did not know how to create a powerpoint presentation, so she backed up, provided them with a template of the presentation, and showed them how to share a google file with their group members so they could all work on the presentation at the same time (Day 12 video (2), 48:00).

Andrea also struggled at times to learn new technologies herself, or the way she understood how to use it did not work and she did was unclear how to troubleshoot through the technology problem. She had multiple websites fail, internet connections falter, and did not know how to use some of the applications on the iPad students were using to collect data like the Vernier Physics app and the Slo Pro app for collecting video in slow motion. When she struggled, she might ask the other adults in the room for assistance, but she would get frustrated and step away from the class to try to trouble-shoot. When this happened, Ms. Godfrey might step in and take over the instruction, although there were times when this happened during extended day and then students would work or talk in their groups until she figured the technology out. Technology was intended to be a resource to support the science and STEM instruction, however it was most often a barrier to the efficiency of the classroom, slowing students and the teacher down in their attempts to accomplish classroom activities.

Threats to science teacher identity. Andrea's teaching identity was inextricably tied to the discipline of science. Stepping into a new role of teaching the integrated disciplines of STEM caused some real threats to that identity, which she both embraced and rejected throughout this experience. Inviting engineering into her classroom opened up the doors to student-directed inquiry and project-based learning that required her to relinquish control of the instruction at times. This was something she valued conceptually, although in practice it was very difficult for her to let go. When students were not as efficient with their use of time it particularly aggravated her. When students were redesigning their first prototype, they were unclear of the parameters for this process, so there were some groups who did not finish within the time limit. When she realized this, she was exasperated and lectured the class:

> **You were given 10 minutes plus** to come up with a new idea in your first group, based on your experience, what would you do differently? And come up with a new idea. Ok, so **everybody should have that idea documented in a drawing format right now**. In your new groups, you are going to bring that new idea. **I am stamping whether or not you have a new idea** (Day 10 video, 59:00).

The threat of the stamp was used to show that she was assigning points to their participation in this process. Unfortunately, discovering new ideas in response to engineering problems is complicated work, and probably not something students could do well within such a short time frame. What appeared to be off-task behavior to her was likely due to students' own frustration and confusion with the engineering design process. Students were unclear as to why they should design a new prototype when they found success the first time. Ms. Davidson's learning of the discipline of engineering likely led to this challenging situation, as well as the fact that we know little about how students learn engineering within the context of classrooms (Wang, 2011).

The collaboration with Ms. Godfrey also caused threats to Andrea's science teacher identity. When Ms. Godfrey would step out of the acceptable arena of language instruction and cross the line into science content instruction, Ms. Davidson would prickle, and hover until Ms. Godfrey stepped away from the front of the room so that she could take over the instruction. In one instance Ms. Godfrey was reviewing the relationships between the three variables of force, mass and acceleration in Newton's second law, while Andrea was taking attendance. When she heard where Ms. Godfrey was going with the instruction, she jumped out of her chair and interrupted, "Wait! I want to make sure we get this right. I want to make this clear that acceleration is equal to f divided by m, not the other way around. Yes, ok, perfect" (Day 5 video, 16:00). She then stayed standing at her desk until Ms. Godfrey finished her mini-lesson and she could take over the instruction again. Andrea's control of the science content instruction was an important part of her teaching identity, and when a disciplinary outsider introduced other interpretations of the science content, that identity became threatened.

Summary

This case highlights the situated nature of STEM integrated curriculum and instruction in an inner-city 9th grade physical science and English language classroom. Andrea Davidson developed a curriculum that she believed would support the particular needs of English language students in both meeting the standards for science, and supporting their language development. She saw the STEM unit as an opportunity to bring engineering into her classroom, which would provide an engaging purpose for students to learn physical science. Through collaboration with the English Language teacher Ms. Godfrey, instruction of the disciplines of STEM included important language scaffolds for teaching the academic language of the disciplines, as well as multimodal pedagogical representations of disciplinary concepts that facilitated students' learning in the disciplines. The students in this classroom relied on their lived experiences in refugee camps in Thailand as background knowledge to what it meant to be an engineer, and to understand the work of engineers as solvers of problems in the physical world, for broader social purposes. Student discourse in small lab groups was held in their primary language of Karen, and maintained a focus on the accomplishment of assigned tasks through functional discourse. Academic discourses were apprenticed in the classroom, however students did not reach the high levels of disciplinary discourse that Ms. Davidson had hoped to accomplish through this unit. Ms. Davidson recognized that she was a learner of STEM, and although she felt much more confident that she could do engineering in her classroom after this experience, she knew she still had much to learn. Andrea's position as a STEM learner was evident in the mismatch between her instructional goals in the other disciplines of mathematics, literacy, and technology and the actual instruction she delivered. It was also evident in the ways Andrea responded to perceived threats to her identity as a teacher when she struggled to successfully explain mathematics concepts, fumbled with technology glitches, and vied for control over the science content when Ms. Godfrey crossed the line into her physical science territory. This case helped to developed a portrait of STEM instruction as it looks in practice, and explored the many ways teachers and students co-construct this new frontier in science education.

Case 2: Heidi Fischer

Heidi came to the EngrTEAMS project as a teacher leader in her district, serving as the curriculum lead for the science department. Heidi taught 9^{th} grade physical science as well as Physics and Advanced Physics for seniors at Highlander high school, one of two large high schools in an-inner ring suburban district. Like Andrea, Heidi had attended previous STEM professional development opportunities with university faculty on the project, and had a few years of experience implementing an inquiry-based curriculum in Physics. This curriculum was organized around the larger core ideas of Physics, and flipped the traditional curriculum to provide lab experiences from which students could derive the principles and formulas of the discipline through experimentation and teacher questioning. For Heidi, the use of the inquiry-based curriculum had transformed her teaching in very positive ways. She felt that students learned more, at a deeper level, and were more engaged than they had been when teaching in other ways. Heidi had also earned an advanced degree in Physics, and her husband was an engineer. Heidi came to the project with a clear vision for what engineering and STEM integration would offer her 9^{th} graders, and had well-established goals for what she hoped to accomplish from this experience (Fischer Interview, June 23, 2015).

Throughout the year of professional development experiences, Heidi was a leader in our curriculum development team. Andrea and I turned to her for explanations of some of the more advanced concepts of physics as we were developing the curriculum, and her disciplinary expertise was a valuable resource to us. Heidi's case highlights the role of a teacher's science and engineering disciplinary expertise in the classroom implementation of a STEM integrated curriculum. This case describes the ways that a teacher's disciplinary expertise and her enacted identity as a teacher practitioner facilitated students' uses of STEM disciplinary discourses and the social practices of doing STEM in a suburban high school.

Modeling and Apprenticing STEM disciplines

Bringing students into the discourse of science. Heidi's primary goal for teaching the STEM unit, which was also a broader purpose for her science teaching in general, was to support students' development of deep conceptual understandings of the physics content she was responsible for teaching. Every teaching decision she made reflected her desire to reach that goal. She perceived this goal to be a challenge because 9th graders have not had a lot of the advanced mathematics courses that could support their learning of physics, but she also believed that the use of STEM integration and engineering activities better supported their conceptual understandings than traditional science approaches (Fischer Interview, June 23, 2014). When developing the student assessments for the unit, she talked about her desire to get students using the "language of science" when they had to explain their engineering design decisions. She introduced this goal by telling students she wanted them to "explain things in terms of Newton's laws" and that she would be asking them to do this in multiple ways throughout the unit.

> We're going to be doing a lot of practicing this unit explaining things **in terms of Newton's laws**. We'll look at something like a video or lab, and explain what you

> saw **in terms of Newton's laws** because the presentation you will be doing at the end of this unit will require you to explain the design decisions you made **in terms of Newton's Laws**. The idea is to give you guys lots of opportunities to practice that and get feedback on that. That's what I'm trying to get you guys to practice (Day 2 video, 00:29).

The primary pedagogical approach she took to encourage students to "use Newton's laws" in their explanations was to provide students with an observation or a hands-on problem-solving activity, ask them to explain what they observed, and then she would extend their responses by using the language structures and vocabulary of the discipline of Physics. A common place where this happened was as a "warm up" activity at the beginning of class. Heidi would show a video or do a demonstration, and then ask students to explain what was happening. For example, in the inertia warm-up, Heidi did two demonstrations: she pulled a table-cloth off a lab table and kept a tower of dishes standing, and then knocked a pie plate out from under a stack of toilet paper rolls and the plastic eggs dropped into containers of water (see figure 2.5). She and the students had a lot of fun with these demonstrations. The students were worried that the dishes were going to fall and one student yelled, "Don't do it! It's going to crash, please don't do it!" but of course, they were amazed that it worked. She asked them why the dishes did not fall when she pulled the tablecloth out, and Zoey shouted, "Because they were at rest!" to which Ms. Fischer repeated, "They are at rest, so they stayed at rest." She then asked them to consider why she stacked the dishes in a tower and a student said, "Something about the weight." She explained further, "It's easier because it has more weight, and more mass, and mass is a measure of inertia. When it is in a tower it acts as one object with lots of inertia instead of several things with a little bit of inertia." In these activities she would use questioning to elicit students' understandings and then she would translate those understandings into the language of physics; in this example, "Something about weight" became "mass is a measure of inertia."

Figure 2.5 Inertia Demonstrations

Recognizing that the whole-group conversations were meant to be introductory, she planned to use informal one-to-one student conversations at lab tables as a way to informally assess individual students' use of the science discourse she believed to be integral to their conceptual understanding of the physical science standards. These "informal check-ins" as she called them, followed a similar discourse pattern as the whole-group demonstration conversations. She would ask a question, a student would respond, and she would repeat their words exactly and extend their response with a further question or use of a specific science vocabulary term. In the following example of this, Ms. Fischer came to a lab group of all boys and rolled a die to call on one student at random, in this case Jin, to "explain the example of inertia in question number 8" of their lab sheet. He was able to rely on his written answer for only the first part of her inquiry, until Ms. Fischer pushed him to think beyond the scope of the original question, and then another student in the group, Carter, had to jump in.

Jin:	The washer's at rest and it will stay at rest while the paper (.) um (.) paper's being flicked.
Ms. Fischer:	Ok. So why is the washer staying at rest?
Jin:	Because whatever's at rest stays at rest.
Ms. Fischer:	Ok. And what would you need <u>to get</u> the washer <u>to move</u> with the card?
Jin:	(.)
Ms. Fischer:	We are going to do a little more on this…
Jin:	Maybe lift it?
Ms. Fischer:	Ok. And why would <u>lifting it</u> make the washer move?
Jin:	Um, I don't know that one.
Ms. Fischer:	Ok, can somebody help him out?
Carter:	What's the question?
Ms. Fischer:	What would it take to get the washer to move?
Carter:	If it had... if it was <u>attached</u> to the paper.
Ms. Fischer:	Ok, and why would attaching it to the paper make it move?
Carter:	Because it is a part of the paper (claps hands together), <u>it is one with it.</u>
Ms. Fischer:	Ok, so what is the paper <u>exerting</u> on the washer that makes it move?
Student:	((Inaudible))
Ms. Fischer:	Yeah, it would be some kind of force (Day 2 student group, 00:10).

In this exchange, she turned each of Jin's responses into a question, pushing him to think beyond the obvious answer to get at a deeper conceptual understanding of inertia. What is interesting is that before this exchange happened, Jin and Carter were discussing this very same question. Jin was not sure "how to word it" and asked Carter to explain the answer. Then, he asked him to slow down so he could write it down exactly. In this lab activity, Carter was positioned as knowing the right answers, and he had more of a "disciplinary insider" status than the others in the group, especially Jin. Jin relied on

Carter's use of the language of science in his own verbal responses to Ms. Fischer's questioning, an important part of his learning the language of science.

Similarly, in the whole-group warm up conversations Ms. Fischer would ask a line of questions to the students individually, and then open it up to anyone to answer, thus creating a climate of collective knowledge construction, and a social process of apprenticing the disciplinary discourse. The conversation in table 2.4 illustrates how ideas around inertia were developed, first through a back and forth between one student, Zoey, and Ms. Fischer in segment one, and then in segment two Ms. Fischer physically moved across the row of students to stand in a different place. This signaled to the group of students in that section to respond, of which four of them offered answers to her questions. Then in segment three the student Jade, seated in the back of the room, exclaimed as she made a connection to a roller coaster. This brought the students seated around her into the conversation and they laughed as she got excited to share her idea. Their laughter was also likely caused by her use of an informal register to explain her thinking. Ms. Fischer accepted her answer, as she had everyone else's, with little evaluation, only extending the response and bringing it into the discourse of science. She even mirrored Jade's register in her own, signaling her acceptance of Jade's response.

Table 2.4 Warm-Up Conversation on Inertia, Day 2 Video 04:00-06:00

1	Ms. Fisher	Are there a couple of people who would be willing to share their example of inertia?
	Zoey	When a car brakes really fast.
	Ms. Fischer	Ok, and <u>what happens to you</u> when you have a seatbelt on?
	Zoey	You <u>lean forward</u> but your seatbelt catches you and if you

	 Ms. Fischer Zoey	didn't have one on you would probably get flung forward. Ok, that is a great example of inertia. Why is it that you keep moving forward, or you get flung forward when the car brakes? Because an object in motion stays in motion.
2	Ms. Fischer Wafa Ms. Fischer Iris Ms. Fischer Becky Ms. Fischer Emmett Ms. Fischer	Alright, anyone have another example? Is riding in an elevator one? Ok, and when in particular in riding in an elevator do you experience inertia? When it goes up? *(gestures with hand going up)* Ok, when it's starting to go up. What do you feel when that elevator starts going up? Pressure going down *(gestures with hands going down)* Yeah, you kind of feel pressure going down. So what is your body trying to do when it starts accelerating upwards? Hmmm stay still? *(Nods)* trying to stay still.
3	Jade Ms. Fischer Jade Ms. Fischer	Oh, like a roller coaster! Ok. When on a roller coaster do you experience inertia? That's what I got from ((inaudible)) when you like goin down them hill and you like leanin out to see… *(student laughter)* yeah. Ok, when you're goin down a hill and your body's getting kinda flung around. Your body's again trying to keep moving in the direction it was already moving so you need those safety straps.

Three levels of engineering discourse. In addition to Heidi's goal for students to use the language of science to explain their conceptual understandings of Physics, she also expected them to learn about the field of Engineering. Since Engineering was a new area of study for students, Heidi spent a considerable amount of time introducing engineering through explanation of the context of the design challenge. First, she explained the challenge as follows: "The idea is there are some local chemical companies that are looking for a good way to transport their waste. And you guys are tasked with doing a small-scale model of what that could be. So you have to come up with some way to carry dangerous chemical cargo. And you have to convince the chemical companies that yours is the one that should be scaled-up, that should be turned into an actual chemical cargo carrier" (Day 4 video, 00:12). She then asked students to define the words "prototype," "constraints," and "criteria," and provided examples and descriptions of each of these new terms as student wrote notes in their science notebooks. Throughout this 15 minute introduction, Heidi introduced the broader discourse of engineering through direct vocabulary instruction, modeling, and application of the broader social practices of engineering. Table 2.5 breaks down the engineering discourse used in this lesson by three levels of abstraction. In the first and most abstract level, engineering was explained through the concerns of professional engineers as they engage in their professional practice. In the second level, engineering was explained through the activity of the classroom and the concerns of the teacher that students were learning science and having fun. In the third and most concrete level, engineering was understood through the concerns of the students that they knew what they needed to do to be successful, and also how much freedom they would have to contribute to the class activity. In addition, the use of the concept of "testing" is evident in each of the three levels, however the concept takes on three very different meanings as it moves through the levels, and by the third level, the term "test" is replaced with a "target" students will be trying to reach, as this is "not a contest." During the explicit instruction of engineering, there were different levels of abstraction, or applications of engineering that together worked to introduce the discipline of engineering to students.

Table 2.5 Levels of Engineering Discourse, Day 4 Video, 16:00

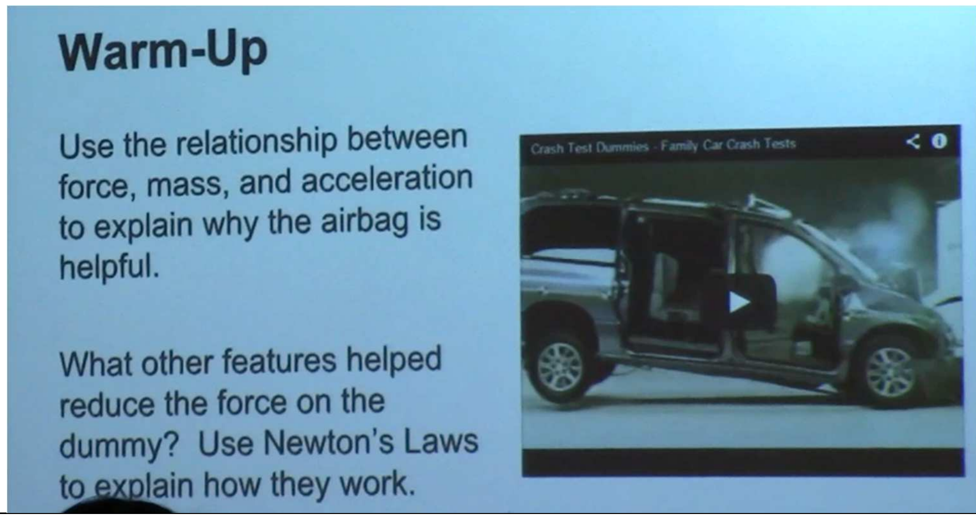
Level I	Level II	Level III
Engineering concerns *Engineers also have to do a lot of different **tests** because things don't always work quite the way you expect them to. So it's very, very common in any kind of engineering to do a prototype where you build it, you **test** it, and you try to break it to figure out what's working, what isn't working, so then you can improve it later on* (Heidi).	Science class concerns *So that's what you guys are going to be doing at this point. Over the next few days you are going to be working on a prototype and we're going to shoot for **testing** things out on Friday, which should be fun, we'll crash things and hopefully make a bit of a mess* (Heidi).	Student concerns *You're not going to be held accountable for how well your prototype does. But there are going to be some criteria. So, we've got what we're calling the success criteria. This is what a successful design will be. We're not doing a **contest** at this point. You're going to have a **target** that you're going to reach* (Heidi) *Can we bring our own materials?* (student)
Engineers are hired to design and build solutions to the client's problems	The teacher assigns a task to design and build a prototype that meets the "design challenge"	Students want to know how they will be graded and also how much freedom they will have to contribute

Engineering discourse was also used throughout the unit as an application of the science content of Newton's laws of motion. When Ms. Fischer asked students to "explain their design in terms of Newton's laws" she was also modeling and scaffolding students' use of the engineering process of testing and evaluating the design. For example, when students were asked to think about why their design worked or not, Ms. Fischer made sure that students understood the physics behind their evaluations. When students were working on their final presentations Ms. Fischer moved around the room and provided feedback on students' use of physics to evaluate the strengths and weaknesses of their designs. In one example, Ms. Fischer listened to Becky's explanation of the strengths of her design and corrected her use of the term "force":

> Becky: I have a question.
> Ms. Fischer: Ok
> Becky: On the first slide we're going to explain what Newton's first law is.
> Ms. Fischer: Ok, cool.
> Becky: And then on the next slide we're going to have pictures and we're going to speak during that. But um, tell me if this is going to work for it. We had cotton balls on the side and when it was going down it smashed. And when it smashed <u>the cotton balls were slowing it down, like the force.</u>
> Ms. Fischer: Ok, that's good. Um, I would say <u>slowing down the acceleration</u>. And then you could say that <u>made the acceleration smaller</u>, which <u>made the force</u> smaller (Day 11 student group, 00:14).

In another warm-up example, Ms. Fischer moved through the three levels of engineering discourse again when asking students to consider a video of a crash-test of a mini-van. In the video, the dummies were not wearing seatbelts, so the students were able to observe the results of a high impact force on the free-moving objects in the vehicle. She first introduced the activity as a "practice" for their final unit assessment where they would need to explain the success of their own engineering design "using Newton's laws." Then, she moved out to a broader level of engineering discourse by sharing what engineers do in this example of car manufacturers testing their designs through the use of slow-motion video. And finally, the task students were assigned after watching the video was to answer the questions about Newton's laws of motion as they observed in the video, which is a use of engineering discourse for the purposes of learning science. Again, she used these three levels of engineering discourse to design a learning activity for her students that integrated science and engineering (see table 2.7).

Table 2.6 Crash-Test Dummy Warm-Up, Day 5 Video, 01:00-11:00



Level III	Level I	Level II
Student concerns	Engineering concerns	Science class concerns
One of the things you'll have to do in this project as I've mentioned is you're going to have to use Newton's laws to explain why some element of your design was useful. Why did doing something a certain way make your cargo carrier better? ***I want to give you lots of opportunities to practice this.***	*Car manufacturers try to design their cars in a way where people are going to be relatively safe in a car accident and* ***part of how they test that*** *is they take a car, put some crash-test dummies in place, and smash it in various ways to* ***try to replicate*** *the different types of car accidents that could happen. And usually they do some video recording* ***so they can look back,*** *usually in slow-mo, to see what happened and* ***ask***	*As you're watching this, think about two big questions. First, using that relationship between* ***force, mass, and acceleration (Newton's second law)*** *try to explain why that airbag would be helpful in the crash. And I also want you to think about what are some features in a car that help* ***reduce the force*** *on the dummy.*

	themselves, *'Ok, what part of the car failed? What part of the car did exactly what we wanted it to do?'*	
This task is practice for the final assessment.	Engineers test their designs to evaluate the strengths and weaknesses	The classroom activity is to answer questions about Newton's laws of motion

Student Experiences of Learning STEM

Student problem solving. A large portion of the recorded student discourse while they worked in their engineering design teams could be characterized as "problem solving" and the nature of the problem solving conversations they had varied. Two of the recorded student groups consisted of predominantly male, and predominantly white students. In both of these groups, when the boys were talking with one another it was for the purpose of presenting ideas, dissenting ideas, and arriving at decisions. Additionally, most of these conversations included argument over the mathematical calculations they were responsible for generating. The two examples in table 2.7 present a typical back-and-forth about the calculations. The discourse pattern here is that a student presented a question or observation about an unknown calculation, followed by someone else disagreeing with the original result, and then after some back and forth they moved on to other tasks. Sometimes the discussion would come back up again after a few minutes, but often the original challenge to the calculation remained unresolved verbally, however they may have written down an answer. Also, because there was an evident right or wrong dichotomy to this discourse pattern, there was some offensive and defensive positioning happening in the conversation. In both of these examples, the boys were questioning the calculation produced by a technology, the LabQuest, which did not align with their own estimates. Although the boys recognized there was an error, they expected the technology tool to provide an accurate calculation, so they questioned their own understanding of the mathematics.

Table 2.7 Student Problem Solving Using Mathematics

Group 1 (Day 5 student group)	**Group 2** (Day 3 student group)
Emmett: Jesus. Our acceleration is 2,968 m/s? Anthony: For our last one? Emmett: Yeah, for our 30. Anthony: I did not get that. I got 3.3 Emmett: That was off of the labquest wasn't it? Anthony: I don't believe so. Emmett: What the actual equation is, that's a bit sketchy *(Silence)* Anthony: You sure? That seems like a lot. Emmett: Wait hold on. Anthony: Yeah, it should be .179, or it should be like 3.3 or something. Emmett: Not it's 2 hundred and something. Anthony: 296? I really doubt that. If that's meters per seconds squared, I really extremely doubt that. Would you need to divide it by 2 to get meters per second squared, or whatever? Emmett: Squaring 296 is like, 15. Anthony: Yeah.	Derek: What's .006 x .006? Carter: .006 x .006? That'd be like .0000036 or something like that. Derek: Is it really? No it's not. Carter: I don't know. Chaz: Cause you subtract a zero once you get to 36, it's point 00036. Carter: point 00, point 00036. Derek: According to this thing it's 434. Mason: 434? What? Jin, you can't even untie that, can you? *(Bouncing a ball on the table)* Jin: Yeah, it's four zeros and then 36. Derek: I don't know if that's right, but whatever. Here put a bolt on there.

There was also evident problem solving in the lab group discourse when students were creating and building their designs. In these conversations, one student would offer a suggestion for a placement of a material item or a way to attach things together, and then another would agree or disagree as they kept working on the physical materials, and decisions would get made fluidly. These conversations were fast-paced, there were multiple speakers, and less of a hierarchy of power than in the conversations regarding perceived right-answers. In this short excerpt from a longer conversation, Anthony and Emmett go back and forth making multiple decisions in just a few seconds' time. The flow of ideas went back and forth between them until they arrived at a decision, which opened the doors to another decision that needs to be made.

> Emmett: Ok do we want to attach it on top of the board, or on the side? Like this, or like this?
> Anthony: We might want to cut the curves off for the bottom, because it will have more area down. And then we would have (…) huh, we would need (.)
> Emmett: We're going to cut these in half.
> Anthony: It might be too short.
> Emmett: So then do we need (.)
> Anthony: We need <u>four more popsicle sticks</u> and we don't have the budget. <u>Ok ok, solution!</u> You don't need that much. You only need support <u>at the bottom</u> or top pretty much, or just the bottom to keep it secure. The top could bear the weight because <u>it's triangulated</u>. So if we cut these down so that there's support only at the bottom…
> Emmett: I don't agree (.) I could see how it could work like this. With it <u>at the bottom</u> and the top of it would be fine.
> Anthony: Ok, and then the two would be there? (Day 5 student group, 20:00).

In the groups of girls, the nature of the problem-solving conversations was very different. For the girls, the discourse was more contextualized in the social world and less focused on the specific problem they were trying to solve. There was still a back and forth, but the ideas they presented and the questions they asked one another were less specific to the aspects of the design than in the boy groups and instead opened up broader social discourses. For example, Alexa's description of her plan did not include specific measurements of materials or reasons for her thinking, while Wafa's interest in the conversation was to make jokes and laugh about their design together. She even took a photo of Alexa's design and texted it to a friend of theirs in another class.

> Alexa: I think we're gonna duct tape like the egg down, and then the egg if it doesn't hold with the duct tape, it will crash into there.
> Wafa: But what if it goes to the side? Then we all die?
> Alexa: But then the tin foil's gonna like cover the egg so the duct tape won't stick to the egg, but I don't know about that.
> Wafa: *(laughing)* So you're gonna wrap the egg in tin foil?
> Alexa: I mean, like the top.
> Wafa: I texted this to Emily and was like, this is our class experiment, and she was like, what the heck is that? *(laughing)* I was like, it holds our egg! (Day 9 student group, 00:18).

Although Wafa might appear cruel in this exchange, they were both smiling and laughing during this conversation, seemingly not taking the task as seriously as the groups of boys. In fact, at the end of the first design challenge day while the girls were laughing and taking pictures of their designs, Anthony was audibly frustrated that his group ran out of time before they could finish building. He was angry because they were not given adequate scissors to cut popsicle sticks. He cursed the scissors and the task, and said into the audio recorder that if their design failed it "wasn't their fault because the scissors were shit" (Day 5 student group, 00:38). This unexpected difference between the all boy and girl groups revealed that the nature of problem-solving discourse in STEM integrated curriculum is contextualized within the broader social contexts of the students who participate in it.

Social practices of a STEM classroom. Ms. Fischer's students experienced STEM integration and the disciplines of science, mathematics and engineering through the already established social identities and practices within this classroom space. Most of these students had been together for years in middle school and elementary classrooms, therefore it is likely that their pre-established social identities and practices influenced the ways they interacted with this curriculum. For example, Chaz was perceived by the teacher and other students as a joker, and he did tell quite a few jokes while he worked in the lab group. Ms. Fischer called Sarah “a quiet student” and when her group was audio recorded, she did not speak for the entire 20 minutes, nor did she answer any questions I asked when I visited her group in class. Vince and Zoey were often off-task during lab activities, which Ms. Fischer confirmed was typical behavior for them. We would expect to see these same social behaviors during the STEM unit, and for the most part I did, but what was interesting were the few moments where students enacted a different and surprising social identity. For example, Vince, who was often off-task and barely passing the class, came over to Emmett and Anthony’s group during an engineering building lab day. In the video recording of this instance, he moved slowly over to their table and leaned back on a lab stool; his body language communicated boredom and disinterest. However, listening to the audio recording it became apparent that he was actually frustrated with a group member who was micro-managing the entire project, and not letting him participate. He went over to Anthony and Emmett to vent because Anthony was that same student’s lab partner for another project and could relate (Day 5 lab group, 00:15). Another student, Becky, was the only student in the class receiving special education services for a learning disability. Ms. Fischer perceived her as “hard working” but “struggling” to keep up with the course content. However, listening to the audio recording of her lab group during the presentation writing and designing day, she was very much the leader of the group, delegating tasks and answering other students' questions about the science content, powerpoint and google technologies, and the order of their presentation (Day 11 student group). Although it is not clear if these were in fact new social identities for the students, they were surprising to Ms. Fischer and me. Ms. Fischer believed that the engineering design challenge offered many students who were typically disengaged with science class new ways to participate socially in class (Fischer interview, November 21, 2014).

The students in this classroom also used the majority of their lab time as a time to socialize and have fun with their friends. They accomplished the tasks that Ms. Fischer assigned to them, and they also found ways to socialize about other topics, or play made-up games with the lab equipment and engineering materials at their stations. This made the lab group discourse very complex and interdiscursive, quickly shifting back and forth in topic between the task at hand, other social activity in the groups, and broader social activities in their lives like relationships, other classes, sports, television and movie references, etc. As students were engaging in science and engineering activities, they were relying on familiar social discourses and not using the "language of science" with one another in the way that Ms. Fischer had hoped to see. In fact the only times when students were using the discourses of science and engineering was when Ms. Fischer directly asked them to do so, either verbally in small groups or in writing when they needed to hand something in as an assignment. The social practices of the students were an evident context through which they experienced the STEM integrated activities of the classroom.

Heidi as a STEM Practitioner

Teacher as facilitating efficiency. Heidi's teaching identity could be characterized as a teacher practitioner; she had a high opinion of teaching as a profession and worked hard to meet high expectations for herself and lead other teachers to do the same. Part of this identity was tied to efficiency; she believed that if she was being efficient as a teacher then she was being effective. This was evident in the day-to-day tweaks and changes she made to the design testing procedures throughout the unit. On the first day of testing their designs, student groups were assigned to be at one of the four testing stations. She walked through the instructions for how to complete a test, and told them that they should observe the other groups that were testing when it was not their turn (Day 6 video, 00:29). On the second day of testing, she projected a list of each student group assigned to the four testing stations so that students could take responsibility for the schedule for rotation. "When you are done testing," she told them, "you should tell the next group on the list that it is their turn," however she still had to track down students to tell them when it was their turn throughout the class period (Day 7 video). The next testing day was a few days later when students were testing their second prototype, or what was called their "redesign." This time she had signs taped to the ramp boards with the list of student groups in order, and again reminded them that it was their responsibility to tell the next group of students when it was their turn to test. This time the process ran efficiently, and what took two class periods the first time was cut down to one (Day 10 video). In an interview with Heidi after day 10, she expressed her satisfaction with how smoothly the testing went this time around and felt accomplished that she was able to get it done in a shorter amount of time.

Using Engineering to validate teaching decisions. For Heidi, being a STEM practitioner was also about modeling for students "what engineers do" throughout the unit. She did this by using examples of how engineers might approach one aspect of the engineering design to validate her own teaching decision. For example, in response to a student's question about the high price for bubble wrap on the budget list Heidi explained:

> The point of having prices on materials is not to limit the amount of materials because I could get an infinite amount of cardboard if I wanted to, but the point of having the prices is to <u>give you guys some experiences</u> that <u>real</u> engineers have to deal with. For example, if you go work for Apple and you've designed the new iPhone, they have <u>an idea</u> of how much customers will <u>pay</u> for devices so they tell the engineers to design a device that costs <u>no more than this dollar amount</u> so they can still <u>make money</u> (Day 4 video, 00:25).

Another time she decided to have groups pair up with a group at a different table so that they could share their design ideas with new people to get feedback. She justified this decision to them by reiterating an earlier point she made about how engineers are collaborative: "Since this is not a competition, we're trying to get everybody to have a successful design. The reason for this is that if we were working together to get the best design for our company, we would all benefit from putting forward the best idea possible" (Day 8 video, 00:41). Before the first day of testing, she asked them:

> Would an engineer do just one test and say, <u>that's good enough</u>? No! What do they want to try to do? They want to do multiple, yes, but an engineer will usually try to <u>break their design</u> when they're testing their prototype. They want to figure out, <u>where does their design fall apart</u>? Where does it <u>stop working</u>? We're going to have you guys try to reach that same point. Every group is going to be trying to smash their egg. So, we want to figure out <u>what is the limit</u> of your

> design. So you're hoping that it will survive when the ramp is at 30 cm, but you will go all the way up until it breaks. So we want to make a mess in here (Day 6 video, 00:16).

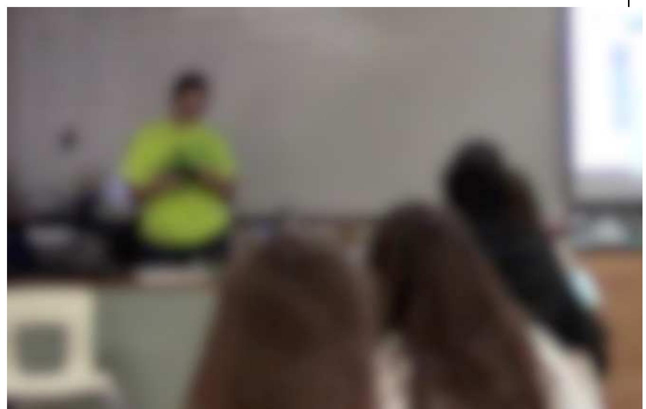
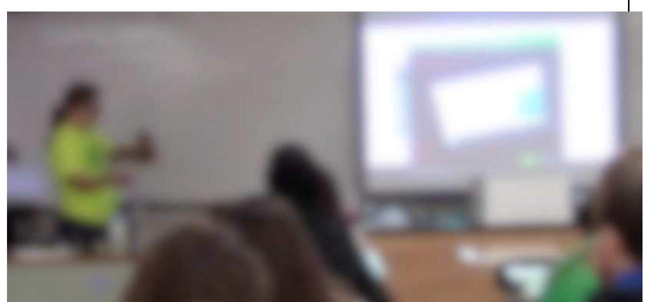
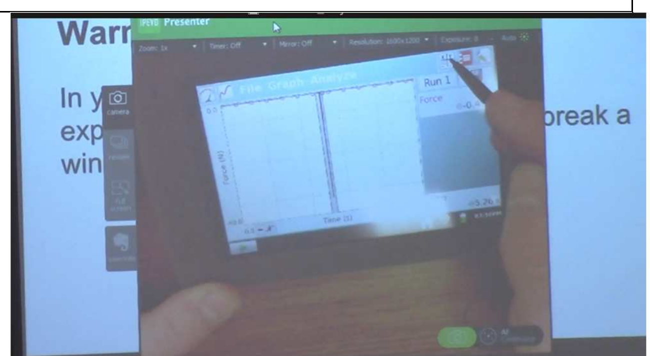
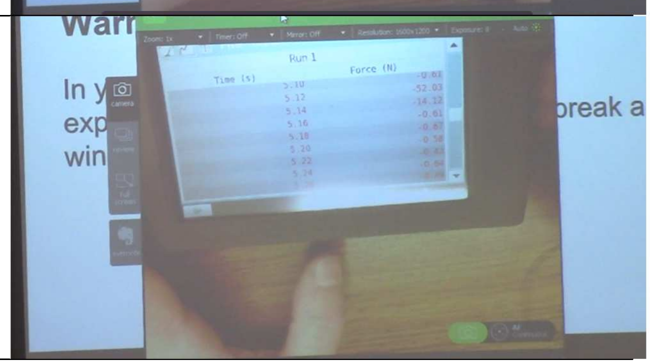
The challenge to this set-up for her activities was the assumption that the engineering design process would successfully be replicated through the activities she assigned. At the end of the first day of testing, many students' eggs did not break. They raised their ramps as high as they were able to, but their designs were very successful. This made the purpose for the re-design less authentic because an engineer only redesigns their prototype once it reached a breaking point, and theirs did not break. When this situation arose, Ms. Fischer shifted from validating her teaching decisions from the context of engineering, to regain credibility through the context of doing school and learning. She raised the challenge level, telling students that there was a fire in the Dixie cup factory so the price of Dixie cups went up, she moved them into new groups, and she also challenged them to be more inventive by trying out a new idea (Day 7 video).

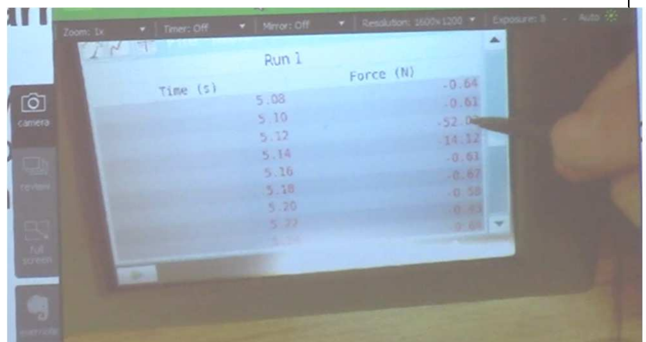
Throughout the unit, engineering was positioned as a way to give a broader purpose to students for participating in Ms. Fischer's assignments and activities. Ms. Fischer believed that engineering provided an engaging context and purpose for her students' learning, and it also seemed to do the same for her teaching decisions. The use of engineering as a motivator offered to students seemed to give credibility to her teaching decisions.

Modeling and applications of technology. An important part of Ms. Fischer's teaching identity was the efficient use of technology to support her teaching and her students' learning. She came to the project having just purchased a large amount of

LabQuests, force sensors, and a force plate that could measure larger forces of impact than the sensors. Because this was an important goal for her, she took the time to model the use of various technology tools throughout the unit, and explained to students how the use of the technology would better help them to observe Newton's laws of motion. The discourse when modeling and introducing new technology tools took the form of a step-by-step how-to demonstration. She modeled the use of the various technologies in procedural order that the students would use them in their lab. Technology was not presented as an exploration tool, or offering a way to innovate, instead it was very much a tool for collecting data following a specific procedure determined by the teacher. Table 2.8 presents a modeling lesson where Ms. Fischer used a document camera to project the LabQuest on the SMART board. She demonstrated the procedure for collecting force data from the LabQuest while explaining what she was using. As she explained, there were a number of times where she used "thing" or "thingy" to describe an object she was looking at. When she did this, she would try to expand her use of the pronoun with more specific vocabulary, but at times she did not have the vocabulary, like in segment 5 where she said to "grab this thing" to select a larger section of the graph. The use of an informal register and unspecified nouns when explaining technology was very different from the modeling of engineering and science discourse than Ms. Fischer did during the unit. Technology had less of a clear disciplinary vocabulary base than the other STEM disciplines in the discourse of Ms. Fischer's classroom.

Table 2.8 Technology Modeling, Day 6 Video 10:45-14:00

1	There's another piece of data we can get and that is the force. So we have this handy-dandy force sensor that you guys are going to use today. So these cars they got this peg in the front (…) what we can do is these force sensors can just slide right over the peg… The force sensor just plugs in to one of these LabQuests, and you guys used these the other day.	
2	So what you'll do is when you're ready to test your going to go to the graph, you're going to have whoever is in charge of the LabQuest to hit play, and let the car roll down the ramp and when it smashes into the wall you get a nice big spike.	
3	Now we want to actually put a number to that spike. The easiest way to do that, to get exactly what that force is, is you can use that little stylus, that pen-thing, to highlight the spike on the graph. (adjusts the lighting)	
4	Then, if you click that button up here that has x, y, it's going to bring you to a table and those two things, those data points that you highlighted on the graph, are going to be highlighted on here.	

5	You can tap these arrows to scroll up and down on the grey part, or you can grab this thing, it goes a lot faster and you want to find the biggest number. So the biggest number here is at 52. So that means that's the biggest force that when I just slammed my hand against the force sensor that the car picked up.	

Ms. Fischer wanted to use a variety of technology tools in her STEM unit, but she only wanted to use it if it was going to benefit her students' learning of STEM concepts. She decided to discard the plan to use the Vernier Video Physics app on the ipads because it did not collect accurate enough data for the students to be able to do the calculations and graphical analysis she wanted them to do with the collected data. Instead, she decided that she would use a stop watch and have students collect time and distance and graph the acceleration by hand, a more traditional approach. Ms. Fischer was confident and competent in her use of a wide range of technology tools, however even with this competence, the technology was at times ineffective in achieving her instructional goals. When this happened, she was quick to let go of the use of technology for the goal of efficiency.

The authority of science. In this classroom, despite the integrated nature of the STEM unit, the discipline of science was dominant in the learning goals, the activities, the instruction, and the modeled discourses. Ms. Fischer's identity as a physical science teacher, and the context of science class, was the vehicle for STEM integration.

Engineering, mathematics, and technology were all *applied* in order to learn and teach science content. Even more broadly, Ms. Fischer's identity as a *physicist* was important to her enacted science teaching identity. When concluding a lab on Newton's second law, she modeled to the students how to make a trend line in a graphical representation of the relationship between mass, acceleration and force. She explained, "That relationship is a very important one in science. I'm going to give you guys a formula that gives this relationship that I want you guys to put on the reference page of your notebook…So getting this formula **is the big payoff** of this lab, and that formula is going to end up being a very, very important relationships as you guys start designing your cargo carrier tomorrow" (Day 3 video, 47:50-52:50). Although the students experienced Newton's second law in a variety of experiments during the lab, Ms. Fischer only validated this one way of knowing through the formula for Newton's second law. This disciplinary way of representing the knowledge of physics was extremely important to Ms. Fischer. Even though she articulated her desire that students "understand conceptually the principles of forces of motion," she did privilege the disciplinary ways of representing those concepts over student-constructed ways of knowing that occurred during lab activities.

In another example, Ms. Fischer had a student drop a basketball onto the force plate when it was bare, and when it had a towel on top of it. They saw that the force of impact was less when the towel was on the force plate. She asked a student to explain why the force was smaller when the towel was on top of it. He said it "absorbed the force" to which Ms. Fischer extended with "The towel can squish, so that gave the basketball a little more time to change its motion. Acceleration is a change in velocity over time so like an airbag, we want to design something that will decrease the acceleration of the egg" (Day 4 video, 10:00). Here she took a students' understanding "it absorbed the force" and rephrased it within the disciplinary discursive way of explaining acceleration. She then uses that disciplinary understanding as justification for an engineering design decision, "like an airbag."

The privileging of the science discourse over other ways of explaining and representing scientific concepts in this classroom was most evident in the final presentations of the students. Although there were a variety of visual elements of the final powerpoints, the explanations students wrote and verbalized during their presentations were very similar, making use of the disciplinary discourse modeled by Ms. Fischer throughout the unit. As evident in table 2.9, the groups explained in terms of "balanced and unbalanced forces," "forces of impact," and "more or less force" applied to the design. When pressed further during their presentations however, students moved back into the use of familiar discourses to respond to Ms. Fischer's questions. For example, when asked to further explain their design, Iris explained, "This front part here acted like a seatbelt for the egg, and kept it from flying out" (Day 13 fieldnotes, 20:00). It was evident in these presentations that students did learn about Newton's laws of motion at both a conceptual level, which they used their own words and analogies to explain, and were just beginning to understand the laws of motion at a disciplinary level as they were apprenticing the disciplinary discourse that was modeled and privileged in Ms. Fischer's classroom.

Table 2.9 Apprenticing Discourses in Student Presentations

Group 1	As the cart accelerates the three sides of the triangle act as an **unbalanced force** preventing the egg from moving.
Group 2	Put more cushion on the top and bottom part of where the egg will be so that so that when the cart crashes into the wallboard the cushion will compress causing **less force** to be worked on the egg.
Group 3	The foil & cotton encased the egg, restricting acceleration which **reduced the force of impact** on the egg.

Summary

This case highlights the disciplinary discursive ways of representing science content knowledge during a STEM integrated unit. Heidi's goal of supporting students to "explain things in terms of Newton's Laws" was evident in her modeling of the scientific discourse she expected students to use when creating their own explanations of their observations. She provided students with a variety of interactive demonstrations, videos, and lab activities to develop students' physics conceptual content knowledge and to elicit students' use of scientific language. Students in this classroom community apprenticed the disciplines of STEM through their use of scientific language and participation in an engineering design challenge to solve a real-world problem. The discipline of engineering, a relatively new discipline to K-12 education, was presented to students through three levels of engineering discourse; professional concerns, classroom and learning concerns, and student concerns. Each of these levels of discourse introduced engineering as having a set of vocabulary and practices that were particular to the discipline, unlike technology which was presented to students as a procedural tool for collecting and presenting scientific data, and not its own discipline.

The students in this case learned STEM by engaging in problem-solving discourses within their small groups, and these discourses presented gendered patterns among groups. While the boys dissented in order to arrive at the best idea or decision, the girls offered ideas to either be accepted or rejected by the group, and took the design process far less seriously than the boy groups. For all students, engineering offered new ways for students to participate socially in their science class. The lab groups were always a fun time to socialize with friends, but during the STEM lab activities, students took on different social identities than in traditional labs. While in lab groups, students used familiar social discourses with one another, and did not use the language of science unless the teacher was directing the conversation or activity.

Heidi's enacted identity as a teacher throughout this unit was one of a STEM teacher practitioner, who had extensive disciplinary expertise and confidence in her knowledge base and pedagogical representations of her knowledge. She was an efficient teacher, who adjusted her instructional approaches until she achieved a desired level of efficiency. The use of a STEM integrated curriculum gave her an opportunity to use the discipline of engineering as a way to validate her pedagogical and instructional decisions with students, situating her goals for them within a broader social discourse of engineering in society. Despite the integrated nature of STEM, the discipline of science and scientific discourses were privileged over other ways of knowing and representing student learning in this classroom community. In Heidi's approach, STEM was very much a vehicle for teaching physical science content, and the discourses and languages of the classroom revealed that science was at the epicenter of teaching and learning.

Summary of Chapter 2

This chapter has presented the two cases of Ms. Andrea Davidson and Ms. Heidi Fischer in order to examine the nature of disciplinary integration of a co-developed STEM curricular unit in two very different classroom contexts. The next chapter presents the cross-case analysis and a discussion of a process for disciplinary integration in science classroom discourses. Implications for teachers across school and community contexts are also considered in the upcoming chapter.

Chapter 3:

A Process of Disciplinary Integration in Science Classroom Discourse: A Cross-Case Analysis

Introduction

This chapter presents the results of a cross-case analysis for the study of disciplinary integration in 9th grade physical science classroom discourses. Through the use of analysis strategies for grounded theory as well as Critical Discourse Analysis theory and methods, a model of a process for STEM disciplinary integration in science classroom discourse was developed. Each of the four domains of the disciplinary integration model are presented with evidentiary support from each case, as well as data displays of results from the CDA approach. The chapter concludes with a discussion of the developed cross-case model of disciplinary integration in STEM classroom discourses.

Review of Research Questions and Theoretical Perspectives

The following research questions were addressed in this contrasting case study of 9th grade physical science classroom discourse. The verbs are italicized to place emphasis on the issues of power of interest to this study, and the underlined nouns represent the unit of analysis:

4. How do teachers and students *position* and *negotiate* disciplinary knowledge within classroom discourses during STEM integration and what does this *reveal* about broader disciplinary Discourses?
5. How do teachers and students *disrupt* the authority of discipline divisions during a STEM unit and how does that *impact* the co-constructed learning and situated identities of participants?
6. How do the evident classroom and disciplinary Discourses compare across two classroom communities using the same STEM unit, and what might account for any differences?

As was discussed in chapter two, the study of classroom discourse is a fruitful direction of study in questions of learning and social practices of classroom communities. Specifically, this inquiry is concerned with what teachers and students learned during a STEM integrated unit, with learning defined through a sociocultural theory of learning (Lave & Wenger, 1991). In this study, learning was observed and analyzed as the reconstruction of knowledge that took place in social practice. I considered the ways participation in discourse communities involved learning by how participants took up existing discourses or disrupted and transformed fixed discourses, as well as the ways identities and relationships were impacted by social experience (Lewis, Moje, & Enciso, 2007). Learning is not only participation in discourse communities, but also the process by which people become members of discourse communities, resist membership, are marginalized from or marginalize others from membership, reshape discourse communities, or make new ones (Lewis, Moje, & Enciso, 2007). Therefore, opportunities to learn are shaped by power relations and access to power, so questions of agency and access to knowledge and social practices are also addressed through the study of learning.

The research questions also address the relational and situated issues of power inherent to the teaching of academic disciplines at higher levels of schooling, and therefore call for the use of a critical approach to discourse analysis (Fairclough, 1992). As Fairclough explained, critical approaches differ from non-critical approaches in the description of how discourse is shaped by relations of power and ideologies, as well as the effects discourse has on social identities, relationships, and systems of knowledge and beliefs. Relevant to this study, the ways participants positioned knowledge and the academic disciplines, as well as the ways broader institutional disciplines were negotiated, re-presented and disrupted within classroom discourse were addressed, which provided necessary analysis for the development of a grounded theory of STEM integration.

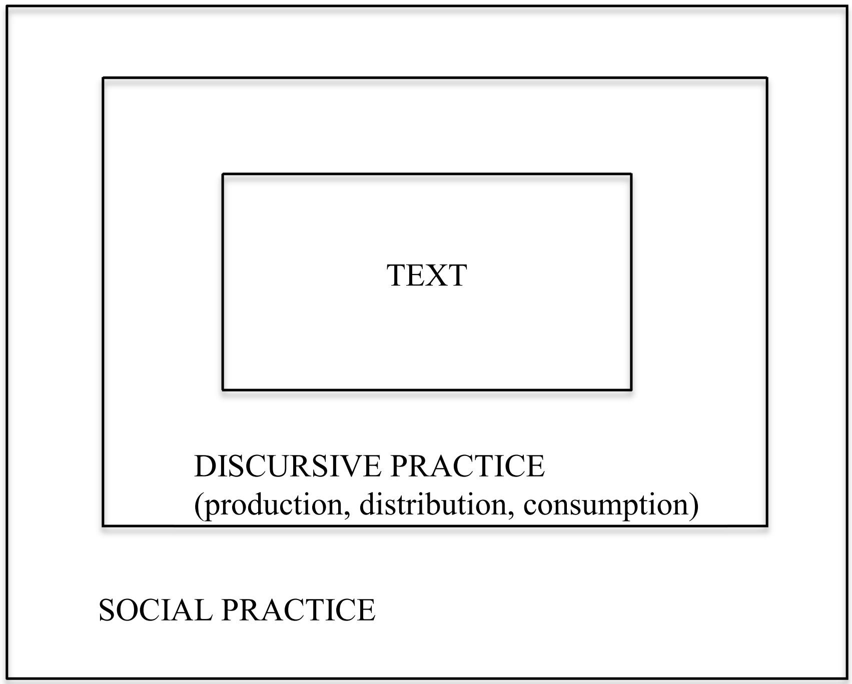
Critical Discourse Analysis

What is a discourse? In linguistics, discourse has historically been used to refer to extended samples of spoken dialogue (Harris, 1952, as cited in Fairclough, 1992) however, more recently linguists have viewed discourse as a transaction between speaker and listener, or writer and reader, and therefore a *process* of producing and interpreting texts through language (Fairclough, 1992, p. 3). Discourse is also used by social scientists to refer to different ways of structuring bodies of knowledge and social practice (e. g., Foucault, 1982). From a social view of discourse, Gee (2014) distinguishes discourse as "language-in-use," or language used for specific purposes in specific social contexts. Through this view of discourse, analysts can study the information/content, the actions, and the identities apparent within language-in-use (Gee, 2014, p. 20). Gee's approach foregrounds the identities found within discourses, and more broadly, all of the evident cultural practices, attitudes, motivations, limitations etc. that are a part of communication within cultural groups. For Gee, discourses involve situated identities, ways of performing identities and activities, ways of coordinating tools and symbols, and ways of "acting-interacting-feeling-emoting-valuing-gesturing-posturing-dressing-thinking-believing-knowing-speaking-listening (and in some discourses, reading and writing as well)" (Gee, 2014, p. 38). Participation in a discourse requires "recognition" by the other participants of that discourse; one must be able to combine language, action, values, symbols etc. in such a way that others can see you as a "particular type of *who* (identity) engaged in a particular type of *what* (activity)" (2014, p. 18). Some examples of local discourses that this study examined within science classrooms are "science discourses" and "student discourses." While examples of broader social and institutional discourses analyzed in this study include "Engineering discourses," "STEM integration discourses," and "Physics disciplinary discourse."

What makes discourse critical? According to Fairclough (1992), discourses do not just reflect or represent social life, they construct or constitute them in different ways, and position people in different ways as social subjects. For this reason, discourse analysis that applies a social theory of discourse moves beyond describing discursive patterns and practices, but also shows "how discourse is shaped by relations of power and ideologies, and the constructive effects discourse has upon social identities, social relations and systems of knowledge and belief, neither of which is normally apparent to discourse participants" (Fairclough, 1992, p. 12). Therefore, the "power" of CDA is in the methodical study of how broader social discourses are produced in everyday discourses, and "how these productions reflect and instantiate systems, structures, and institutions of power" (Lewis, Moje, & Enciso, 2007).

Also, a critical approach requires examining the relationships between discursive, social, and cultural change by showing connections that are hidden (Fairclough, 1992, p. 9). Fairclough offers a three-dimensional conception of discourse, where the text is featured at the center, with discursive practice (explained as the production, distribution, and consumption of the text) around it, and social practice circled around them both (see Figure 3.1). The analysis of discourse then, takes into account all three of these dimensions of discourse. Additionally, in his theory, texts are both "intertextual," which he explains as the property texts have of being related to other texts, never existing in isolation from others, and are "historic," referring to the connections texts have to texts of the past (p. 84). Interpretation of the apparent discourse from Fairclough's social theory of discourse offers opportunities for examining historical as well as multiple discourses, connecting the social with the linguistic.

Figure 3.1 Representation of "Three-dimensional Conception of Discourse" (Fairclough, 1992)



Analysis Procedures

Cross-Case Analysis

After the development of each of the cases, I moved to the construction of theoretical categories by engaging in theoretical coding of the data, reading data across cases incident by incident, and seeking out patterns that were both descriptive and insightful. I aimed to establish patterns that also demonstrated "analytic precision and the establishment of abstract theoretical relationships" (Charmaz, 2014, p. 213). Identification of theoretical patterns led to expanded and collapsed theoretical codes, which were then used to group and sort the data across cases. From the grouping of the data by theoretical codes, I was able to establish broader theoretical categories that responded to the research aims of constructing a grounded theory of disciplinary integration in classroom discourse. These categories were drafted a number of times, each time revisiting the data within each case and asking how the language of the categories reflected the studied experience, how the ordering of the categories reflected the studied experience, and if each category adequately accounted for all of the data, not just those data that best fit into the logic of the model. Once all data were accounted for in the model, I renamed each incident of data by category in order to see which codes were the same across cases, and which codes were specific to each case (see Table 3.1). I then tallied the number of codes within each case to ensure evidentiary warrant for each of the established categories across cases (see Table 3.2).

Table 3.1 Codes and Categories Across Cases

	Unique to Heidi's Case	Across Heidi and Andrea's Cases	Unique to Andrea's Case
Re-presenting disciplines	Sharing joy of learning in the disciplines	Working for an engaging purpose Applying disciplines to understand other disciplines	Collaborating on instruction
Modeling & Apprenticing disciplines	Positioning science disciplinary knowledge over other ways of knowing Relating conceptual understanding to disciplinary knowledge	Explicit purpose is teaching disciplinary discourse Scaffolding science discourse with questions Scaffolding disciplinary discourse with literacy instruction Appropriating disciplinary discourses	Relying on functional discourses & resorting to primary language
Disrupting disciplines	Experiencing disciplines through social worlds	Disrupting science learning goals with engineering activity	Experiencing disciplines through lived experiences

	Appropriating student everyday discourses Disrupting disciplinary discourse with multimodal pedagogy	Vying for control of instructional decision-making
Learning new disciplines	Positioning and responding to technology challenges Positioning technology as a tool to teach literacy and mathematics Skipping over literacy and mathematics instruction Threatening science teacher identity	Positioning and responding to challenges of teaching “other” disciplines

Table 3.2 Frequency Counts of Codes for Each Case

	Andrea	Heidi
Re-Presenting	6	9
Modeling	12	32
Disrupting	21	17
Learning	20	14

Data Displays

The transformation of the data into transcriptions and data displays were an important first step in the CDA approach as I view transcription as the application of a theoretical lens (Ochs, 1979, as cited in Fairclough, 1992). In all languages, speech is produced in “small spurts” and unless we pay attention, our ear puts them together and gives us the illusion of speech being an unbroken and continuous stream (Gee, 2014, p. 148). In English, these little spurts are generally a single clause long, with a verb and the information around it, or what Gee calls "idea units." These little spurts also use one "intonational focus," or one pitch change, further signaling the bundling of ideas (Gee, 2014, p. 234). Thus, the first act of CDA was transforming smaller transcripts of speech into data displays that broke the text down into smaller idea units. I selected texts based on theoretical sampling from the larger "corpus" of data, choosing segments of texts that represented typical discourse patterns observed within each of the cases in order to compare across cases. I then used a modified version of the Jefferson transcription conventions to signal aspects of my analysis in the data display (see Appendix C). Some of these data displays are included within each section of the chapter, however due to limitations of space, many have not been included. Each of the included displays were chosen for their ability to support the categories and themes clearly and concisely, and for the extent to which they represent typical discourse patterns of other texts within the same genre.

Application of Fairclough's Framework

Textual analysis. During the second level of analysis, I used Fairclough's (1992) framework of textual analysis, which includes seven features of analysis. These include attention to vocabulary, grammar, cohesion, text structure, force of utterance (or types of speech acts), coherence of texts, and intertextuality of texts (p. 75). After segments of texts were transcribed into data displays I read through each text and conducted a textual analysis by attending to the most salient features of that particular text. I was able to identify salient features of the text by relying on my broader understandings of how these texts were constructed and used in the classroom, as well as on my analysis and development of each case.

Discursive practice. Often during the textual analysis, I began to ask questions of the text regarding the processes of text production, distribution, and consumption in the social groups and relationships within the classroom community. Specifically, the features of discursive practice that were most useful to answering the research questions in this study were interdiscursivity (p. 124-130), which attends to the ways multiple discourses coexist within a text and the nature of the relationships between those discourses, and manifest intertextuality (p. 117-23), which raises questions about what goes into producing a text and the features that are "manifest" on the surface of the text. The results of this analysis are signaled in the text through textual analysis and are described within each section of the chapter.

Social practice. The objective of the analysis of social practice is to specify the nature of the broader social practices of which the discourse practice is a part, and the effects of the discourses on social practices (Fairclough, 1992, p. 237). The analysis of social practice within which the discourse practices belonged included questions of power relations, and whether or not the social practices were reproducing or challenging existing hegemonies regarding the teaching and learning of academic disciplines.
Here I considered what each text and discourse practice revealed about ideologies, epistemologies, and identities of individuals and communities when working to integrate

academic disciplines. These broader social practices are not always apparent to the participants of discourses and social groups, as Fairclough explains:

> It should not be assumed that people are aware of the ideological dimensions of their own practice. Ideologies built into conventions may be more or less naturalized and automatized, and people may find it difficult to comprehend that their normal practices could have specific ideological investments (p. 90).

Ideologies arise in societies characterized by relations of domination on the basis of class, gender, cultural group, and in the case of this study, disciplinary membership. During this level of analysis, it was important for me to remember that participants were actively creating their own connections between practices and ideologies, as well as being subjected to ideologies and hegemonies in their social practices. Therefore, the analysis of interview data where participants described their own experiences from their points of view were essential to this level of analysis.

Findings

From the four developed themes and categories of the cross-case analysis, a theory for a process of disciplinary integration was built. This theory was conceptualized as a process, because there was a loose chronology that happened for the teachers: 1) An act of re-presenting the disciplines of science and mathematics within an engineering framework, which then led to 2) planned and implemented instruction on the modeling of academic disciplinary discourses and students' apprenticing of those discourses, which then resulted in 3) unanticipated disruptions to the traditional disciplines of science and mathematics, and thus caused teachers to 4) learn new disciplinary content knowledge and practices. Each of the four themes are developed in detail through a presentation of the data an analysis, with discussion of the model of this process following in the subsequent section.

Re-presenting Disciplines

Re-engaging science. An important feature of the K-12 engineering framework is a motivating and real-world context for the engineering design challenge (Moore et al., 2014). The engineering design challenge of the *Chemical Cargo Carrier* unit worked to re-engage the discipline of science into new representations of science as applied within engineering situations. The teachers explained their instructional decisions in terms of "in the real world" and "what engineers do" which worked to provide a new purpose for students to learn and apply the scientific knowledge of Newton's laws of motion. Students experienced science by evaluating the success of an engineered product's ability to anticipate the force of impact. The experiences of observing the MARS rover landing, automobile crash-tests, and tests of their own prototypes re-engaged Newton's laws for them in engineered contexts. In a student focus group with Heidi's students, one student, Maya, explained what she liked about this engineering unit over others she had been a part of:

> I learned Newton's laws and a lot of engineering because the science class we had before, we had a lot of Legos and just put something together but I didn't learn a lot of science. In this class we had to understand Newton's Laws in order to build our design so like the science was important (November 19, 2014).

In the same focus group conversation, another student, Iris, shared that she learned more science through the use of engineering because it was more "hands on":

> I think this was better because when you are in a class taking notes, you might understand but when you're hands on and you need to know the things in order

> for it to be successful you like get a grip on it a little more. You can actually understand because you *need* to know in order to like do stuff and be successful with it (November 19, 2014).

Collaborating across disciplines. The collaboration between Ms. Davidson and the English language teacher, Ms. Godfrey, re-presented the science and mathematics content that was taught through the use of explicit academic language and vocabulary instruction, co-planned and co-taught science instruction, and the use of multimodal pedagogy. The collaboration between a science teaching expert and a language teaching expert resulted in a level of "metadiscourse" that was not achieved in Heidi Fischer's classroom. Metadiscourse implies that "the speaker is situated above or outside her own discourse, and is in a position to control or manipulate it" (Fairclough, 1992, p. 122). Although Andrea was not seen to be metadiscursive herself, a level of metadiscourse was achieved through the collaborative efforts of co-teaching. In one example of this, Ms. Fischer directed students to "Justify your reasoning using the word 'compression' or the meaning of it and Newton's laws of motion," to which Ms. Godfrey jumped in with further instructions to the students saying, "You have to say 'because.' So choose one and say, 'I would use blank because' which is how scientists justify with evidence" (Day 12 video, 06:00). Collaborating with the EL teacher elevated the level of discourse to a meta-level as a means to cue students into how the language of science was used and created. This was not evident in Ms. Fischer's classroom, where although there was modeling of the academic discourse of science, explicit language and vocabulary instruction was not evident and the discourses were an implied aspect of learning science.

Applying disciplines to understand others. In this section, I address the issues of intertextuality in the STEM classroom discourses, which Fairclough explains as the way texts are linked to other texts, constituting elements of other texts often "giving the sense of multiple discourse types trying uneasily to coexist in the text, rather than being more fully integrated" (p. 117). Gee (2014) explains, "Intertextuality is where different people's words mingle and marry in a wide variety of ways" (p. 61) and it is a "borrowing" of different social languages in texts, keeping in mind that "texts" can be written or oral language (p. 75). In both classrooms, the STEM approach was a way to apply other disciplines to teach and learn science, and the teachers "borrowed" the language of engineering to re-present the other disciplines.

One of the places during the unit where this was most evident was in the development of arguments for the final presentation. In this task, students were asked to develop an argument to justify their design decisions to a hypothetical boss of the engineering firm where they worked. The teachers co-authored a slide to present argumentation, and then Andrea created an additional slide to further scaffold students' language use (see figures 2.2 and 2.3). Through a discursive practice analysis of the slides and Andrea's teaching of them, we can see the ways the discourses of science, engineering and academic language instruction overlapped, intersected, and conflicted with one another (see Table 3.2). In this display, I have pulled out the salient word choice from the written and verbal texts and organized them in terms of their disciplinary uses. Then, I examined the broader disciplinary assumptions within their discursive practices and summarized these below the word choice. Finally, I identified academic vocabulary that had multiple meanings and conflicting definitions in this text, which are displayed in the third row of the table. Words and phrases are underlined for analytic emphasis.

Table 3.3 Interdiscursivity of an Argumentation Lesson

	Science Goals	**Engineering Goals**	**Language Goals**
Text	Predictions According to Newton's laws Claims/evidence/solution (CIS) Evidence	Justify the redesign Problem Assumptions	Write in complete sentences If ___ then ___. Use evidence to support
Assumptions of the discursive practice	*Scientists* work within the context of scientific inquiry. They make predictions before they conduct an experiment to answer a scientific question. Those predictions are based on scientific, factual knowledge of the natural world. They collect evidence, in the form of numerical data to confirm/disconfirm their prediction. They present their findings in the form of a written argument, or scientific claim	*Engineers* work within the context of real-world, social problems. They explore all of the assumptions beneath a problem before they design a solution. Assumptions are based on scientific, factual knowledge They design and redesign solutions in response to the evidence of success. They present their findings in the form of a verbal "pitch" to a client or boss.	*Students* use complete sentences when writing for academic purposes. Written arguments must have ample evidence to strengthen it. Students follow a prescribed argument structure supplied by the teacher.
Intertextual academic vocabulary	Problem	Solution	
	Evidence	Argument	

Through this analysis, it is evident that the academic vocabulary terms of "problem" and "solution," had different meanings within science and engineering discourses. The terms "evidence" and "argument," had even broader implied meanings because of their use in the discourse of written academic language instruction as well. In this lesson, because the disciplinary objectives were integrated, the "arguments" students were to construct and the "evidence" they were to provide were not located within a clear community of practice. An individual uses and understands the meanings of vocabulary through membership within clear discourse communities, and when those communities of practice are undefined, individuals struggle to make a coherent meaning from language (Gee, 2014). When we consider this analysis in light of the goal of instruction and learning, it is clear that this lesson was very complex and intertextual, and the introduction of additional language scaffolds only extended the complexity of the academic vocabulary that was used. When the lesson integrated multiple disciplines, the academic vocabulary and concepts of argumentation were re-presented in interdiscursive ways.

Sharing joy. As was discussed in the case of Heidi, she had a much stronger identity as a disciplinary insider than Andrea. This was most evident in her instruction during lessons where she was sharing her joy and fascination with the world of science as it was applied in engineering contexts. In one example, she was excited to share the recent landing of the European Space Agency's Rosetta spacecraft on the surface of a comet. She played a video of the landing, and described with enthusiasm how this was an example of "the incredible patience you have to have as an engineer in space exploration" and a "cool feat of science and engineering." She encouraged students to be curious about this event, and visited a website to get answers to some of the students' questions. Heidi's instructional goals for this activity were to simply share her interest and passion for science and engineering with students, and "hopefully get them excited about science" (Fischer Interview, November 21, 2014). Her own disciplinary expertise and membership was an important part of how she re-presented the disciplines of science and engineering, and this was not the case in Andrea's classroom. Andrea expressed discomfort with some of the higher levels of mathematics and physics concepts and did not have the same level of enthusiasm for the content as Heidi.

Modeling and Apprenticing Disciplines

Explicitly teaching discourses. Both of the teachers had an explicit focus on apprenticing students into "the language of science," however what that meant was very different for Andrea and Heidi. For Andrea, language instruction included explicit academic vocabulary instruction and the use of language scaffolds that broke down learning tasks into steps, as well as "fill in the blank" writing prompts, as was shared through the presentation of her case. Heidi felt it was her purpose to explicitly teach the discourse of science, which included purposeful modeling and scaffolding a way of thinking and talking about science, but did not include targeted language or vocabulary instruction. For example, when introducing the formula for Newton's second law, she used a large amount of disciplinary vocabulary (bolded), but only explained the meaning for the word force. Also, she used the discourse of science when explaining the formula (underlined) but did not break down this discourse with metalanguage or by directing students' attention to the elements of discourse.

> So this **formula** *(writes on the board),* so, if you were to **graph force** and **acceleration** you would probably get a nice straight line, which means that force is equal to something times acceleration. And it turns out that something is the **mass** of the **object** that **accelerates**. *(writes on board)*. So in this formula, the f is force so how hard you're pushing or pulling an object. And then, I don't think we talked yet about the **unit** for **force**, it's gonna be in a **unit** called **Newtons**, usually written with a capital N (Fischer, Day 3 transcript).

Despite these differences, in both classrooms, it was an important goal and outcome of instruction to explicitly model the language of science as a way to get students comfortable with their own use of that language.

Relating concepts to disciplines. In order to model scientific discourse, Heidi would encourage students to first experience a scientific phenomenon through a demonstration or observation of the physical world. This would happen physically in person, or virtually through a video. She would then prompt them to reflect on what they learned by asking a specific question that introduced a new science concept related to the observed phenomena. Once students had a chance to write, they would then explain what they saw and attempted to use this new concept in their explanation. Heidi would follow up with a question to extend student responses, often using the exact words the student said, and then tacking on an additional word or phrase that would signal the disciplinary discourse she was trying to model. Students would then be able to relate their conceptual understandings to the disciplinary-specific way of understanding that knowledge. In the example of a warm-up conversation on inertia, Ms. Fischer accepted student answers nonjudgmentally, and extended their examples with the specific language of science concepts. This is presented in Table 3.4; the use of academic vocabulary is italicized and the use of everyday discourse to explain concepts is underlined. Each of the words and phrases of relevance to this analysis are bolded for further emphasis.

Table 3.4 Textual Analysis of Introduction to Inertia

1	Ms. Fisher	Are there a couple of people who would be willing to share their example of ***inertia***?
	Zoey	When a car brakes really fast.
	Ms. Fischer	Ok, and what happens to you when you have a seatbelt on?
	Zoey	You lean forward but your seatbelt catches you and if you didn't have one on you would probably <u>**get flung forward**</u>.
	Ms. Fischer	Ok, that is a great example of ***inertia***. Why is it that you ***keep moving forward***, or <u>**you get flung forward**</u> when the car brakes?
	Zoey	Because ***an object in motion stays in motion*.**
2	Ms. Fischer	Alright, anyone have another example?
	Wafa	Is riding in an elevator one?
	Ms. Fischer	Ok, and when in particular in riding in an elevator do you experience ***inertia***?
	Iris	When it goes up? (gestures with hand going up)
	Ms. Fischer	Ok, when it's starting to go up. What do you feel when that elevator starts going up?
	Becky	Pressure going down (gestures with hands going down)
	Ms. Fischer	Yeah, you kind of feel pressure going down. So what is your body trying to do when it starts ***accelerating*** upwards?
	Emmett	Hmmm stay still?
	Ms. Fischer	*(Nods)* trying to stay still.
3	Jade	Oh, like a roller coaster!

	Ms. Fischer	Ok. When on a roller coaster do you experience ***inertia***?
	Jade	That's what I got from ((inaudible)) when you like goin down them hill and you like leanin out to see… *(student laughter)* yeah.
	Ms. Fischer	Ok, when you're goin down a hill and your body's getting **<u>kinda flung around.</u>** Your body's again trying to ***keep moving in the direction it was already moving*** so you need those safety straps.

Appropriating new and relying on familiar discourses. Both Andrea and Heidi used specific, targeted questioning in their instruction to elicit students' understandings and extend those understandings with scientific discourse that attempted to "fill in the gaps." They would do this repeatedly until students were able to appropriate the disciplinary discourses into their own written and verbal speech. In lab group conversations in Heidi's classroom, students would rely on their familiar social discourse to communicate with one another, and then appropriate specific disciplinary discourses when prompted to do so by Ms. Fischer, or in some cases, when the students had a high level of disciplinary understanding they would incorporate disciplinary discourse into their conversations. In the group of Emmett and Anthony, there were a number of times where their discourse took on the social practices, identities and language of engineers, like in this example where their conversation moved into an exciting solution to a problem they were having with their design (see Table 3.5). Emmett came up with the idea (segment 1), and Anthony used the disciplinary discourse modeled in the classroom to give credibility to the idea (bolded in segment 3). In segment 4, Emmett drew a sketch of the design in order to communicate his ideas with Anthony, a social practice that was modeled as an engineering practice in the classroom. Then, Anthony used his conceptual understanding of forces and everyday language to further evaluate Emmett's idea (bolded in segment 4).

Table 3.5 Appropriating Disciplines in Student Lab Groups

1	Emmett Anthony	Oohh, we could put them along up top here, and support them even more. That's a good idea.
2	Emmett	((pause)) Alright, so who wants to glue?
3	Anthony	Oh my God, that was a genuine good idea because if we had it hanging off of this, and then if we had rubber bands on it **if it did get hit it might be able to slide along it but it will be pulled back so that it won't have that sudden force**, **it would slide and then have friction and be pulled back.** That's a good idea! Now we just need to make a triangle.
4	Emmett Anthony Emmett Anthony	So like, this (draws) it's going to go like this, and across (.) Another triangle. Like that? On both sides? Maybe a bit lower? Just so that **if we have this lower it would support more, because we need it where the cup is and to have the width of the cup pretty much.** We might just scrap that.

In Andrea's classroom, students would switch to their primary language and rely on functional discourses in their lab groups. Because students were often speaking in Karen when they were working together in lab groups, the nature of their discourse was to use every day, functional language to complete their assigned tasks. In one example, two female students were designing their final presentation, and were often silent while they each worked on their own laptop computers on different slides for the presentation.

When they did have conversation, it was to verify the teacher's directions or to get help with making a decision about what information to include on the slide. According to a loose translation from Karen into English, the following represents the types of verbal discourse evident in lab group conversations.

> Student 1: The teacher said we have to include these numbers. What did the other teacher say?
> Student 2: I don't want to do it.
> Student 1: We have to finish it.
> Student 2: What is it?
> Student 1: The teacher said it's not right. She told me to do this one. This one is smaller. This one is right.
> Student 2: So this one is 13?
> Student 1: I have to ask.

The modeling and appropriating of disciplinary discourses was important to both classrooms, however the level of student appropriation of these discourses varied between classrooms and between groups of students. Students' prior experiences, interests in the disciplines, and proficiency in English language and academic language and discourse were apparent contributing factors in this aspect of disciplinary integration.

Disrupting Disciplines

Participating through own lives. The most surprising finding from this study were the many ways that the science classroom contexts, teachers, and students would disrupt traditional disciplinary discourses. As was evident in Andrea's case, students related their new learning of engineering to prior experiences they had in refugee camps in Burma. Engineering was presented as an academic discipline to be studied, but it soon became re-presented as a practical application of problem-solving for survival. For these students, their own lived experiences were an important contributing factor in their learning and understanding of what it meant to do and know the disciplines of STEM.

Additionally, for students in both classrooms, science lab group was a place where they could work together with friends, co-construct knowledge and help each other when they did not understand. This social participation was an important aspect of their understanding of the disciplines of science and engineering. When working together, students would create ways to have fun with their project. For the boys, it was ways to turn the engineering materials into little sports games they could do when in transition between assigned activities. For the girls, it was decorating and personifying their egg by drawing a face on it and giving it a name. These broader, gendered social practices of how to be together in peer groups were an integral part of how they experienced the disciplines of STEM, which disrupted the traditional ways the disciplines were taught as static, fixed ways of knowing and representing knowledge.

Conflicting instructional goals. The engineering activity itself at times caused a disruption to the science and mathematics knowledge that the teachers were trying to teach. For example, in an introductory activity to elicit students' ideas about redesigning the initial prototypes, Ms. Davidson led students through an evaluation of the limitations of a failed design in order to offer advice to the group for ways to improve their design (see Table 3.6). In this conversation, there were ample opportunities to extend students' conceptual understanding of forces and motion into disciplinary ways of knowing and representing that knowledge. Instead, the conversation remained focused on practical and obvious considerations of engineering designs. Since students had a pre-established idea of a seatbelt and doors to prevent motion upon impact, they fixated on the existing engineering design solutions and struggled to move beyond the obvious (segment 3). At the end of the conversation (segment 5), Ms. Davidson attempted to get students to think about the direction of forces, however, she did not move into a clear use of scientific language or explicitly move into instruction on Newton's laws of motion. There was a missed opportunity here to talk about why certain engineering designs are more or less effective in terms of Newton's laws of motion. In this example, the instructional goal of moving students into a redesign process was in competition with the goal of learning Newton's laws of motion, with engineering taking precedent over science learning.

Table 3.6 Fixating on Existing Engineering Designs

1	Ms. Davidson Ms. Davidson	Turn to your groups and talk about what kind of advice would you offer this group in their redesign? (Students talk at their tables) Alright, so what did you come up with? What kind of ideas did you come up with for this group?
2	Student Ms. Davidson	**Seatbelt** Ok, we need some kind of **seatbelt** for this thing. Alright, as simple as you say to put some kind of tape or maybe a rubber band around the back. What other ideas?
3	Student Ms. Davidson Student Ms. Davidson	(inaudible) More cotton? Where? How would that keep the egg from flying out? (inaudible) Ok, someone would maybe put duct tape around it and that might stick to it and rip the aluminum foil, but that might work. However, can you think of something other than a **seatbelt**? Because that is kind of like a seatbelt, right?

4	Student Student Student Ms. Davidson	Bubble wrap! A balloon! Put cotton inside the cup. Ok so that the cotton inside and that would kind of wedge the egg in tightly? Ok? You could also do that and **that would also give cushion to the egg**. <u>Did anyone think about direction?</u> Cause, where did it fly out? It flew out the back and rolled to the side here. So what could you do to the container itself?
5	Student Ms. Davidson	Tape **the door** tight. You could tape **the door** tight and that would keep it from flying out the back. <u>Is there anything else you could do to the container itself that would help? (.) To the actual vessel itself? (..) Could you situate it differently? Put it in a different position? (..)</u> Alright. Another idea 7th hour came up with, what if you just switched it around like this? Then you have another problem, right? What would it do? It **moves in a straight line motion this way**, and then it might break the egg. Is there something we could use to keep the egg from breaking? We'd need **some kind of cushion there**. Good.

Appropriating everyday discourses. The pedagogical representations of the disciplinary content teachers taught also worked to disrupt those very disciplines because they required an important step away from the discipline toward the discourses used by students. In the example of Ms. Fischer's introduction to inertia lesson, (table 3.4) it is clear how she used the everyday language of students to reinforce student thinking, and also extended their examples into more specific disciplinary uses of the language of science (for example, segments 1 and 3). However, sometimes the explanations did not move beyond students' everyday discourses, thus disrupting the disciplinary discursive ways of representing scientific knowledge. In one example of this, Ms. Davidson had students first read from their notes Newton's first law of motion, then turn to a partner to restate this law into their own language. One student gave an example: “I am going to continue walking down the hallway until something else messes with me,” to which Ms. Davidson extended with, “If somebody bumps into you or you bump into the wall, are you moving in that straight line motion anymore? No, right? Your motion changes. Your speed or your direction changes.” In this example she has appropriated the discourse of the student who shared, and although her extension used some of the vocabulary of Newton’s laws of motion, she did not provide a complete translation into disciplinary discourse.

Multimodal pedagogy and vying for control. As was discussed through the case of Andrea Davidson, the disciplines of STEM were also disrupted by the continued interruption of English language instruction during science instruction. These interruptions were necessary to student learning and use of English language, although they produced alternative representations of content knowledge. Particularly when the EL teacher, Ms. Godfrey, cross over into science content instruction. In these instances, Ms. Davidson would physically move closer to the front of the room in an attempt to take the class back under her control. Also in these instances, Ms. Godfrey would introduce new content through multimodal pedagogy like songs, physical gestures, student participation in physical embodiments of new concepts and vocabulary, and drawings on the board etc. These multimodal pedagogical representations of science knowledge disrupted the typically privileged ways of representing knowledge in the classroom through exclusively written and verbal communication modes.

Learning New Disciplines

Positioning disciplines. The teachers in this study were learning the disciplines of STEM along with their students. Although science remained the dominant lens in which the teachers viewed the other STEM disciplines, the practices of "doing science" were redefined by its application to engineering contexts. This presented new learning opportunities and teaching experiences for the teachers, worked to position the disciplines within a hierarchy, and threatened the teachers' established teaching identities. This section presents findings from an analysis of final interview transcripts where teachers were asked to reflect on the overall experience of STEM integration in a 30-40 minute interview. Specifically in this analysis, I attended to Fairclough's (1992) analytic element of manifest intertextuality, which includes discourse representation, or how a discourse is translated by the speaker, and presupposition, which he explains as ideas that are taken by the producer of the text as already established or a 'given' (p. 120). These analytic features help us to explore how previously existing discourses and texts are incorporated into the texts of others; specifically in this case, the disciplinary discourses of STEM and the broader social practice of STEM education reform.

Andrea's interview text revealed multiple discourse types co-existing and contributing to the meaning Andrea created for herself of her experiences learning and teaching STEM integration (see table 3.7). In segment 1, Andrea borrows the language of "design," a feature of engineering discourse, to talk about possible changes to the curriculum, and she also talked about "a fair test" which is a feature of experimentation, a scientific discourse. Her low affinity is evident in the use of pronouns "you" and "we" rather than the more direct, "I," which signals distance from her idea for this new test she is talking about. At the end of segment 1, she suggested modifying the engineering constraints of the design challenge, thus positioning engineering as a context for teaching the science content. She also talked about the use of mathematics as a tool for understanding "the weight force" applied from above. In segment 2, she borrowed from science teaching discourses when she talked about learning as doing and cooperative learning discourse when she discussed the "roles" of students. Manifest in this text is the broken use of language and discourses drawn from the broader social practice of EngrTEAMS summer professional development and curriculum design. Andrea is very much learning what it means to do STEM from the wider experience of participating in this project, however she, like her students, drew from familiar discourses to make sense of new experiences, thus resulting in a positioning of discourses, and disciplines.

Table 3.7 Manifest Intertextuality of Andrea's Interview

	Text	Discourse Practice
1	And I was thinking too, we had a lot of flipping? So how does it undergo **an impact** from the top? So is there a <u>**test we can design**</u> that would be **a fair test** that would also **test the impact** on the side or on the top. *Yeah, do you have any ideas?* I don't think a hammer would be a fair test (laughter). **Maybe** <u>we</u> **would** need to figure out a force, a relative force that it **would** be undergoing <u>**you**</u> **know**, if it was 200 Newtons **or whatever**, would there be a way to rig **some** force test with 200 Newtons?	"test we can design": Borrowing engineering as a process of design→ curriculum as a process of design "fair test": scientific experimentation Modality: low affinity to her suggestion

	You could take the CCC and put it on a force place and then take a book, and put books on top of it, so the CCC would have to have some kind of flat top so **you could require that in the constraints**, so that we could **test** later to see **how much force** can be piled on top of it. And that way the force plate underneath would **measure** the amount of books placed on top of it and you could **subtract** the **force of the weight** of the CCC from that.	"require that": engineering as teacher-controlled lesson frame for science teaching Mathematics as a tool for understanding forces of motion
2	*So, using those kinds of tests and changing the criteria of the design, how would that change their understanding of Newton's Laws?* They would also be learning about um (..) they would have **more practice** with **weight force** which would **help support that idea of the second law** (…) So that's a second way to **practice** with it and then therefore if you have one kid working with the force sensor on the actual impact on the ramp, then you could have the other two kids with the force plate, so **I think it would actually help with the roles of students** themselves and making sure that each one of them was **testing**, **using Newton's second law** which I felt was a lack, you know a little bit, the kids who were actually **doing the calculations were the ones learning Newton's second law**, and the second law seemed to be the weakest when we initially tested them, and all four students didn't understand all of the laws as well as we'd hoped. We could have **multiple tests** and that would **help get more students involved**.	Practicing = learning: science teaching discourse "roles of students": borrowing from cooperative grouping discourse → science teaching discourse of "doing" Doing = learning: science teaching discourse

Responding to challenges. As was evident in the case of Andrea, the teachers were learning throughout their experiences, and learning brings inevitable challenges that arise unexpectedly. Many of these challenges were discussed in the individual cases, so a full presentation of data will not be necessary here, but a considerable amount of the final interviews were spent talking through the technology challenges, and each teacher responded to the opportunities and headaches of technology in their own individual way. Both teachers happened to be in the midst of 1-1 technology roll-outs in their districts, specifically this unit happened just before students were scheduled to receive iPads. With this in mind, the teachers encouraged students to use phone apps and a class-set of iPads to collect video data and to collaborate on Google aps. However, both teachers experienced barriers to the success of sharing data between devices and student accounts. While Andrea expressed dissatisfaction with her own comfort level with the use of technologies, Heidi blamed the technologies for their lack of precision in collecting data and poor platforms for sharing and collaborating. After talking through these challenges, she said, “I guess I’m kind of debating if I want to just go back to using stopwatches next time around. I think they could still make a graph of the force pulling it forward verses time that way” (Fischer Interview, November 21, 2015). While Andrea internalized her learning experiences in a personal way, Heidi’s learning was externally focused on the uses of new curriculum and technology.

Skipping over other disciplines. When faced with the time crunch of trying to accomplish all of their instructional goals during the unit, the teachers often ended up skipping over their planned literacy and mathematics instruction. Heidi decided to skip over the instruction she had planned on graphical representation of Newton’s second law, even though she felt it was an important goal of science literacy for students to understand graphs. A big reason why she skipped this instruction was because the technology tools did not work as well as she had planned, but also because the graphical representation of acceleration was "complex for students" and "not intuitive" so it was difficult to teach it well in a limited amount of time.

> Between the state mathematics test, and the state science test, and the ACT they have to do a lot of interpreting graphs and I would argue that's a core science literacy skill anyway, so I'm all for bringing the graph into that. And we could do, depending on how quickly they go through that, I might add in having them change the mass of the cart and then do a graph of that **just to see** as the mass gets heavier it takes more time, which means less acceleration (Fischer Interview, November 21, 2015).

The challenge of integrating mathematics instruction in her science teaching was not her own knowledge of mathematics, which was the case for Andrea, instead it was the fact that higher levels of mathematics understanding was an ideal for her, or a bonus that could extend students thinking, as is evident in her words "just to see" as a reason for using higher levels of graphical representations of scientific ideas. When positioned as a bonus, it is no wonder that it is one of the first things to go when faced with the limitations of instructional time.

Threats to teaching identity. Interdisciplinary teaching also introduced threats to the teachers' existing science teacher identities. Although it remained true that the identities of science teachers were defined by the subject matter to a greater or lesser degree (Siskin, 1994; Helms, 1998), the introduction of new content and practices brought challenges to existing identities. These enacted identities can be observed within the texts and discursive practices of individuals through the use of analytic tools like attending to the modality present, or the degree of affinity with the propositions in the texts (Fairclough, 1992, p. 158), and the ethos, or selves that are constructed through the text. Through these analytic tools, the ways the teachers aligned themselves with various aspects of the disciplines in their speech can be considered. In Heidi's final interview, what was manifest in her text was the strong use of a teacher practitioner discourse (see Table 3.8), where she followed a pattern of reflection on action that included consideration for students' misunderstandings (segment 1), possible reasons for those misunderstandings (segment 2), and planning for future action in response (segment 2-3). What was also evident in this text was the struggle she had with the inefficiency of her own learning. An example of this is in segment three where she was opening up possibilities for other ways of teaching Newton's second law, but then she brought her reflection back to her goal of saving instructional time, which in turn gave weight to her other reasons for making modifications for future uses of the curriculum.

Table 3.8 Ethos in Discursive Practices of Heidi's Interview

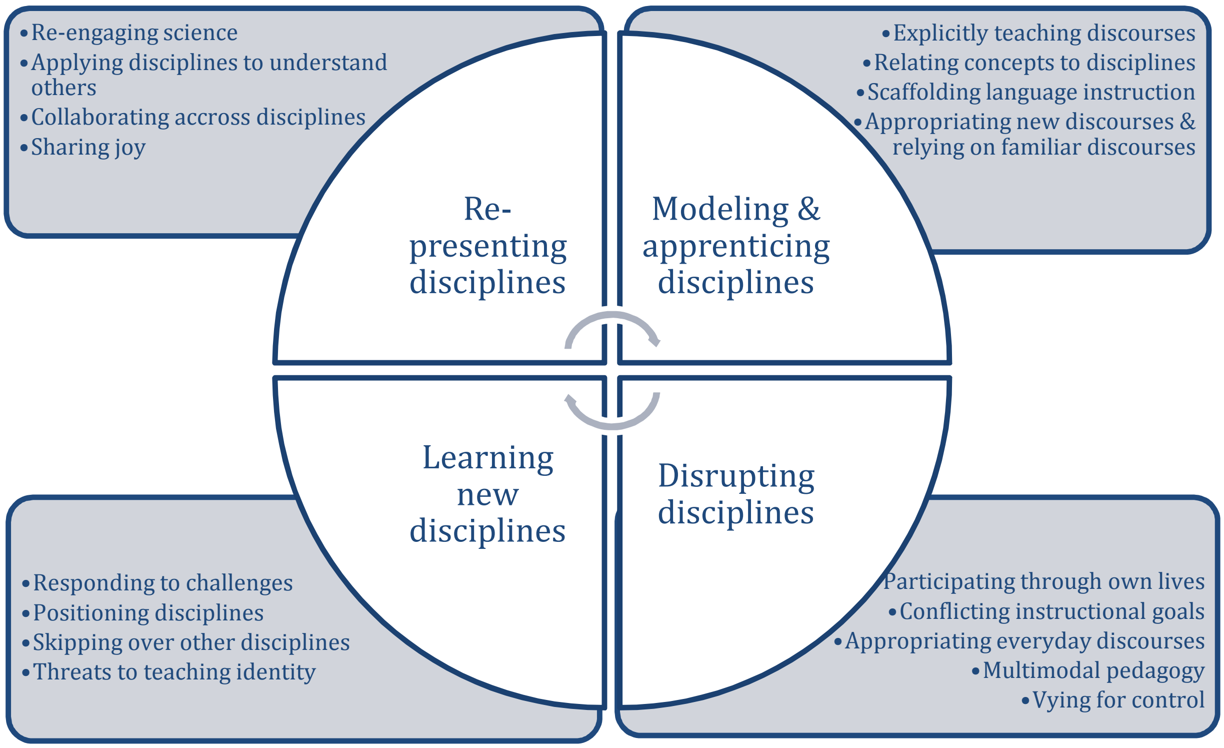
	Text	Discourse Practice
1	I did notice that a lot of kids had trouble **coming up with a design** that the egg would actually stay inside of. A lot of them were just not putting lids on, **even on the redesign.** And I guess it surprised me a little bit that they saw some eggs spilling out the top in the first go around, and they still didn't do that the second go around.	"coming up with a design": science teaching as inquiry discourse
2	*So why do you think that was?* I don't know. Um, I think some of it might have been trying to keep the cost down. And I think they were very, very focused on that **front end collision**, and they weren't focused so much on what could happen **as a result of that front end collision**. And so I think next time around, and I think this could be **a better way to get them to** better incorporate the use of the video stuff, is **get them thinking about** not just the **impact**, but what are some things that happen **as a result of that impact**. What's kinda some of that **chain of events** that gets started and how do you have to make sure your egg	Reflective teacher practitioner discourse Focused on student understanding

	stays safe throughout that **entire chain of events**?	
3	So not just when the truck hits, but when it tips to the side, or when it bounces back up. So **kind of what I'm thinking** is when they do the prototypes um, really **push them to get video of that** and then as they're, after they've had a chance to look back at the video **have some probably** whole class discussion about, 'well, was it just the impact that was necessarily damaging the egg, or were there other things that happened because of the impact?' so, **I think the testing could go quicker next time around.**	Modality: moderate to low affinity Efficiency identity

Discussion

Through this cross-case analysis, a model of a process for disciplinary integration in STEM classroom discourses was developed. This model (see figure 3.2) presents a process of disciplinary integration that moves from re-presenting disciplines, to modeling and apprenticing disciplines, to disrupting disciplines, and learning new disciplines in the classroom community. As teachers moved through this process of integration, issues of power relating to who had access to disciplinary knowledge and how that knowledge was represented in discipline-specific ways became evident, and influenced the STEM integration practices of teachers and students. Specifically, this study offers discussion on the ways teachers and students positioned and negotiated the disciplines during their STEM integrated unit.

Figure 3.2 Model of a Process of Disciplinary Integration in Science Classroom Discourses



RQ1: How do teachers and students position and negotiate disciplinary knowledge within classroom discourses during STEM integration and what does this reveal about broader disciplinary Discourses?

The use of an engineering design challenge in the STEM integrated unit provided a context for the application of science and mathematics content knowledge in learning activities of the classroom. This context worked to "re-engage" the science content of Newton's laws of motion into new representations of that knowledge for the teachers and students. Additionally, the collaboration between Ms. Davidson and her EL co-teacher worked to re-present science and mathematics content knowledge through the use of language scaffolds and multimodal pedagogy. The EL co-teaching experience also introduced a level of "metadiscourse" to the science classroom that was not achieved in Ms. Fischer's classroom. Metadiscourse has been argued to support students' knowledge production when they work together in peer groups (Goldman & Scardamalia, 2013; Moje, 2008). Also, the use of informational metadiscourse has been found to support students who are uncomfortable with the content being taught, more so than for high achieving students (Crismore, 1990). The use of metadiscourse was an important aspect of modeling disciplinary discourses in the EL teaching context, although it remains to be seen if it would have similar positive affordances in other teaching contexts.

The teachers in this study positioned science disciplinary knowledge and ways of representing that knowledge over the other disciplines, most of the time. However, when disciplinary integration was achieved, it created an intertextual "borrowing" of various social languages and practices that at times confused the uses of academic vocabulary as its use was not clearly situated within a defined community of practice (Lave & Wenger, 1998). The disciplines were also positioned within a hierarchy where the teachers' low affinity to engineering and STEM discourses and higher affinities to science teaching discourses reveal the distances of membership for the teachers within these broader social practices. This is ultimately an identity issue, as teachers identify themselves both through their professional practice within disciplines, and through their own notions of their inner selves (Rogers & Scott, 2008). Professionally, the teachers did not align themselves within the new disciplines of STEM, however, personally, Heidi aligned herself strongly within the broader social disciplines of Science and Engineering, which contributed to new enactments of a teacher identity.

For both teachers, this learning experience was fraught with unanticipated challenges and barriers, specifically in the difficulty of maintaining a commitment to teaching the other disciplines of STEM, including science literacy and language instruction. Although the teachers valued "science literacy" and mathematical representations of science concepts, they did not own these instructional goals as they did their science standards and goals. This resulted in skipped and fragmented instruction of the other disciplines. The teachers also struggled with the uses of new technologies to teach and engage the discourses of STEM. Many of these challenges were beyond the teachers' control and pertaining to a mismatch between the teachers' purposes for using the technologies and the designs of the technologies themselves. However, Andrea took this failure personally and felt she should have done more to integrate these technologies into her teaching.

RQ2: How do teachers and students disrupt the authority of discipline divisions during a STEM unit and how does that impact the co-constructed learning and situated identities of participants?

A surprising finding of this study was the ways that the use of an engineering activity caused a disruption to the science and mathematics knowledge that the teachers were trying to teach. At times the conversations around engineering design solutions were not "elevated" to include higher levels of mathematics and science content knowledge, instead focusing on obvious solutions already in existence, like seatbelts. This is inconsistent with the literature on engineering applications in science education, which has found that engineering promotes successful application of science and mathematics content (Berland, Steingut, & Ko, 2014), as well as supporting disciplinary literacy learning (Wilson, Smith, & Householder, 2014). Roehrig, Moore, Wang, & Park

(2008) have argued that STEM integration may be best implemented when mathematics and science teachers work together as curriculum designers and co-teachers, which may account for the gaps in disciplinary knowledge and instruction that were evident in this study.

The use of multimodal pedagogy and language co-teaching in Andrea's classroom resulted in unexpected disruptions to traditional disciplinary discourses and representations of disciplinary knowledge, as well as an interesting "vying for control" of disciplinary content instruction between the EL teacher and science teacher. This experience is consistent with the literature on co-teaching, particularly when specialists work in general education classrooms (Robinson & Buly, 2007). The conflict that arises in co-teaching is attributed to a lack of shared language and practices (Villa, Thousand, Meyers, & Nevin, 1996), conflicting alignment between behaviorist and constructivist approaches to education (Robinson & Buly, 2007), and differences in personal goals for learning (Gross, 2012). It may be the case that with further support in developing a successful co-teaching relationship, that the conflict over who "owned" science instruction could have been avoided.

The observed enacted teaching identities of the classroom teachers were grounded in previously developed identities. Andrea's identity as a learner of STEM, evident in the interdiscursivity of her final interview, was an important feature of how she approached the academic disciplines of STEM. Similarly, Heidi's identity as a disciplinary insider in science and engineering discourse practices positioned her as a knowledgeable authority within this broader social group, and sharing her joy of her disciplines was a motivating purpose for teaching STEM. These identities were at times threatened by the introduction of new content and practices, for example, Heidi's identity as an "efficient" teacher was threatened by the inefficiency of moving through the engineering design process, particularly testing a prototype until it breaks. This draws parallels to studies on teacher identity development in preservice teachers. In the first few years of learning to teach, individuals develop a new image of themselves as teachers, which is often in conflict with previous self-image (Sutherland, Howard, & Markauskaite, 2009). Just as it is argued that new teachers need support in this identity development (Beauchamp & Thomas, 2009), it may be true that STEM integration efforts will require similar support for the changes to identity teachers are experiencing.

The students in both classrooms disrupted traditional disciplinary modes of understanding when working together in social groups. When in these groups, students relied on familiar social discourses to experience the STEM disciplines. Students also used their own prior experiences to interpret engineering, particularly in the case of the refugee students from Burma. For these students, engineering was best understood as a way of solving problems to better one's survival in the physical world. This was not the case in Heidi's classroom, where the students had prior experiences with engineering in school that contributed to a more traditional understanding of engineering. Some of Heidi's students even took on the disciplinary discourse practices of engineers when moving through the engineering design process.

RQ3: How do the evident classroom and disciplinary discourses compare across two classroom communities using the same STEM unit, and what might account for any differences?

Both of the teachers had an explicit focus on apprenticing students into the "language of science," however what that meant was different in each of the classrooms. While Andrea focused on explicit teaching of academic vocabulary and used language scaffolds to teach disciplinary discourse, Heidi modeled the expert use of disciplinary discourses in her own speech and instruction. In both classrooms, students were predominantly using familiar and functional social discourses when working in lab groups, and only appropriated disciplinary discourse when directed to do so by their teachers. When modeling the uses of disciplinary discourses, the teachers related broader scientific concepts to the discipline-specific ways of representing and explaining those concepts in social practice, they appropriated students' everyday discourses to relate students' understandings of concepts to discipline-specific ways of explaining and representing those concepts, and they used questions to scaffold higher levels of disciplinary understanding, particularly as it pertained to mathematics. This is consistent with the arguments made by disciplinary literacy scholars (Moje, 2008; Shanahan & Shanahan, 2008) who content that students need access to disciplinary discourses through the use of everyday student language and literacies.

These classrooms represented very different communities, in terms of student demographics, language uses, and socio-economic status of the wider communities in which the schools were located. The suburban context of Heidi's classroom community was reflected in the disciplinary insider status she enjoyed, and the traditional representations of engineering that were found in student and classroom discourses. The inner-city context of Andrea's classroom represented a more interdiscursive space where a wider diversity of lived experiences brought a broader range of STEM discourses and discourse practices. Also, Andrea's disciplinary identity was less dominant in her teaching, with a stronger identity as a learner guiding her approach to STEM integration. The contexts and social practices of the community at large was an important presence in the classroom discourses observed through this study, which is consistent with studies of the lived experiences and literacies of students within classroom communities of practice (Moje, 1994; Rogers & Fuller, 2007).

Conclusion

This chapter presented the cross-case analysis and critical discourse analysis results of the case studies of Andrea Davidson and Heidi Fischer. A model of a process of disciplinary integration was presented, with discussion of how this model is informed by and informs the literature. The next chapter presents a case of a new coach's development for coaching teachers in STEM integration. The concluding chapter will return to the discussion presented here, and outline implications for practice as it relates to teaching and learning in STEM.

Chapter 4:

How One Coach Became a Partner to Teachers in STEM Curricular Reform

Introduction

This chapter presents a manuscript of the study of Madison, a new coach, and her work with two middle school teachers as they integrated the disciplines of STEM for EngrTEAMS . This manuscript was written as a journal article for submission to a peer-reviewed journal in the field of teacher education. An earlier version of this manuscript was co-authored with committee member Gillian Roehrig, thus the use of the pronoun "we" throughout the chapter. Appendices and references have been moved out of the chapter, and instead integrated into the dissertation format.

Rationale

National policymakers have promoted improvements in K-12 STEM education as both an argument for maintaining global competiveness and the needs for a STEM-literate citizenry. Foremost in impacting K-12 classroom practices is the *Next Generation of Science Education Standards (NGSS)* (National Research Council, 2012), which promotes the integration of engineering into K-12 science classrooms. However, without effective professional development, the possibilities and promise of these national STEM reform efforts will not be fulfilled.

Bybee (2013) has argued that successful STEM reform initiatives will "require the establishment of professional learning communities with teams of teachers analyzing teaching, engaging in lesson study, reviewing content, and working on the implementation of instructional materials" (p. 58). Such professional learning opportunities benefit from the inclusion of classroom-based coaching (Killion, 2009), as the coach can contribute to enhancing teachers' science and mathematics knowledge and teaching practices (Loucks-Horsley, 2013). As teachers learn to implement new curricular and pedagogical practices of STEM education, coaching has the potential to become an important vehicle for the success of STEM reform initiatives. Coaching in STEM classrooms is a relatively new phenomenon, and most coaches transition from teacher to coach with little to no formal coaching training (Banilower, Boyd, Pasley, & Weiss, 2006). Thus, exploration of the development of STEM coaching is critical to understanding the potential of classroom coaching in achieving the goals of national STEM reform initiatives.

Loucks-Horsley (2010) proposed that there are some common practices of coaches that can extend beyond specific school, district, and state contexts. She argued "it is equally important [as it is to teachers] to develop the knowledge, skills, and abilities of these facilitators of adult learning and to provide them with ongoing, sustained opportunities to reflect on and make improvements in their practice" (p. 8). The development for novice instructional coaches should not be overlooked when designing professional development for teachers of STEM.

The guiding question for this study seeks to understand how novice coaches develop knowledge, beliefs, and identities in support of their coaching practices with classroom teachers. Additionally, we hope to better understand the nuances and particularities for coaching in a STEM context, where teachers, coaches, and students are all breaking new ground in interdisciplinary curriculum and instructional development.

Theoretical Framework

In this paper, we discuss identity as being situated in a person's lived experiences, and exacted within broader cultural models (Gee, 2000; Lave & Wenger, 1991). Gee (2000) argues the situated identities of individuals can be described through four different lenses, one of which includes an affinity identity, which is enacted through the experiences individuals share in the practice of affinity groups (p. 100). The use of an affinity identity perspective offers a way to analyze the social construction of an individual's identity; however, this framework does not offer a way to examine the processes by which identities are developed (Avraamidou, 2014). In order to explore a process of identity development, we turned to the conceptual literature on coaching, including the domains of knowledge, beliefs, and practices.

The knowledge and practices a novice coach develops could contribute to their developing identities as a coach. The practices of coaching include a range of verbal and linguistic protocols and skills (York-Barr et al., 2006; Knight, 2007; Ippolito, 2010; Neuberger, 2012), ways of building and maintaining relationships including trust, establishing oneself as a member of the classroom (Lieberman, 2001), and skillful facilitation of adult reflection and learning (York-Barr et al., 2007; Garmston &

Wellman, 2009). Novice coaches develop a coaching knowledge, which is theorized in the literature to consist of an understanding of partnership principles (Knight, 2007), role definitions (Toll, 2007), coaching frameworks and protocols (York-Barr et al., 2006), and an understanding of the goals and designs of broader professional development initiatives (Loucks-Horsely et al., 2010; Killion, 2009). Partnership as an essential component of the coach-teacher relationship (Cornett & Knight, 2009), and is explained as a balancing of power between teachers and coaches, where the coach encourages teachers to set their own professional learning goals while engaging in mutually beneficial reflective dialogue (Knight, 2007, 2009). In the partnership approach to coaching, coaches do not work from a position of formal authority, but use their relationships with teachers and their teaching expertise to facilitate reform (Taylor & Moxley, 2008). Studies that have explored the development of an individual's coaching knowledge and practices have found changes in the first year of coaching (eg., Ippolito, 2010; Gibson, 2005; Al Otaiba et al., 2008), yet it is unclear how a coach's learning experiences in formal classes, workshops and professional development settings relates to his or her development of a coaching identity.

A teacher's system of beliefs begins to form as early as their childhood experiences of school and changes are slow and incremental (Cohen & Ball, 2001; Hall & Hord, 2006). We propose that as a coach takes on new professional roles and identities, a new system of beliefs begins to emerge (Rainville & Jones, 2008; Neuberger, 2012). A system of beliefs necessary for coaching includes beliefs about the process of change for adult learners (Hall & Hord, 2006), the critical role of relationships in adult learning (Garmston & Wellman, 2009), a deep commitment to reflection on experience for oneself and for teachers (York-Barr et al., 2006), and believing that every teacher can change with support (Garmston & Wellman, 2009). To this list we add a sense of coaching self-efficacy, wherein self-efficacy is defined as the belief in one's ability to find success in the future (Tschannen-Moran, Hoy, & Hoy, 1998). A sense of coaching self-efficacy is essential to a novice coach's motivation to continue coaching when presented with the inevitable challenges of the first year.

Shulman's (1987) process of pedagogical reasoning and action further informs the process of the development of a coaching identity. While Shulman's work focused on teachers' transformation of content into instructional representations for student learning, Gibson (2005) argued that a similarly complex knowledge base is developed in the first years of coaching, which can be understood as a process for coaching reasoning and action. In this process, a moves through five stages of this cyclical process: 1) coach learning, 2) designing and developing, 3) acts of coaching, 4) self-reflecting, and 5) reflecting in partnership with teachers and peers. Let me explain each of these stages in the process in further detail.

First, a coach must understand the reform-based literature, as well as relevant political initiatives in order to understand how their coaching connects to the larger purpose for professional development. This understanding serves as a guide for coaching practices and informs coaching decisions. In addition, a coach must spend time seeking understanding of the teacher's current reality and integrating that reality with the coach's understandings before "coaching" can begin. This can be conceived as the essential "coach learning" that needs to happen before any coaching decisions are made. After the coach has done sufficient learning of the contexts and purposes for the work, they will move to the second stage of transforming their understanding to a coaching plan that will guide their work. The third stage constitutes the acts of coaching itself, including practices such as observations of teaching, co-teaching, modeling lessons, engaging in lesson study, facilitating peer-learning groups or other learning designs that the coach creates in order to transfer his or her understanding into learning experiences for the teacher. Next, reflection is critical and allows the coach to look back at the coaching and learning that has occurred and "reconstruct, reenact, and/or recapture the events, the emotions, and the accomplishments" (Shulman, 1987, p. 19). And finally, the coach and teacher then co-construct new understandings when they reflect together and these new understandings guide them as they move forward in the coaching process.

Opportunities and Barriers to Instructional Coaching

Since the Reading First grants acclaimed literacy coaching as effective professional development (U.S. Department of Education, 2002), coaching programs have become common in school districts. However, there is limited empirical support for their prominence (e.g., Annenberg Institute for School Reform, 2004). Though initial evaluations of the Reading First coaching programs revealed mixed results (Garet et al., 2008), more recent studies have linked components of coaching to changes in teaching practices and increased student learning (eg. Walpole, McKenna, Uribe-Zarain, & Lamitina, 2010; Lockwood, McCombs, & Marsh, 2010). Coaching has also been linked to increased teacher self-efficacy (Cantrell & Hughes, 2008), as well as cultural collective efficacy of schools (Goddard, Hoy, & Woolfolk Hoy, 2004).

Recent case studies of coaches have highlighted the struggles and contextually dependent roles that coaches enact in actual practice (Walpole et al, 2010). Rainville and Jones' (2008) case study of literacy coaches revealed that coaching required situated identities that are different from the well-established teaching identities individuals bring to coaching. Similarly, Chval et al. (2010) found that the transition from being an "expert" mathematics teacher to a "novice" coach caused the participants in their study to develop new professional identities, which the coaches saw as different from negotiating their roles with teachers, and was shaped by the expectations the novice coaches had of themselves. This identity development caused unexpected misunderstandings and miscommunications between coaches and teachers, as well as emotional distress for the coaches.

There is a lack of research related to how coaches develop the necessary coaching practices, knowledge, personal beliefs, and identities for coaching (Gallucci et al., 2010), particularly in new STEM educational contexts. Although there has been an expansion of instructional coaching positions in recent years, as well as a call for attention to the necessary job requirements and development of coaches (Lockwood et al., 2010), much remains unexplored regarding coaching development. By focusing on one novice coach's development of a coaching identity for coaching in STEM, this study contributes to the recent case studies of coaching development so that we can proceed to educate and support the development of school-based instructional coaches who work to implement STEM reform initiatives.

Research Questions

In order to study one coach's development, the following research questions were addressed:

1. What coaching knowledge, beliefs, and practices does an experienced teacher transitioning to novice coach develop in her first year as a coach?
2. What is a novice coach's process for developing new knowledge, beliefs, and practices for coaching and how can this inform a model for coaching development?
3. What informs or causes dissonance to a novice coach's developing coaching identity?

Methods

Research Design

This embedded, single-case explores the work of one coach, Madison (all names are pseudonyms) with two middle grades science teachers, Joe and Kim. A single-case design allows for examination of a critical case in testing a well-formulated theory (Yin, 2009, p. 47), while an embedded case is used when the study requires more than one unit of analysis (Yin, 2009, p. 50). This study of one critical case provided insight into the experience of one coach so that generalization to the theory of coach development could be made, and direction for future study could be determined.

Context

The context of this study was an NSF grant-funded STEM initiative developed in partnership with three large schools districts in the Midwest (two urban and one suburban). Forty-nine teachers (grades 4-8) from 36 middle and elementary schools volunteered for a yearlong STEM integration professional development. Teachers participated in a three-week intensive summer professional development program, where they first experienced STEM curriculum as learners, and then collaborated in inter-district teams to develop their own STEM curricular unit. Their curriculum unit was piloted at a university summer camp, supported by a STEM graduate student coach. During the academic year, each teacher implemented the curriculum in their own classrooms, working in partnership with the graduate student coach and their team throughout the year.

Participants

The purpose of the larger study from which this paper draws is to explore outcomes of coaching and development of STEM coaches in a large-scale STEM reform initiative. The 17 graduate student coaches participated in a yearlong graduate level course to learn theory and practices of a partnership approach to instructional coaching. The course met once a month, was structured like a graduate level course where readings were assigned from primary and supplementary texts, and included a variety of learning experiences for coaches including class discussion, practice coaching sessions, and written reflection assignments. As a part of the class, coaching protocols were developed to support the coaches in their use of new coaching skills, and were presented as optional resources. The protocols included a series of questions specific to either reflecting back on a teaching experience or reflecting forward to an upcoming lesson, reminders of verbal cues like pausing, paraphrasing, and clarifying, as well as visual graphics that mapped the flow of a particular type of conversation (see Appendix E).

The science teachers, Joe and Kim, individually volunteered as participants in order to learn more about STEM curriculum, to work with STEM experts, and to have support in making changes to their existing curriculum. Joe was the lead science specialist in an urban elementary school, and highly regarded as an instructional and curricular leader in his school and district. He taught in the district for nearly twenty years, and worked in his building for most of his career. Kim was a science teacher at a suburban middle school, who had taught for approximately 15 years. During the year of the study, the student population at her school changed dramatically, and for the first time in her career, she found herself faced with significant behavior challenges and language barriers. She relied on collaboration with her colleagues in and out of her building to support her in responding to these changes.

We identified Madison as a critical case of interest. She considered herself a novice coach because of her self-declared lack of coaching experience, and her openness to learning about coaching teachers. Madison was a Mathematics Education graduate student, who was assigned to coach six teachers. She had ten years of experience teaching mathematics at the secondary and community college levels. She had less than one year of experience using STEM integrated curriculum, and had no prior experience with classroom-based coaching.

Data Sources

The primary source of data for Madison's knowledge and beliefs about coaching and teaching consisted of three formal interviews, conducted and transcribed before, at the mid-way point, and at the end of year one of the project. Questions were asked to address the coach's current knowledge, beliefs, and recent experiences with coaching teachers and STEM integration (see Appendix D).

The primary source of data for Madison's coaching practices included transcripts of monthly coaching conversations she recorded with each of her teachers throughout the school year. Secondary sources of data included written coaching logs completed before and after each coaching transaction and monthly written reflections to open prompts reflecting on her experiences as a coach, which allowed us to access her learning over the course of the year, as well as to cross-reference her perceptions of her experiences with the actual coaching exchanges she had.

Additionally, the teachers were interviewed throughout the project to elicit their perceptions and experiences with STEM integration and instructional coaching. The interviews followed a semi-structured interview guide (see Appendix B), which included questions such as, "How did you use engineering in your science teaching?" and "What were the benefits and challenges of having an instructional coach?"

Data Analysis

Analysis was conducted in three phases, for the purpose of data reduction. In the first phase of analysis, we used open-coding and created memos (Maxwell, 2013; Corbin & Strauss, 2008) of the three interviews to document initial impressions, observations and questions we had for each of the coaches who participated in the project. From this analysis, we identified Madison as a critical case of interest and chose to focus further analysis on Madison's work with two of her teachers, Joe and with Kim. These teachers were selected because Madison identified them as "effective" partnerships, though the experiences she had with each teacher was very different both in terms of how she perceived the coaching exchanges, and the content and nature of the conversations.

Table 4.1 Deductive Codes and Indicators

Code	Description of Code	Indicator from the data
Q	Questions	Coach's use of questioning to generate or extend teacher reflection
P	Paraphrase	Coach's use of paraphrase to facilitate conversation or extend teacher reflection
T	Telling	When the coach tells the teacher what she is thinking, either directly or suggestively
R	Relationship building or maintaining	Language used by the coach to position herself within a desired relational state
CB-coach	Coach Beliefs—coaching	Something that indicates a personally held belief about coaching
CB-T	Coach Beliefs—teaching	Something that indicates a personally held belief about teachers or teaching
CB-self	Coach-Beliefs—self	Something that indicates self-efficacy for coaching or teaching

The second phase of analysis included deductive coding (Corbin & Strauss, 2008) of Madison's written reflections, coaching logs, transcripts of coaching conversations, and interviews, using pre-determined codes generated from our theory of coaching development (see Table 4.1). The final phase of analysis included collapsing and expanding codes to establish categories of interest (Corbin & Strauss, 2008). All data sources were then reanalyzed using these final categories to confirm the evidentiary warrant of the significant patterns of interest (Corbin & Strauss, 2008).

Findings

Coaching Identity: Building from Student and Teaching Identities

In this section, we use an affinity identity perspective (Gee, 2000) to describe who Madison was as a novice coach in order to explain her development of a coaching identity. As a student in the coaching course, Madison remained positive and open to learning new theories and coaching skills, often asking personally relevant questions to apply her learning directly to her work as a coach. She was also open with her classmates and instructors about feeling insecure in her coaching abilities, though she maintained a hopeful attitude that she could continue to improve. Her student affinity identity was interpreted as reflective, conscientious, and diligent. In one class assignment, coaches were asked to collect audio of a coaching conversation of at least ten minutes. They were asked to listen to the conversation, reflect on their coaching "moves," and complete a visual map of the conversation as a way to analyze the content and flow of the conversation. This "conscientious student" affinity identity is evident in the level of detail included in her map (see Appendix F) and also through the careful description of her thought-process she provided in an accompanying written reflection, from which the following is an excerpt:

> When creating my map, I chose to focus on several layers of the conversation… I selected 'conversation focus' as an overarching guide for me to follow the content of the conversation and to help me identify key transitions within the conversation. Some growth areas I previously identified for myself as a coach are attending to the opening and closing of conversations, growing in my ability to

> simultaneously listen to and effectively process the information that is shared in a conversation, and developing in my use of transitions to maintain an appropriate flow to the conversation as well as facilitate reflection back and forward for my teachers. (Written reflection, December, 2013).

Through this assignment we are able to see how she conceptualized one conversation as a series of four focus areas within her broader coaching purposes for the conversation. She placed her own personal intentions at the bottom of the map, which did not always align with the broader coaching purposes in the circles at the top. This separation visually represents a disconnection between her well-established student affinity identity with her developing affinity identity as a coach. Though we can recognize her coaching identity in some places in this assignment, for example in the paraphrasing and questioning examples she provided, she framed this and other learning experiences almost exclusively from her identity as a graduate student.

Additionally, in her post-coaching written logs and reflections, it was common for Madison to maintain a dominant student affinity identity, presenting herself as a learner who was working on self-improvement: "I still do not feel like I am effective at being a 'listener' in our coaching conversations, but I notice that I am able to better understand… I also was able to ask questions… I am not yet good, but I am better than I was 30 days ago" (Written Reflection October, 2014). We conclude that Madison's student identity contributed to how she framed her developing coaching identity. Similar to the way preservice teachers develop an identity for teaching (Avraamidou, 2014), Madison framed her learning first within a familiar and well-established identity as a student Madison's teaching affinity identity also informed her experiences in her first year as a coach. In the pre-interview, Madison explained her belief that STEM was about connecting science, technology, and mathematics content together within the context of a meaningful, engineering challenge. She felt it was also a disposition toward learning—learning as a process of discovery and reflection that only happens when students are involved in the work themselves.

> When I think of effective STEM curriculum, I think of the design-redesign engineering cycle idea. It's not just teachers going through it, but students too. Like, really being reflective in their own practice of being a student and how they're understanding the material and really doing work that connects multiple of those [STEM] letters together (Interview, June 6, 2013).

Her initial teaching beliefs about content integration in STEM served as a guide in her conversations with teachers. In a later interview when asked about problems she saw in teachers' interpretations of STEM integration, he said that though she would not call it a problem, she observed that her middle school teachers saw mathematics as "something separate… they say they do mathematics about once a month, and I'm thinking, you are really doing mathematics more often than that, and maybe it's a misconception about math" (Interview, November 13, 2013). She was excited when Joe and his team identified some really "out of the box" ways of bringing mathematics into their curriculum, but she was disappointed when they did not follow through with those ideas, instead falling into traditional ways of teaching math. When asked if it was something she thought she could address, she responded, "I don't think it's my role to come in with my attitude or my belief that, hey, this truly is mathematics and you should see it that way, that's not my role. It's my role to nudge them to think about it differently" (Interview, November 13, 2013). Madison did not believe that using her own mathematics teaching expertise should help her to establish a focus for her conversations with teachers. She tried to keep her mathematics content knowledge separate from her coaching practices, rather than use that knowledge to inform her decisions about coaching. This is surprising, considering her initial excitement about the opportunities for STEM integration. Somehow Madison held a belief that her teaching identity was something to be wary of when she stepped into a coaching role.

Although Madison believed her teaching identity should take a back seat when coaching, her own interest and beliefs in interdisciplinary teaching were at the foreground of her work with teachers. Often her conversations would move toward the topic of integration, in which her questions would reveal her own curiosity about STEM teaching. In a pre-implementation conversation with Joe, the elementary school science specialist, they talked about the upcoming unit that would feature an engineering design challenge of building a greenhouse to best support plant growth within the constraints of a given scenario. Joe explained that his overarching goal for the unit was "that bridging between the science and the engineering piece," to which Madison responded:

> The word that comes to my mind when I hear you talk about that is that word of 'integration.' And so as you're looking towards integration, what are you going to look for in your students' experiences to monitor their actual experience with it being integrated so that it doesn't feel like, 'today is science, tomorrow is design, the next day, we're going to do math.' What are you going to be looking at in their experience and what they're doing that will let you know that they're seen as integrated? (Transcript, November 1, 2014).

Throughout this conversation, Madison continued to ask Joe to explain his reasoning when he talked about integration. She used a coaching stance of "probing for specificity" in order to extend the teacher's thinking (Garmston & Wellman, 2009), but she also shared her genuine curiosity about integration. It was clear that Madison maintained a focus on integrated teaching even when Joe tried to broaden the conversation out to other topics within his curriculum. When Joe mentioned "mathematics and measurements"

Madison seized an opportunity for integration by suggesting, “maybe having those experiences all in one day.” From an affinity identity framework, we saw how Madison was shifting between a teaching identity and a coaching identity by the content of her questions, and the way she directed the conversation toward her own teaching interests. It seemed she was unable to achieve the ideals of a purely reflective coach (Costa & Garmston, 2002) because her teaching identity was an apparent guide in her approach to STEM coaching. Although she did not value her teaching identity when writing and talking about her work, in practice it was her teaching identity that came through the strongest.

Coaching Defined and Redefined

Here we describe what Madison learned about coaching and her development of specific coaching practices in her first year as a coach. Throughout her experiences, Madison reflected on her learning and talked about what it meant to her to be a coach. Based on these reflections, as well as how these played out in her actual coaching practices, it was clear that her conception of what coaching was and what it was not continued to be defined and redefined throughout the year.

Initially, she described coaching as, "…working alongside [teachers] and asking questions and helping them find different questions to ask, not always having the answers but it is more about finding the questions" (Interview, May 13, 2013). By December, Madison was determined to improve her ability to ask effective questions during coaching. Her belief that good coaches ask good questions came up repeatedly in her reflection and interview data, though she became increasingly aware that crafting a good question was difficult: "I am learning that coming up with good questions is quite challenging. The conversations I am having with my teachers are rich, and I can think of better questions or better places for questions after the conversation is over" (Written reflection, December, 2013). At the end of the year, Madison's conception of a coach as inquirer remained intact, though it deepened with her realization of the complexity of crafting good questions in the moment of conversation, which is evident in her change in questioning practices throughout the year with Joe and Kim.

Early conversations with Joe and Kim were somewhat awkward and unfocused; Madison was unclear of the purpose for the conversations. Often, she led the conversation with a series of pre-planned questions that prompted the teacher to respond in quick, short bursts. Because Madison was so focused on her questions, she often missed what the teacher said. Madison was much more focused and precise in her questioning strategies during the spring conversations with Joe and Kim. Her previously lengthy, disconnected, and unfocused questions became focused and responsive. Table 4.2 presents examples of typical questions asked at three points during the year. It was evident in the coaching transcripts that Madison's focus on improving her questioning skills led to a change in her coaching practices over time. She became a better listener, constructing her questions in response to the teachers' ideas. Her language use became much more decisive. She often struggled for words as she crafted questions in the fall, while in the spring there was much more evidence of clear phrasing with appropriate vocal inflection at the end of the question to signal the teacher's turn to talk. Her development of questioning practices became aligned with the goals of the coaching class and literature on questioning strategies (York-Barr et al., 2006; Knight, 2007; Costa & Garmston, 2002).

Table 4.2 Use of Questioning in Coaching Conversations

	September-November	December-February	March-May
	Unfocused, lengthy, unclear connections	**Focused, unclearly phrased, responsive**	**Focused, clearly phrased, responsive**
Kim	*That's really interesting to think about because I think that the students sort of experience them as separate ideas often and so, do you sort of anticipate any like challenges coming up for the students like they weren't expecting it or so forth or…?* (September 25, 2013)	*Something that you have spoken about before also has been sort of the use of like, a product as the assessment as well in particular, like you know in the context of like, project based learning and so forth, do you see that as being an option here?* (February 12, 2014)	*How would you structure that?* (March 5, 2014) *And what do you see is the benefit also for having them try the different items?* (March 5, 2014)
Joe	*And so as you're looking towards integration... What are you going to be looking at in their experience and what they're doing that will let you know that they're seen as integrated?* (November 1, 2013)	*So tell me the end product. We have about two minutes. How did it end up, like did you see things you wanted in their project, in their process of their design, what were you seeing?* (February 14, 2014)	*Just so that I understand, the classroom teachers here do all the math?* (March 11, 2014)

Coaching for Madison was also enacted through her use of protocols provided for the project. The protocols were presented in the coaching class in addition to multiple other coaching resources, though it was the protocols that Madison adopted into her coaching practices, especially in the first few months of the coaching project (see table 4.3). It took time for Madison to decrease her reliance on the supplied protocols. Early on, she would take one with her to conversations, reading directly from it as she led conversations, with little adaptation for different coaching contexts. Later in the year, Madison started to develop her own series of questions specific to the context and needs of her teachers. While this is evidence of growth in her coaching abilities, she continued to rely on her pre-prepared coaching plans, often at the expense of the teacher's learning, which we discuss further in the following section.

Table 4.3 Frequency Analysis of Protocols Used in Coaching Conversations

	September-November	December-February	March-May
Reflecting Forward Conversation	2	0	0
Reflecting Back Conversation Map	2	1	0
STEM Pedagogy Map	2	1	0
Her own pre-planned objectives	0	2	3

By the end of the year, Madison's definition of coaching included the use of questioning strategies and protocols, but excluded any conversations that were not primarily focused on STEM reform. Analysis of Madison's pre and post coaching logs showed her stated coaching purpose as focused on STEM 83% of the time in the case of Joe, while with Kim only 50% of the time. In these logs, she often described the focus of the conversations with Kim as "checking in" or "catching up." When we asked about this in a follow-up interview, Madison explained that Kim often wanted to talk about content other than STEM teaching, and when this happened, Madison chose not to record the conversation as coaching, explaining, "…it doesn't necessarily pertain, it pertains to her as a person, as a teacher in her context, but it doesn't pertain to the goals of STEM growth" (Interview, November 13, 2013).

In one such hour-long exchange with Kim, Madison explained that only 10 minutes of this conversation was relevant to the goals of the coaching program. When asked about the rest of the conversation, she responded that it was mostly just Kim "spilling her stress" and that she struggled to shift the conversation from "venting" to "growing as a STEM teacher." Kim's venting was in response to the challenges she was facing in her first year at a new school. Kim was also co-teaching with an English Language teacher for the first time and was using her time with Madison to process the many challenges this presented. Although the experiences Kim talked about were not directly related to STEM, they were pertinent and relevant to Kim. It is interesting that Madison did not consider these conversations to be "coaching." She did not record them or write about them in her written reflections, likely because she wanted to protect Kim from any negative perception that she was struggling. Additionally, Madison felt upset with herself that she did not know how to help Kim with these challenges, as she explained in the following excerpt:

> So we have these conversations then, and so for her wrap up, like, it's difficult, and I really feel like I struggle with asking questions so I could get her to think about her situation in a way that would be really sort of proactive and productive. Because I think she's just feeling a lot of frustration and that's really difficult for her then to sort of reflect in a way that's not like, 'oh my gosh, I'm failing!' and like sort of that negative cycle of thought and I really -- like I'm just really sort of blown away. And so I think it's extra challenging by the context of her situation (Interview, November 13, 2013).

Madison's conception of coaching legitimized only one kind of conversation—those focused on the specific reform goals of STEM education. She was not able to reconcile what she perceived to be competing goals of STEM reform although it would have supported Kim in her everyday challenges in a multicultural, multilingual environment.

For Madison, successful coaching happened when teachers were able to reflect accurately on their instruction. She believed this level of reflection would not happen unless she was well planned in advance, with the use of notes, structured protocols, and well-crafted questions. She recognized that developing good questions in the moment was very challenging, as was good listening, both essential ingredients of good coaching exchanges, however she did not identify the possibility that having a pre-planned conversational protocol, and narrow definition of coaching conversations, might have hindered her ability to respond in the moment to coaching opportunities that arose.

Coaching Beliefs: Decreasing Sense of Self-Efficacy

Throughout the year, Madison frequently talked about herself as a “novice,” mentioning that she was “not confident” and “not good at” aspects of coaching. Some examples of the specific coaching skills she cited included: ending the conversation in a natural way (Interview, November 13, 2013), transitioning to specific action steps (Interview, November 13, 2013), and asking questions in the moment (Written Reflection, December, 2013). Although Madison maintained a positive attitude and openness to learning about coaching, she expressed dissatisfaction with her own growth as a coach at the end of the first year. She was concerned that meeting with teachers once a month was not enough time spent on coaching to really grow to the level she had hoped. These challenges in the first year of coaching contributed to a decrease in her coaching self-efficacy.

A few studies have found similar decreases on measures of self-efficacy for novice teachers in their student teaching. In these studies the teacher candidates had inflated levels of self-efficacy before they began the teaching experience, which then dropped at the end of their first year to what was interpreted as a more realistic level (Hoy & Spero, 2005; Emmer & Hickman, 1991; Weinstein, 1989). It is possible that Madison's decrease in efficacy is a result of this overconfidence at the start of the program, however analysis of Madison's pre-program interview does not align with this theory. She entered the program with an understanding that she would be learning and that she did not have all the answers. When asked what she was looking forward to in upcoming work as a coach she responded, "I'm looking forward to learning from my teachers, learning with my teachers. Teaching my understanding of STEM and what it looks like on the ground, and just really being reconnected to teachers in practice" (Interview, May 13, 2013). She also talked about how she would develop positive relationships with teachers, making sure she wasn't perceived as "the ivory tower coming in," and laughed about her lack of experience in elementary schools as a possible place where teachers would have more answers than she would. If she had an inflated sense of self-efficacy for coaching her responses would have reflected a stronger belief in her own ability to transform teachers.

At the mid-year interview, Madison talked about some of the progress she felt she had made regarding her self-confidence. She described how she still felt "shaky" as a coach, but that she thought she had improved a great deal from the beginning of the year. When asked to give an example of a success she had, she stumbled, and couldn't think of one. She then began to talk more about the areas she wanted to improve instead.

> I don't feel like I lead a good conversation, it's very new to me to do something like that. So I think that there's just been struggles, like I don't know if my teachers know how nervous I am, but you know, like I go in and I usually have the protocol out that I am trying to use, and I just feel like I can start it well but then I don't do a good job of sort of wrapping it up (Interview, November 13, 2013).

Madison's coaching self-efficacy was context-specific, derived from the culmination of coaching and learning experiences she was a part of in her first year as a coach. These experiences drew decreases to her self-efficacy beliefs as a novice coach and it is inconclusive from our analysis what caused the decrease. We suspect that Madison's developing identity as a coach created conflict between her existing affinity identities of student and teacher, causing internal struggles to accept and reject various beliefs; however further analysis is needed to determine the causes of this shift.

The Impact of Novice Coaching

Teacher perceptions. Joe and Kim were not unaffected by Madison's dispositions, knowledge and practices as an instructional coach. When Kim was asked about her coaching experiences, she shared that when they had a full-time coach in her building it was nice to have someone she could go to for ideas like, "how to deal with certain kids" and for "lessons to incorporate more movement into our teaching" (Interview, May 2, 2014). In the same interview she shared that the hardest thing about having a coach was being videotaped because "watching myself on videotape is my worst nightmare" though she admitted that it is a good practice for teachers to do. She felt that a lot of what a coach asks her to do is often hard work. She expressed gratitude in working with Madison because she "took the time to listen" and "always had good ideas" (Interview, May 2, 2014).

Joe's responses to the same questions were more open to co-learning with the coach, than were Kim's. He believed that coaches are great for sharing ideas with and "they are out and about more in other schools so hearing what their experiences are is really helpful" (Interview, May 2, 2014). The challenge of having a coach was that "sometimes they are spread out so thin that a lot of time is spent bringing them up to speed," meaning that when a coach has a lot of other teachers that she might be working with, he has to spend a lot of time explaining his experiences with the coach if he hopes to get to get a lot out of the conversation. Specifically, he expressed great satisfaction in working with Madison because he felt the relationship was "mutually beneficial" and "collaborative" (Interview, May 2, 2014). From these positive responses, it is evident that Madison was able to successfully support Kim and Joe in their STEM integration efforts, and that the learning experience was rich for all three individuals.

Missed opportunities. Additionally, our analysis revealed instances in the coaching conversations that represented a missed opportunity for coaching. These missed opportunities arose unexpectedly in conversations, often on topics not related directly to the protocols or Madison's pre-planned objectives. Madison hinted at being aware of such missed opportunities in her written reflection after completing the coaching map assignment (Appendix F) where she wrote, "I had initially wanted to include a focus on opportunities that I either missed or selected not to focus on in the conversation… I decided not to include the opportunities for focus that I missed or selected not to follow in the map because of the practical reason of limited space" (December, 2013). Although Madison was aware there were some missed opportunities, she did not explain her reasoning for missing them, nor did she talk about those opportunities further in her coaching logs or written reflections. Their absence from her other data sources are likely because our prompts and interview questions did not direct her to include them, as we were not expecting to find this pattern of significance. The following excerpt is an example of one instance where Kim indirectly raised an issue she felt she needed help with, but Madison did not respond with coaching support.

In this conversation, Madison asked about Kim's ideas for her upcoming new unit that would make use of the new wind turbines. In a previous conversation, Kim explained at length that one of her least favorite teaching activities was using worksheets or textbook-based lessons, "When I think I have units where we get more book-centered… It's like worksheet, worksheet, worksheet. Those units are not nearly as – the kids are not as engaged. Sometimes, you just can't do hands-on stuff and everything. It's like you definitely see that engagement change" (Transcript, January 29, 2014). However, when planning the upcoming new unit, her first teaching idea was to create a worksheet. This presented itself as a coaching opportunity for Madison, but she did not engage Kim in reflecting on alternative teaching formats.

Madison: What are some of your initial ideas on that?
Kim: Well, I feel like – I mean I'm going to have to break it down, it's probably going to have… **kind of work sheet based** and what an input and an output is like. **There's an introductory piece**. And then maybe once we start the turbines they can start to identify on their own...

Madison: And like **with those work sheets that had – like you've typically had...**

Kim: **I think we'll have to do some notes on the work sheet.** The book actually has a decent section of it, I looked through to the past because **to be honest it's one of those things that I don't have the background in** so it's like one of those things where **I need other resources** to get me up to speed on it. So it probably will be something maybe a little bit more like **notes or a worksheet intro** (Transcript, March 5, 2014).

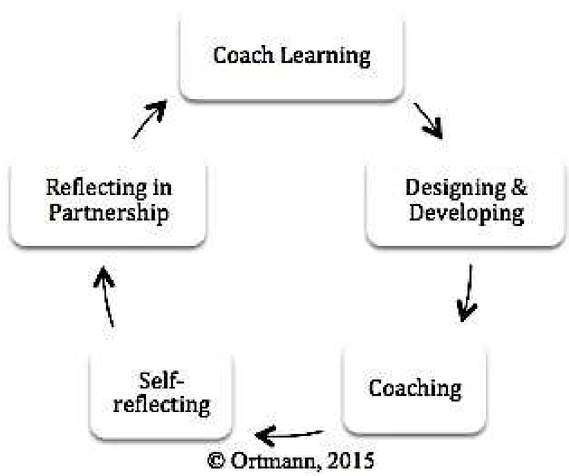
The conversation to plan the new wind turbine unit continued with the use of worksheets and book-work an uncontested method of instruction for what was intended to be an inquiry, reform-based approach to STEM education. We were perplexed by these missed opportunities for coaching, and wonder if Madison made conscious decisions to "stick to the protocol" because of her belief that her role as a STEM coach was to focus her coaching exclusively on content integration. It is also possible that she was not sure how to respond to these indirect requests for assistance, or she did not recognize these as opportunities for coaching at all. It is clear that these missed opportunities were likely indicative of her novice level of coaching experiences, and if she had more experience she would have found a more productive way to respond.

Implications

Understanding the Development of a Process of Coaching Reasoning and Action

We return now to the theory of the process of coaching reasoning and action (see Figure 4.1) in relation to observations from Madison's case. The coach learning stage of the process requires the coach to spend time seeking understanding of the teacher's current reality before "coaching" can begin. Madison spent considerable time asking questions to understand the instructional experiences her teachers had when she was not present. Because Madison was a part-time, externally based coach, she may not have developed a coherent understanding of their realities. We argue that a novice coach needs support in understanding the important role of a teacher's current reality, both for her own creation of a coaching plan, and for her relational development with her teachers.

Figure 4.1 Model of the Process of Coaching Reasoning and Action



The second stage in the process is the transformation of the coach's understanding to the development of a coaching plan that will guide her work with the teacher. We argue that this stage of a coach's development is critical, as it is required for a successful transformation of content knowledge into relatable pedagogy for the teacher. In the first months of coaching, Madison was reluctant to steer away from the provided coaching protocols, but when she did steer away by creating her own series of questions, she felt proud of herself, and the conversations she had were more natural and relaxed. A coaching protocol is an important first step in learning the language of coaching, but the novice coach should be encouraged to move beyond this scaffold to design learning conversation purposes and frameworks for the particular needs of the teachers she works with.

Coaching itself can include practices of observing teaching, co-teaching, modeling lessons, engaging in lesson study, facilitating peer-learning groups or other learning designs that the coach creates. Madison spent almost all of her coaching time in one practice; reflective conversations with the teacher after a teaching experience that she may or may not have observed. Additionally, establishing oneself as an occasional member of the classroom is an important first step to coaching (Lieberman, 2001). Madison's reluctance to do so was indicative of her confidence level as a coach. Her level of reflection with the teachers and coaching skills arguably increased throughout the year as Madison gained confidence as a coach, however she continued to miss opportunities for coaching and did not get creative in how she could best support her teachers' learning.

The coach's individual reflections and reflections with the teacher constitute the fourth and fifth stage of the process. At times, these two stages were intertwined, where reflection with the teachers would trigger her own individual reflection. Her written coaching logs and written reflections were a small window into how she reflected independently both before and after conversations with her teachers, and from these we were able to discern a small part of her development of her own coaching dispositions and knowledge. As she worked through the experiences she had with Joe and Kim she was able to make some sense for herself of what she was experiencing, and these reflections played a small, but important role in her development.

Preparation of School-Based Coaches

Coaching teachers in implementing instructional and curricular change is complex. It requires much more than a sophisticated knowledge of teaching and learning, including a set of dispositions, beliefs, practices and a coaching identity that takes time to develop. Learning how to coach is at least as challenging as learning how to teach (Gibson, 2005). What then should a coaching training program include to support the school-based coach in his or her development? Although coaches are often positioned as knowledgeable experts, they have been found to be co-learners with teachers, often learning the content and pedagogy at the same time as the teachers they are expected to coach; therefore, professional development could be designed to target both coach and teacher learning goals simultaneously (Gallucci et al., 2010; Darling-Hammond et al., 2009). Additionally, Rainville and Jones (2008) concluded that the coach's identity negotiations across multiple contexts in their study suggest that coaching development should include work in roleplaying or analyzing video and audio transcripts of coaching to identify and work through the issues of power present in conversations. They argue that the novice coach needs ample opportunities to analyze how experienced coaches make choices with language to position him or herself for different purposes.

We add to these suggestions with our findings that the novice coach needs further opportunities to reflect in a learning community to support the development of a healthy and optimistic coaching identity. There are a number of instructional activities we used that we felt supported novice coach development. First, we recommend the use of pre and post reflection logs to build a coaching record-keeping system than can be referenced throughout the year. These logs could also include a written, journal-like reflection component that helps to capture the coach's developing ideas and beliefs about coaching over time. This can offer a productive space for personal growth for individuals who enjoy the process of journal writing. For those novice coaches who do not wish to spend time writing, conversational opportunities where they can be coached to reflect on their own developmental progress would be a valuable alternative. Additionally, opportunities to observe and process coaching in action are critical to developing the knowledge base and awareness of the subtle conversational nuances of coaching. These could be live sessions, video or audio recordings, or role-playing scenarios with other novice coaches to analyze the different coaching moves that cause teachers to respond in certain ways. We recommend assignments similar to the visual coaching map assignment (see Appendix F) because it offered coaches an opportunity to listen to themselves coach in a non-threatening environment, as well as produced a wide variety of visual representations that were then shared with peers in class. This offered divergent ways to conceptualize coaching, and worked to build a higher level of understanding of contextually dependent coaching.

In addition, the development of a coaching identity requires institutional support. As Gee (2000) explains, the institutional identities of individuals can be underwritten and sustained by institutional forces. Institutional support could come from building level administrators or grant overseers and other university-school partnership governing bodies. It is important that coaches are given time and resources to develop before they are expected to produce complex and innovative change in teachers' instructional and curricular practices.

As funding for professional development for teachers continues to be spent on large-scale, district-wide or multiple district initiatives, more empirical research on the use of instructional coaching as a vehicle for teacher change is needed. Consideration for how coaches will be trained and supported through their first years of coaching must be made. Since the field of STEM education is a relatively new field, the novice coaches in STEM are co-learning with their teachers. It is a particularly novel challenge to develop as a coach while also determining the possibilities for STEM. Because of this, the novice STEM coach has a unique opportunity to influence the learning of classroom teachers, but they must also simultaneously be supported in their own development, so as to avoid a decrease in coaching self-efficacy, missed coaching opportunities, and awareness of the ways their professional identity is changing as they take on a new role in education. Novice coaches should have ample opportunities to explore the possibilities of their new position, including the dispositional shifts and identity development that will inevitably happen in the first year. Coaches must be encouraged to reflect with teachers as they explore together the opportunities and challenges of STEM integration in secondary schools.

Chapter 5:

Synthesis, Implications, and Future Directions

Conclusion

Few research studies have examined the disciplinary discourses and discursive practices within science classroom contexts when teachers integrate the disciplines of STEM. In order to develop a grounded theory of disciplinary integration practices and a better understanding of the coaching practices that can best support teachers in their interdisciplinary efforts, the three cases presented in this dissertation study aimed to describe in detail the situated nature of learning in and across disciplinary boundaries, and the practices of teachers and coaches who worked together to develop a process of STEM integration from the ground up. The first manuscript that documents two case studies, presented the classroom discourses and discursive practices of two 9^{th} grade physical science teachers who co-developed an integrated STEM unit, and taught that unit in their own respective classrooms. The second manuscript presented a cross-case analysis and critical discourse analysis of these two cases, and outlined a process of disciplinary integration in science classroom discourses that accounted for differences across teaching contexts. The last manuscript presented a case of one novice coach's development as she learned how to coach teachers in STEM integration efforts, and presented a model of coaching reasoning in action. Together, the manuscripts detail various investigations and present an important portrait of STEM integration efforts, the classroom discourses that contribute to sociocultural theories of literacy and learning from within and across the disciplines, and the ways that teachers and classroom coaches can work together to achieve their goals for disciplinary integration.

Summary of the Major Findings

A Process of Disciplinary Integration in Science Classroom Discourses

The literature on disciplinary integration has examined integrated curriculum in terms of the overall design of the unit (Davidson, Miller, & Metheny, 1995; Huntley, 1998), the core concepts and processes that are taught in the unit (Drake, 1998; Fogarty, 1991), and has measured "integration" by the amount of content/processes that are drawn from multiple disciplines (Berlin & White, 1995; Davidson, Miller, & Metheny, 1995). For example, Huntley (1998) proposed a theoretical framework for science and mathematics integration that included three concepts: *intradisciplinary*, where one discipline is the focus; *interdisciplinary*, where two or more disciplines are taught side-by-side; and *integrated*, where explicit connections are made between and among multiple disciplines. However, very little research has been done to examine disciplinary integration as it exists in classroom discourse, or what Lemke (1990) called the "lived curriculum," which exists through students' lived experiences in classrooms. Lemke (1990) argues that the only way to truly understand the "lived curriculum" is through analysis of classroom dialogue and comparison to the "official" curriculum (p. 94). This study responds to these gaps in the literature by offering an analysis of classroom discourse and the broader social and discursive practices that surround it through application of social theories of learning and literacy, and critical theories of classroom discourse.

The first manuscript, *Exploring Disciplinary Integration in Science Classroom Discourses*, presented the cases of two 9th grade physical science teachers and analysis of data collected during the implementation of a STEM integrated curriculum. The case of Andrea Davidson highlighted the nature of STEM integration discourses when the students were English learners and the course was co-taught with an EL teacher. The inner-city context of this case offered important insights into the application of a STEM curriculum to the goals of teaching science and engineering standards as well as supporting students' academic and English language development. Instruction in Ms. Davidson's classroom included important language scaffolds and multimodal pedagogical representations of disciplinary concepts that supported her students to learn science and engineering content, concepts, and practices. Though important to the situated learning of her students, co-teaching also served as a threat to Ms. Davidson's established teaching identity, particularly when the English Language co-teacher would "step across" into science content instruction instead of staying within her established role as the language teacher. Also unique to this case, were the lived experiences of students in the class, who had first experienced "engineering" while in refugee camps in Thailand and Burma. For these students, engineering was relatable to them when they understood it as a way to solve problems for survival in the world.

The case of Heidi Fischer highlighted the disciplinary discursive ways of representing science content knowledge during STEM integration. Her strong identity as a STEM teacher practitioner was enacted throughout her instruction which used explicit modeling of scientific discourse, as well as multimodal pedagogy, which included interactive demonstrations, videos of recent “feats of engineering,” and visual demonstrations of the use of new technology tools. Students in this classroom apprenticed the disciplines of STEM through their scaffolded use of “the language of science” and by participating in an engineering design challenge that mimicked the professional practices of engineers through Ms. Fisher’s applications of engineering discursive practices. And finally, despite the integrated nature of the STEM disciplines, science ways of knowing and representing knowledge were privileged over other ways of knowing and representing learning in this classroom community. In Ms. Fisher’s case, STEM was very much a vehicle for teaching physical science content, and the discourses and uses of language revealed that science was at the epicenter of teaching and learning practices.

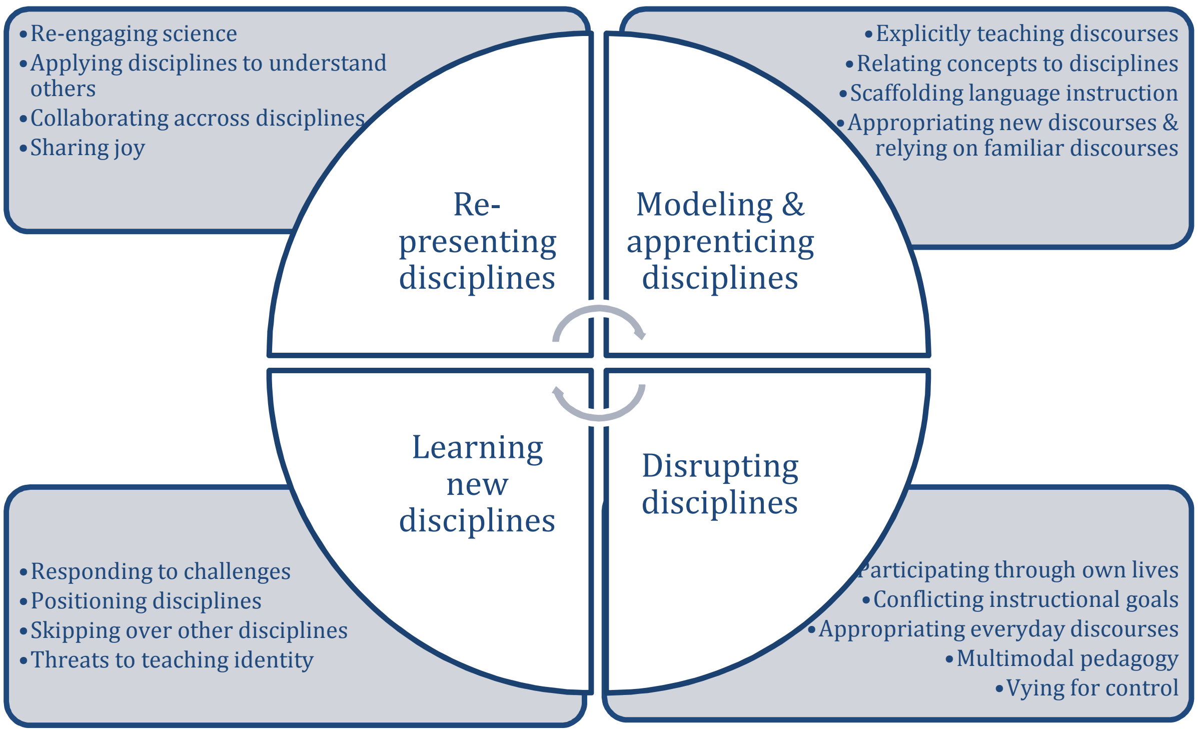
Across both cases, students relied on familiar social discourses and functional discourses when working together in small groups. The use of the “language of science” or other disciplinary discourses when their teachers were not directing their activity and conversations was rarely observed. This is consistent with the literature that highlights students’ uses of familiar literacies in order to learn new disciplinary literacies in school (Hagood, 2002; Xu, 2004, 2008). This is also consistent with Lemke (1990) who argued that even though an important goal of science education is to teach the language of science, students are most engaged when the language of the classroom is familiar and accessible.

Also across the cases was evidence that a large part of the teachers’ identities was aligned with the disciplinary discursive practices and broader social discourses of the discipline of science. Although it may be true that science teachers do not identify themselves as "scientists," they do align themselves with the discipline of science more so than the other disciplines of STEM. This is consistent with teacher identity literature that has found teachers' disciplinary expertise a dominant construct within enacted teaching identities (Rogers & Scott, 2008), and when teachers sense others are crossing over into their disciplinary domains, their identities may become threatened (Robinson & Buly, 2007; O'Brien, Stewart & Moje, 1995).

The second manuscript, *A Process of Disciplinary Integration in Science Classroom Discourse* presented a model of the process of disciplinary integration in classroom discourse (see figure 5.1) through a cross-case analysis of the two cases presented in the first manuscript, and also application of critical discourse analysis methods (Fairclough, 1992) to selected texts. The developed model responds to the existing literature, and extends the study of disciplinary integration in important ways. First, studies of disciplinary integration have found that teachers apply the other disciplines of STEM in order to teach the discipline of science (Wang, 2011; Bybee, 2013). This was true across both cases, however the application of mathematics and engineering to the science instruction of the classrooms in this study was found to *re-present* the discipline of science. Traditionally, the language of classroom science sets up a pervasive and false opposition between a world of objective, authoritative scientific fact and the ordinary, personal world of human uncertainties and interests (Lemke, 1990, p. 130). However, the application of mathematics, technology and engineering opened up the discipline of science to include human endeavor and connection to the physical world.

The teachers in both cases were excited to connect traditional science to a more relatable world of engineering for their students. Through applications of the science content to engineering contexts, science was re-presented in everyday language and familiar social discourses.

Figure 5.1 A Process of Disciplinary Integration in Science Classroom Discourses



Secondly, explicit instruction of disciplinary discourses that included *modeling and apprenticing* of scientific language was an important feature of the STEM instruction found in this investigation. This is similar to studies in disciplinary literacy that have called on the importance of explicit academic language instruction (Moje, 2007; Snow, 1987; Shanahan & Shanahan, 2008) and modeling of disciplinary discourses (Moje, 2008; Shanahan & Shanahan, 2008) when learning in the disciplines. The findings in the second manuscript confirm these earlier findings, and also suggest that the level of student appropriation of the modeled disciplinary discourses varied among groups and classrooms, and more importantly, that students' uses of everyday language and familiar social discourses were important to their learning of new disciplinary concepts. It was true that teachers were working to model the discourses and language of science, however the students rarely moved from their own familiar social discourses and uses of everyday language when engaged in learning activities. Students' reliance on social language to understand science and engineering concepts and actively participate in STEM activities was an essential component of STEM integrated practices.

Studies of disciplinary integration have also found that when teaching multiple disciplines, teachers often position one discipline over another, and rarely find "true integration" (Harris & Alexander, 1998). The teachers in this investigation positioned science disciplinary knowledge and ways of representing that knowledge over the other disciplines most of the time. However, when disciplinary integration was achieved, it created an intertextual "borrowing" of various social languages and practices that at times confused the uses of academic vocabulary. At times, terms like "argument" and "evidence" implied multiple meanings from three different disciplines, and the way the teachers and students were using these terms was not clearly situated within a defined community of practice (Lave & Wenger, 1998). This worked to *disrupt* the disciplinary ways of knowing and understanding concepts and practices. The disciplines were also positioned within a hierarchy where the teachers' low affinity to engineering and STEM discourses and higher affinities to science teaching discourses revealed the distances of membership for the teachers across disciplinary boundaries.

And finally, STEM integrated teaching was a learning experience for the teachers in this investigation, particularly learning of the disciplines of mathematics and engineering, and the uses of technologies and language/literacies within disciplines. When presented with inevitable challenges of learning new disciplines, the teachers struggled to maintain a commitment to teaching the other disciplines, including science literacy and language instruction. Although the teachers valued "science literacy" and mathematical representations of science concepts, they did not own these instructional goals as they did their science standards and goals. This resulted in skipped and fragmented instruction of the other disciplines.

A Process of Coaching Reasoning and Action

The final manuscript, *How One Novice Coach Became a Partner to Teachers in STEM Curricular Reform,* presents the case of Madison, a coach in her first year of coaching, and her development of coaching knowledge, skills and practices to support teachers in integrating the disciplines of STEM. This single, embedded-case (Yin, 2009) of Madison and her work with two middle school science teachers included analysis of data from recorded monthly coaching conversations, semi-structured interviews of participants, and the coach's written reflections and logs throughout the 2013-14 academic school year. This investigation responds to and informs the literature on coaching by applying frameworks for teacher development and teacher identity (Shulman, 1987; Schon, 1987; Tschannen-Moran, Hoy, & Hoy, 1998) as means to explore coaching development and identity.

The findings highlight the importance of specific aspects of coaching development, including; establishment of a coaching identity, a clear definition of what coaching is in context, challenges to self-efficacy for coaching, and missed opportunities for coaching in the first year.

Madison's developing coaching identity was built upon established student and teaching identities. As a student in a graduate level course on coaching, Madison maintained a strong student identity when engaging in coaching experiences. She presented herself to teachers as a learner who was working on self-improvement goals in her professional practice. Her mathematics teaching identity was an important part of her interest in coaching teachers in STEM integration, and influenced the direction of the conversations she had with teachers. She was interested and excited to see the new ways that science teachers would work to integrate mathematics into their teaching, so she often asked about their uses of mathematics and integration of the other STEM disciplines. This is consistent with literature on coaching identity that has found teachers transitioning into coaching roles rely on existing teaching identities to build new a new self-image as a coach (Rainville & Jones, 2008; Gibson, 2005).

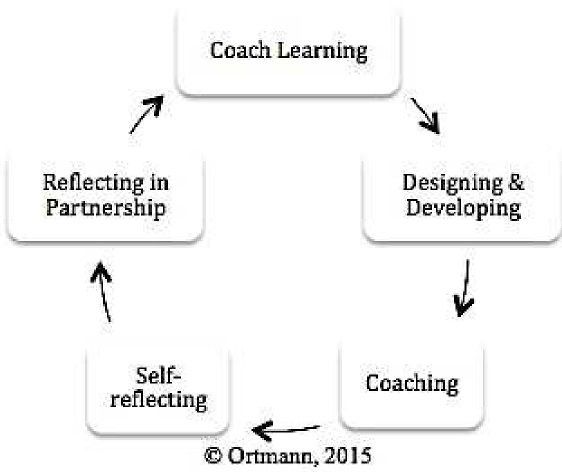
Throughout the year of coaching, Madison continued to define and redefine what it meant to be a coach, and what constituted coaching in her relationships with teachers. She considered coaching to be defined within a frame of reflective practices, including facilitation of conversations and reflection on experiences in partnership with teachers. She also considered coaching to be focused exclusively on "STEM" topics, and when conversations moved to other teaching issues she discounted them as coaching, and instead called these episodes "teacher venting" or "not pertaining" to the goals of coaching. It is important for coaches to connect their coaching practices with the broader goals of coaching, and these must also include the teacher's goals for herself (Gross, 2012). Coaches will need support in connecting the broader purposes for coaching with the context of the coaching relationship with teachers.

Madison also experienced a decrease in self-efficacy during the first year as a coach. She talked about herself as a "novice" and "not good at" aspects of coaching. Although Madison maintained a positive attitude and openness to learning about coaching, she expressed dissatisfaction with her own growth as a coach at the end of the first year. This is consistent with teacher education literature that has found similar decreases in self-efficacy for preservice teachers (Hoy & Spero, 2005; Emmer & Hickman, 1991; Weinstein, 1989). My analysis of Madison did not find clear causes for this decrease in self-efficacy, particularly because Madison's skillfulness as a coach in establishing her own protocols for coaching increased over time. Further study is needed to explore coaching self-efficacy changes over time.

The first year of coaching had both positive and negative impacts on the outcomes of her coaching. The teachers found different aspects of Madison's coaching impactful. One teacher enjoyed the ideas Madison brought to the conversations, and appreciated the reflection on her teaching even though it was at times uncomfortable to consider her own teaching practices. The other teacher enjoyed the multiple perspectives Madison brought from her experiences in multiple classrooms, however he did not like how coaches were "spread so thin" and that a lot of time was wasted getting the coach caught-up. There were also missed opportunities in the coaching conversations where the teacher indirectly asked for help on an aspects of instruction, but because of the coach's novice status she did not recognize these as coaching opportunities and skipped right over them. As coaches learn new coaching skills and gain confidence in these skills, fewer missed opportunities for coaching will be likely to occur (Chval, Arbaugh, Lannin, van Garderen, Cummings, Estapa, & Maryann, 2010; Jones & Rainville, 2014; Ippolito, 2010).

Also from this investigation, a model of a process of coaching reasoning and action was developed (see figure 5.2) to consider the ways coaches learn to make coaching decisions that best support teachers. This model represents a process for decision-making, and also a process of action that can guide the novice coach in his/her development. The model was built from applying my findings to Shulman's (1987) theory of a process of teaching reasoning and action which begins with a teacher's comprehension of a text (explained as a literal text, or a curriculum or lesson concept), the transformation of that text into a pedagogy, acts of instruction, evaluation and reflection, which then leads to new comprehension and the process continues (p. 15). When applied to coaching, the first stage in the process requires the coach to build comprehension, which I have named "coach learning," before making any decisions or assessments of what type of coaching to move into. This learning could look like informal observations in the classroom, clarifying goals for coaching, or reading about an instructional best practice.

Figure 5.2 Model of the Process of Coaching Reasoning and Action



The next stage was found to be essential to the establishment of a coaching identity and self-efficacy for coaching, something that Madison only touched upon in her first year as a coach. This is what Shulman called “transformation,” and what I call “design” of the coach’s understanding of the purposes for coaching into “pedagogical representations” that will inform the coaching decisions the coach makes. This is comparable to creating a lesson plan, or designing a professional development plan, but it need not be as formal as a written document. When we consider it as a reasoning process, it is more important that the coach conceptually begins to develop a way to move forward in the coaching relationship in a way that will be well received by the teachers he or she coaches. This is similar to differentiated coaching models that articulate the need for coaches’ responsiveness to the uniqueness of each teachers’ personality, context, and style (Kise, 2006).

The next phase is the observable performance of “coaching,” which could be as simple as leading a teacher through a process of reflection that includes a cycle of planning, observation, and reflecting, or as complex as a year-long co-teaching experience, modeling lessons, or engaging in lesson study. In the case of Madison, the activities of "coaching" were limited to reflective conversations, before or after an implemented lesson. As coaches gain more confidence and experience, their creativity in designing coaching experiences will also grow. Establishing oneself as an occasional member of the classroom is an important first step to coaching (Lieberman, 2001). The more connected the coach is to the workings of the classroom, the more relevant the coaching will become (Gibson, 2005).

Self-reflection and reflection with the teacher are activities the coach engages in when he or she looks back at the coaching experiences that have occurred and "reconstructs, reenacts, and/or recaptures the events, the emotions, and the accomplishments" (Shulman, 1987, p. 19). Partially this should be done alone in quiet, individual reflection, and also partially in concert with the teachers s/he has been working with in order to arrive at new learning. Just as John Dewey has famously said, "We do not learn from experience, we learn from reflecting on experience" and the same is true for coaching. If the coach is not learning, the activities of coaching will remain lifeless and prescriptive, which in the case of Madison turned conversations that were intended to be reflective into scripted interviews. A focus on coach learning is particularly important in cross-disciplinary coaching contexts like the case of Madison, a mathematics teacher, coaching middle school science teachers. When Madison was aware of her own learning, particularly her learning about mathematics integration into science classrooms, she became more invested in developing successful coaching experiences for her teachers.

This offered motivation for the coach, and also worked to lessen the power differential between Madison and her teachers, which is pronounced in content-coaching approaches (e.g., West & Cameron, 2013). These conclusions lead me to offer the following implications from this dissertation study.

Implications

Literacy in the Disciplines

Zollman (2012) conceptualized STEM literacy as being composed of skills, abilities, factual knowledge, procedures, concepts, and metacognitive capacities, and being social and personally relevant to students. Bybee (2013) defined STEM literacy as knowledge, attitudes, skills, understandings, awareness, and engagement in STEM-related issues. Despite these sociocultural views of STEM literacy, studies that have sought to examine the literacies of adolescents in science and STEM learning contexts have applied a functional definition of literacy, where literacy is seen only as the production and consumption of texts. Thus, this dissertation study responded to a gap in the literature by applying a sociocultural view of literacy and learning to a study of the disciplinary discourses found in STEM integrated teaching and learning contexts. The findings of this dissertation have important implications for the teaching of literacies and discourses within disciplinary and interdisciplinary contexts.

First, findings reaffirmed the need for teachers to model and explicitly teach the language and discourses of the discipline. Lemke (1990) has argued that the job of science educators is to teach students to "talk science" according to the thematic patterns of science in writing and speaking (p. 100). However, because integrating the disciplines of STEM resulted in the teachers borrowing words from one discipline and applying their use in another, the disciplinary communities of practice became unclear and language became oversaturated with multiple meanings. This implies that the uses of explicit discourse instruction can only go so far in cueing students into the language of the discipline. Students, and teachers, also needed to understand how vocabulary changes meaning when it moves across disciplinary domains. Students and teachers will need to also consider the broader social purposes for language within each classroom activity. For example, students will want to consider how their teacher's use of the phrase "test your design" could mean "conduct an experiment on your design" if the teacher is using science discourse, or "grade your design" if she is using a science classroom discourse, or even "find the point of failure" if she is drawing from engineering discourses. Also, true appropriation of the disciplinary discourse needs to move beyond parroting back the words. Instead, we want students to be able to construct the essential meanings of their learning in their own words, and in slightly different words as necessary (Lemke, 1990, p. 91).

The findings from this dissertation also add to the literature that has found that the use of specific language instruction in science supports traditionally marginalized youth in learning and succeeding in science subject areas (Ciechanowski, 2009; Villanueva & Hand, 2011; Henrichs & Leseman, 2014; Lee & Fradd, 1998). Because science is not a "culture-free" enterprise, nor a consistent body of knowledge, scientific concepts, discursive genres, and assessment practices common to U.S. schools, are infused with culture-specific practices that are not equally accessible to all groups of students (Luykx, Lee, Hart, & Deaktor, 2007). The goal of "science for all" (Villanueva & Hand, 2011) is consistent with the findings of this dissertation, however because students were learning important science concepts *through the use* of engineering, the students' reliance of familiar social discourses and home languages became far more essential to their engagement with the science concepts than a forced use of science discourses. This implies that teachers should encourage students to rely on their prior linguistic and cultural knowledge when engaging with scientific information and learning of science (Luykx, Lee, Hart & Deaktor, 2007), and that uses of students' "out of school literacies" can maintain their engagement in disciplinary learning (Hagood, 2002; Xu, 2004, 2008).

Lemke (1990) concludes his recommendations for science teaching with two important points: 1) teachers should use all of the stylistic and rhetorical means available to communicate science to students, including humor, irony, metaphor, fiction, fantasy, personal anecdotes and historical examples; and 2) Students should be encouraged to use alternative stylistic forms in speaking and writing science when learning science, and they should be taught when formal language is needed and when alternatives may be used (p. 174). My findings confirm Lemke's arguments. Teachers and students should be invited to use any and all language resources they have available to them to learn within the disciplines, and, when the nature of the activity requires a specific use of a disciplinary discourse or set of vocabulary, instructional practices that include modeling, explicit language instruction, and metadiscourse work to cue students into the disciplinary discourses that are drawn upon in the classroom.

Cross-Disciplinary Coaching

Coaching teachers in implementing instructional and curricular change is complex. It requires much more than a sophisticated knowledge of teaching and learning, including a set of dispositions, beliefs, practices and a coaching identity that takes time to develop. Learning how to coach is at least as challenging as learning how to teach (Gibson, 2005). Although coaches are often positioned as knowledgeable experts, they have been found to be co-learners with teachers, often learning the content and pedagogy at the same time as the teachers they are expected to coach; therefore, professional development could be designed to target both teacher and coach learning goals simultaneously (Gallucci et al., 2010; Darling-Hammond et al., 2009). A focus on coaching development particularly during the first year of coaching would ensure new coaches' development of a healthy coaching identity during their vulnerable transition into a new role. The uses of individual reflection activities, study of the literature on coaching, and peer-learning networks could have valuable outcomes on coach development. Also, opportunities to observe and process coaching decision-making and activities could support the development of a robust knowledge-base for coaching and awareness of the subtle conversational nuances of coaching conversations.

The goal of teacher education, according to Shulman (1987) is not to indoctrinate or train teachers to behave in prescribed ways, but "to educate teachers to reason soundly about their teaching as well as to perform skillfully" (p. 13). Just as Shulman (1987) argued that pedagogical reasoning is as much a part of teaching as is the actual teaching performance itself, I argue that designing and developing are as much a part of coaching as the observable "performance" of coaching. This implies that coaches should be encouraged to reason about the teaching they observe and their own coaching practices as they develop new coaching knowledge and skills. It is not enough to learn and use the language of coaching, which has been described as including reflective question stems and paraphrasing, etc. (Costa & Garmston, 2007), but coaches must also learn about the broader social and institutional purposes for coaching, the teacher's goals and purposes for coaching, as well as the everyday realities of the teachers' classrooms. These understandings will inform a process of reasoning and action, and lead to coaching that is more relevant and impactful than a scripted coaching model.

The well-established teaching identities that individuals bring into their coaching work were found to play a dominant role in the establishing of coaching roles, positional authority, and focus for the conversations. This has significant implications for coaching across disciplinary boundaries. When coaches and teachers have different disciplinary expertise from one another, there is a possibility for conflict and miscommunication (Gross, 2012). However, there is also a unique opportunity to learn from one another, and collaborate on a new representation of disciplinary instruction that is cross-disciplinary, or integrated (Roehrig, Moore, Wang, & Park, 2008). These cross-disciplinary experiences will be essential to the successful integration of the STEM disciplines in K-12 STEM education reform efforts. It will not be enough for science teachers to attend workshops to learn more mathematics content, likely taught from a mathematics teaching perspective. Instead, science teachers will need the on-going support of a coach who can offer "mathematics ways of thinking" in the moment for science teachers, and a coach who learns about the science teaching contexts of the teachers she coaches. This pairing coupled with the coaching context will be particularly powerful at advancing the goals of STEM professional development.

Directions for Future Research

The case studies presented in this dissertation work lead to further questions regarding literacy, interdisciplinary teaching, and coaching development. One future direction would be to investigate different interdisciplinary teaching contexts, including different science and mathematics concepts taught through STEM integration, or contexts where language instruction and disciplinary teaching are simultaneous goals in the classroom. This would allow for greater theoretical relevance of the proposed model of disciplinary integration through classroom discourses and expand to disciplines other than science.

Another future direction of this research would be to explore the development of coaching and teaching identities simultaneously, when coaching and teaching in cross-disciplinary contexts. This study found that coaches and teachers relied on existing teaching identities that were grounded in their disciplinary expertise, and I wonder if the same or similar mechanisms for developing new identities can be explored through a study of coaching relationships.

Finally, work of this nature is better conducted through collaboration. Because I do not have a science teaching background, nor do I identify myself as a disciplinary insider in the disciplines of STEM, I expect that there were many interesting occurrences that were unique to an interdisciplinary teaching context that I may not have noticed. In future work, I hope to have opportunities to collaborate with researchers from a wide variety of disciplinary domains in order to further explore the nature of disciplinary integration as it occurs in discourses, practices, and enacted social identities.

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Appendix A: EngrTEAMS Student Interview Protocol

BEFORE TESTING

1. Tell me about your Engineering Design. What are the strengths of your design? What are the limitations?
2. How did you decide on this design? What kind of conversations did your group have before deciding? What kind of writing did you do before you designed it? (Can you show me examples?)
3. How will you know when your design is successful or not? What do you expect will happen when you test it?
4. Is this unit different from other units you do in Science? How is it the same/different?

AFTER TESTING- REDESIGN

5. What was successful about your design? How do you know? What are you going to change for your redesign?
6. Tell me about the mathematics you had to use during this unit. When did you use math? Can you describe it?
7. Tell me about the science you've learned. What do you know about Newton's Laws? How would you describe Newton's Laws to someone who doesn't know anything about them?
8. Did you learn any new vocabulary? Tell me about the new language you've learned. When do you expect you will use this language again?
9. What did you like about this unit? What was challenging?
10. What does STEM mean to you?

Appendix B: EngrTEAMS Teacher Interview Protocol

1. Tell me about the students' Engineering Designs. What were the strengths and limitations of their designs?
2. What kind of conversations did students have during the designing phase? What kinds of writing did they do?
3. What mathematical thinking did students do? How did they talk about math?
4. What scientific reasoning did students engage in? How did they demonstrate their thinking? (Are there examples of student texts we can look at?)
5. What new vocabulary did you hope to teach? When do you expect students will use this language again?
6. What did you like about teaching this unit? What was challenging? What would you hope to do differently next time
7. What does STEM integration mean to you?

Appendix C: Modified Jefferson Transcription Conventions

[ ]	Brackets indicate overlapping utterances
=	Equal marks indicate contiguous utterances, or continuation of the same utterance into the next line
(.)	Period within parentheses indicates 1 second pause
(..)	Multiple periods within parentheses indicates pauses of length in approximate seconds
yes	Underlining indicates speaker emphasis on words or phrases
yes	Bolding indicates transcriber emphasis on important features of analysis
(gesturing)	Items within single parentheses indicate physical gestures or facial expressions important to conveying speaker emphasized meaning
((laugh))	Items within double parentheses indicate some sound or feature of talk which is not easily transcribable
(inaudible)	Inaudible in parentheses indicates transcriber doubt about hearing of passage

Note that normal punctuation symbols indicate intonation in this system, rather than grammatical category. Period, for example, marks a falling pitch or intonation. A comma indicates a continuing intonation with slight upward or downward contour. A question mark indicates a rising vocal pitch or intonation.

Adapted from system developed by Gail Jefferson, printed in J.M. Atkinson and J. Heritage (Eds.), 1984. *Structure of social action: Studies in conversation analysis.* pp. ix-xvi. Cambridge University Press.

Appendix D: Sample Interview Questions

PRE-PROGRAM INTERVIEW

1. What are you most looking forward to about being a part of this project?
2. Describe your personal strengths that you expect will serve you well as a coach.
3. What do you expect you will need to learn in order to be an effective coach?
4. How often do you expect to use your knowledge of STEM in your work with teachers?
5. On a scale of 1-10, how confident are you that teachers will change their STEM teaching practices as a result of your coaching?

MID YEAR INTERVIEW

1. How has it been coaching your teachers?
    a. How would you describe the types of coaching conversations you've had this fall?
    b. What has been the focus of the conversations?
    c. Can you give me an example?
2. Have there been differences in how you've been coaching each team or individuals?
    a. Why do you think that is?
    b. Can you give me an example?
3. Tell me about a coaching experience that went well.
    a. What coaching strategies did you try?
    b. Why did it go well?

END OF YEAR INTERVIEW

1. What did you try this year that did not work so well?
    a. What are some possible reasons for why it didn't work?
2. In what ways did you coach toward STEM integration?
3. What would you say has been your biggest learning curve this year in coaching?
4. What do you think you spent the most time on as a coach?
    a. Does this align with the expectations you had going in?

Appendix E: Reflecting Back Conversation Map

Pause

Cycle back to extend thinking

What happened?

- Remind me of the goals of your lesson
- Do you feel you met your goals? What evidence could you use to support that?
- What are some areas that helped student learning?
- What surprised you about the outcome of your lesson?

So What?

- What are some possible reasons for why things went the way they did?
- What did you learn about your curriculum today? Your teaching?
- What did you learn about your students?
- Given this information, what do you make of it?

Now What?

- What changes are you considering to your curriculum?
- What insights will you take forward in your curriculum design?
- What do you expect will be different when teaching in your own classroom?

Make a plan

- Of all the ideas we've considered, what 2 steps will you take next?
- What do your team members need to know? How will you communicate that with them?
- What challenges or barriers do you forsee to completing your curriculum writing?
- Who will you contact for support?

Reflect on the conversation

- As you think back over our conversation, what will you take away?
- What has been beneficial to you? What hasn't?
- What could I do differently in the future?

Appendix F: Madison's Coaching Conversation Map Assignment