ABSTRACT

Title of Dissertation:	THE ‘NEXT GENERATION’ OF CONSTRUCTIVIST REFORM IN SCIENCE AND STEM: CASE STUDY EXPLORATIONS OF THE PRACTICES OF STUDENTS AND THE PERSPECTIVES OF TEACHERS
	Amy E. Green, Doctor of Philosophy, 2017
Dissertation directed by:	Andy Elby, Associate Professor, Department of Teaching and Learning, Policy and Leadership

This dissertation provides insights into the potential for the *Next Generation Science Standards* (NGSS) and a complementary instructional model, transdisciplinary STEM, to advance constructivist approaches to high-quality education by providing a framework and pedagogical model that authentically communicate these principles for practitioners. Through two research projects, I explore some of the dilemmas facing educators implementing these reform initiatives. First, I present a study of the relationship between discursive epistemic agency and scientific authenticity in school. I argue that epistemological misalignment between perspectives underpinning traditional approaches to school science and those of professional science contribute to tensions regarding the amount of control that students should be given over the discourse of science. Using NGSS as representative of authenticity, I explore and respond to a dilemma faced by many science educators of whether students must relinquish discursive

agency for their participation in science to be considered authentic. Analyses of contrasting types of 'talk' in a first-grade classroom support the theoretical argument that increased discursive agency directly contributes to engagement in authentic science practices (as defined by NGSS). The second report represents a case study analysis of the perspectives of participants in a degree program focused on interdisciplinary approaches to learning. I ask, *how do teachers' epistemological beliefs affect their perceptions of the locus of perceived barriers and the extent to which those barriers may be overcome?* My results indicate that accessing teacher beliefs is productive for understanding the relative alignment between their personal epistemologies and those of the reform. Furthermore, epistemological beliefs may be intimately entangled with, rather than function discretely from, these teachers' perceptions of constraints to implementation of reform. The conclusions of these two research projects indicate that epistemological perspectives pervade the discourse of science, the text of curricular resources, and the language teachers use to talk about the implementation of pedagogical models. Furthermore, authentic enactments of science and meaningful learning are at least partially dependent upon a consistent alignment between the epistemologies underpinning reform efforts, those reflected in the language of school, and the personal epistemologies of educators.

THE ‘NEXT GENERATION’ OF CONSTRUCTIVIST REFORM IN SCIENCE AND STEM: CASE STUDY EXPLORATIONS OF THE PRACTICES OF STUDENTS AND THE PERSPECTIVES OF TEACHERS

by

Amy E. Green

Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
2017

Advisory Committee:
Professor Andy Elby, Chair
Professor Tamara Clegg,
Professor David Hawthorne,
Professor Daniel Levin,
Professor Diane Jass Ketelhut

© Copyright by
Amy Elizabeth Green
2017

Acknowledgements

My journey toward the completion of this dissertation has been inspirational while humbling, challenging yet enlightening. I am deeply grateful to the many wonderful people who have inspired, supported, challenged, and encouraged me along the way.

First, I must thank my advisor, Dr. Andy Elby. I mean it quite seriously when I say that you changed my life. I considered myself an engaging and effective teacher at the point when I joined your physics course as a master's degree student in course in 2008. My experiences in that course and the program opened my eyes to a new (well, new-to-me) perspective on knowing, understanding, teaching, and learning. Your leadership and mentorship paved the way for me to pursue new adventures in higher education and beyond. I must also thank Dr. Daniel Levin, who has served as an advisor, collaborator, colleague, and friend. Andy and Dan, you have consistently provided support in ways that reveal the individualized ways you prioritize my best interests as a student, scholar, instructor, colleague, and more. I feel very fortunate to have had the opportunity to benefit from your guidance and am very much looking forward to teaching and learning with you both again in the future.

I would also like to thank the other instructors and leaders in the STEM Master's degree program on which I worked throughout my time at Maryland: Dr. Ayush Gupta, Dr. Tammy Clegg, Dr. Daniel Chazan, and Dr. Beatriz Quintos. I would like to thank Dr. Chazan and Dr. Quintos for allowing me the opportunity to learn and grow as the program coordinator, liaison, and instructor. This program shaped much of my understanding of teacher education and program administration and provided invaluable opportunities for research. I continue to draw on my experiences with the program in my professional work. I must also thank all the teachers in Cohort 1, particularly those who generously agreed to be a part of my research. You are a group of the most innovative, hard-working, and dedicated educators I've had the pleasure of working with.

I would also further like to thank Tammy Clegg for the opportunities that she provided working with the Bodyvis Program with the iSchool and for helping to inspire me to explore both new technologies and new perspectives, particularly for working with students from traditionally underserved populations.

The 'road to Ph.D.' can often seem daunting, and I was very lucky to have an incredible support system of friends and colleagues to share in the journey. I would like to particularly thank Megan Callow, Linda Krakaur, Michael Neel, and Matthew Griffin (my 'yes we can!' friend).

Another group deserving of thanks are my many new colleagues and friends at the Chesapeake Bay Foundation, especially Tom Ackerman, Deidra Floyd, Norah Carlos, Cindy Duncan, Erin O'Neal, and Rhea Frye. I feel very privileged to have joined such a dedicated group of advocates and educators as we work to empower teachers to educate all students to value and protect our watershed.

Finally, I must thank my wonderful, remarkable family. Thank you to my parents, siblings, and all my incredible aunts, uncles, and cousins. Your unwavering support has been essential for my success here and in most other aspects of my life. To my husband, Bill: you have been my constant champion. Thank you for your unconditional love and never-ending support, you are a major part of who I am. And finally, to Eliza Rose, though you may have played a baby-sized role in the delay of my defense, you're a constant delight and I look forward to learning with and from you every day.

Table of Contents

Acknowledgements ii

Table of Contents v

List of Tables viii

List of Figures ix

Chapter 1: Introduction 1

Chapter 2: Context, Focus, & Rationale 7

Chapter Three 8

Chapter Four 10

Chapter 3: Exploring Relationships Between Discursive and Epistemic Agency and Authentic Enactments of School Science 12

Abstract 12

Introduction 13

Theoretical Framework 16

Nature of Science, Epistemology, & the Discourse of School 19

The Next Generation Science Standards: A New Approach to Student Agency within Scientific Activity 26

Methodology 29

Subject Selection, Setting, Data Collection 29

Data Analysis 33

Results & Discussion – Narrative Analyses 34

Whole Group Science “Talk” 34

Small-group Sense-making Discussion 41

Coding for Evidence of Scientific Practice – Summary of Results 48

Discursive Agency & Authentic Scientific Practice – Detailed Illustrations 52

Conclusions and Implications 56

Chapter 4: Transdisciplinary STEM and Teacher Beliefs: Exploring the Interplay of Epistemology and Constraints 60

Abstract 60

Introduction 61

Guiding Perspectives 64

STEM Education: Constructivist Teaching for Authentic Learning 64

Teacher Beliefs 66

Research Design and Methods 70

Background & Context 72

Subject Selection 74

Data Collection: Individualized Protocols 81

Thematic Analysis 83

Phase 2: Generating Initial 84

Summary & Statement of Limitations 94

Results & Discussion 96

Carrie 100

Kevin 105

Meg 111

Gabrielle 119

Kate 125

Conclusion/Implications 132

Chapter 5: Conclusions & Reflections 136

Conclusions & Implications 136

Reflections 139

Operationalizing Terms and Constructs 145

STEM Education 145

Discipline 145
Integrated Curriculum 146
Multidisciplinary Integration 147
Interdisciplinary Integration 148
Transdisciplinary Integration 148
Appendix A: 'Progress Toward NGSS Proficiency:' 3-D Coding Scheme 152
Appendix B: Transdisciplinary STEM and Teacher Beliefs: Interview Protocol 155
Appendix C: EDCI 614 Developing a Professional Portfolio Syllabus 156
Appendix D: Transdisciplinary STEM & Teacher Beliefs: Sample Categorical Coding Matrices: Constraints I and II 163
References 179

List of Tables

Table 1: Sample Coding for NGSS Dimensions.. 50

Table 2: Participant Information... 81

Table 3: Sample Organization and Application of Coding Analysis.......................... 87

Table 4: Sample Data Categorization Chart -Individual Teacher............................... 91

List of Figures

Figure 1: Discourse Participation (total observed time: 509 seconds) 51

Figure 2: Percentages of Student Talk found to reflect Progress Toward NGSS Proficiency 51

Figure 3: Number of Student Utterances Found to be reflective of Progress Toward NGSS Proficiency 51

Chapter 1: Introduction

We expect a lot from our schools and, consequently, from our teachers. Fundamentally, we expect that they equip our youth to meet the growing economic, intellectual, and social demands of democratic society and, as the demands of society increase, so do our calls for improvements to the practices and outcomes of education systems. Very often reform efforts have tended to target the processes and products *of teaching* as the ultimate target for change; however, the field of cognitive science has rapidly grown over the last five decades and approaches to teaching that begin with an understanding of how students learn have come to replace transmissionist pedagogy as primary reform goals. As the Organization for Economic Co-operation and Development (OECD), explains, many countries around the world are responding to the growing demands of the "knowledge-based societies" of the 21st century by working to ensure "that reforms of the education system focus more strongly on *learning itself* [emphasis added] rather than simply changing structures and educational organization" (OECD, 2008, p.1).

But what does it *mean* to focus on learning?

From a cognitive science perspective, it may mean understanding more about the epistemological perspectives that are communicated in and reinforced through the structures of schooling. Epistemological perspectives pervade the normative practices and structures of schooling, what Shulman, paraphrasing Fenstermacher, describes as the "commonplaces of teaching," such as notions that,

> A teacher knows something not understood by others, presumably the students. The teacher can transform understanding, performance skills, or desired attitudes or values into pedagogical representations and actions. These are ways of talking, showing enacting, or otherwise representing ideas so that the unknowing can come to know, those without understanding can comprehend and discern, and the unskilled can become adept (1987, p. 7).

Inevitably, the ways that these "commonplaces" play out in educational contexts are largely dependent on underpinning assumptions about the stability, structure, course, and validation of knowledge. A 'process-product' model for reform "suggests that an effective teacher uses certain instructional behaviors to transmit knowledge and skills to students," and thus, "good teaching could be observed in the enactment of the direct instructional model of teaching" (Fenstermacher & Richardson, 2005, p. 22). Often referred to as "transmissionist," these approaches tend to reduce teaching and learning to the passive transfer of knowledge from expert to novice (Tobin, 1993). In recent decades, however, stakeholders have argued that so-called "traditional" approaches to process-product education problematically privilege the acquisition of information over conceptual understanding, problem-solving, and real-world applications. Thus, in order to improve the quality and productivity of schools, "curriculum in all subjects and for all students would need to place much greater emphasis on nurturing higher order thinking and the intellectual adaptability called for by the complexities of modern life" (NRC, 1992, p. 11).

In response, scholars, researchers, and other stakeholders have promoted *constructivism* as an alternative to 'transmissionism' as the fundamental perspective through which to understand learning and, thus, to build instructional models. Precise 'definitions,' of constructivism vary depending on context and perspective; however, one of the most significant elements common to most uses is the notion that the development of understanding requires that the learner is actively engaged in meaning-making that draws on the student's prior knowledge (Noddings, Maher, Davis, 1990; Draper, 2002; Grabinger & Dunlap, 1995; Jenkins, 2000; Mayer, 1999; Naylor & Keogh, 1999; von Glasersfeld, 1992, 1995). Fenstermacher and Richardson, for example, describe constructivism as a "descriptive theory of learning that suggests that students develop meaning as their prior knowledge interacts with new or different knowledge they encounter in the classroom from such sources as the teacher, textbooks, and peers" (2005, p. 29). Constructivism is not a model for teaching, but rather a theoretical framework for understanding learning that may productively inform approaches to teaching (Bächtold, 2013; Duit, 2016). Yet despite extensive and pervasive scholarly support of constructivism as a more productive "referent for building models for learning, teaching and the curriculum" (Tobin, 2009, p. xv), paradigms of the normative structures of schooling and the "commonplaces of teaching" continue to reflect and reinforce views of learning as knowledge acquisition, rather than knowledge construction in many contexts (Anrew, 2007; Kim, Kim, Lee, & DeMeester, 2013; Teo, Chai, Hung, & Lee, 2008; Martell, 2014). Thus, the need for models of reform that better communicate how constructivist principles might "play out" in real classroom contexts persist. This dissertation explores two relatively recent reform initiatives that have emerged in response to this need: the framework of the *Next Generation Science Standards* (NGSS) and a transdisciplinary STEM instructional model.

Grounded in the NRC's *Framework for K–12 Science Education* and released by the National Research Council (NRC), the National Science Teachers Association (NSTA), the American Association for the Advancement of Science (AAAS), and Achieve Incorporated, the NGSS represent a collection of benchmarks for learning that have been carefully crafted based on research on how students learn and the research findings of cognitive science (NGSS Lead States 2013d). Together, the *Framework* and NGSS "present a significant shift in the vision for how students engage in science learning and hence how instruction should change" (Pruitt, 2015, p. xi). While NGSS, the *Framework,* and other supporting publications such as *A Vision and Plan for Science Teaching and Learning: An Educator's Guide to A Framework for K-12 Science Education, Next Generation Science Standards, and State Science Standards* do not represent a 'curriculum,' they do offer performance expectations for student learning that communicate *for practitioners* how authentic science may play out in classrooms commensurate with learner-centric perspectives for teaching in ways not utilized by prior national standards (Moulding, Bybee, & Paulson, 2015; NGSS Lead States, 2013d).

As a framework of standards, NGSS both invite and afford a structure and organization for modeling teaching upon constructivist principles for learning. One such model that is growing alongside and, in many ways being shaped by the NGSS, is that of integrated or *transdisciplinary* education, particularly within the STEM disciplines. Once a slogan to highlight teaching and learning within the siloed disciplines of the acronym, more current visions of STEM approach learning through meaningful disciplinary integration (Bybee, 2010a). STEM education represents "an interdisciplinary approach to learning that removes the traditional barriers separating the four disciplines of science, technology, engineering, and mathematics and integrates them into real-world, rigorous, and relevant learning experiences for students" (Vasquez, Schneider, and Comer, 2013, p. 4). Similar to (and in many ways congruent with) other models such as problem-based learning and project-based learning, STEM education is inherently grounded in constructivist epistemologies for learning in that students are at the center of the learning process, knowledge is constructed through collaboration, questions with single 'right answers' that are provided or confirmed by an external authority (teacher or textbook) are deemphasized in favor of investigations into complex issues and phenomena, and thinking skills and "habits of mind" are both products *and* processes of learning. STEM seeks to intentionally integrate the concepts and practices of multiple disciplines (including those not explicitly referenced in the acronym such as language arts and social studies) through experiences in which learning is situated within immediately applicable contexts. These contexts may include authentic technological or engineering design-based problem solving (Sanders, 2008, 2012), real-world challenges to address, or phenomena to explore (Bybee 2013; Vasquez, Schneider, & Comer, 2012).

The individual and collective efforts of NGSS and STEM education present a multitude of opportunities to enhance instruction through a focus on learning. Whether and how those opportunities are endorsed and taken up by the educators responsible for their implementation represents a rich field for investigation. As will be explained in more detail in Chapter Two, this dissertation reports on two distinct research projects designed to explore some of the affordances of and challenges to implementation of NGSS and transdisciplinary models of STEM education.

Chapter 2: Context, Focus, & Rationale

History has repeatedly demonstrated that reform efforts often face various levels of challenge and resistance. Research on education reform and teacher change indicate that the success of very nearly every aspect of school reform depends on highly qualified teachers (Darling-Hammond, 2010) and that close attention should be paid to teachers' understandings and perspectives on the nature of reform (Gitlin & Margonis, 1995). The current reform movement in science and STEM education is likely to require a considerable shift in both paradigm and practice for many educators. These shifts are fundamentally grounded in perspectives on how people learn and, subsequently, on the role of students in the learning process and effective teaching practices. Like preceding restructuring efforts, the success of this latest push toward constructivist-driven reform will hinge on the extent to which teachers are able to interpret, make sense of, "buy-in" to, and implement the proposed changes (Haney, Czerniak, Lumpe, 1996; Milner, Sondergeld, Demir, Johnson, & Czerniak, 2012; Turnbull, 2002).

This dissertation contributes to the field of science education scholarship by providing new insights into the potential for the Next Generation Science Standards and a complementary instructional model, transdisciplinary STEM, to advance constructivist approaches to high-quality education. Together, NGSS and STEM provide a framework and a pedagogical model that authentically communicate these learning principles for practitioners -- and do so in a way that is perhaps more authentic and more productive than many previous standards-based reform initiatives. Through two stand-alone research papers, I explore some of the interconnected dilemmas that educators may face in the implementation of integrated, constructivist STEM education and formal reform initiatives such as the NGSS. As we've learned from past efforts, successful education reform often requires navigating responses to several significant (and often troublesome) questions. One such question asks whether the goals for student achievement are attainable and worthwhile? In other words, can students achieve the (sometimes optimistic) goals of the reform? This question underpins the theoretical and empirical investigations of Chapter Three of this dissertation, "Exploring Relationships Between Discursive and Epistemic Agency and Authentic Enactments of School Science." If the answer to the question of the relative feasibility and worth of the reform is found to be positive, another question arises: Will teachers be able to adapt to the perspectives for "what counts" as learning and doing in ways that are consistent with those underpinning and driving the reform? I explore this issue through cross-case analysis of the perspectives of teachers in Chapter Four, "Transdisciplinary STEM and Teacher Beliefs: Exploring the Interplay of Epistemology and Constraints."

Chapter Three

In this chapter, titled, "Exploring Relationships Between Discursive and Epistemic Agency and Authentic Enactments of School Science," I use discourse as a primary medium for accessing and understanding the relationship between student agency and scientific authenticity within disciplinary learning relative to the NGSS. This research stems from the position that applying a constructivist lens to school science highlights the importance of pedagogies that situate students as active agents in the practices of knowledge construction and validation in ways that authentically reflect the practices of professional communities. What's more, the manner and degree to which students can and should be involved in the practices through which scientific knowledge develops depend largely on underlying perspectives about what fundamentally "counts" as authentic. I argue that these perspectives fuel pedagogical approaches to teaching and learning in school science, particularly regarding the extent to which a student's natural, everyday ways of drawing on intellectual and linguistic resources to interact with and make sense of the world should be given up in order to align with those of science. Given that the Next Generation Science Standards signify what the National Research Council (NRC) has determined that students in grades K-12 should know regarding the practices, values, and products of the enterprise of science (NGSS Lead States, 2013b), I use the NGSS framework as representative of the 'ordinary practices' of science as they ideally play out in educative contexts.

I explore ways that the language of school science exposes underlying "traditional" assumptions about the nature of the discipline and what constitutes authentic engagement therein. I confront the perspectives fueling "the problem with constructivism in practice" (Windschitl, 2002), that in order to maintain the integrity of science in school, teachers must explicitly direct students' discursive participation (ways of talking and interacting). I argue that these perspectives and resulting tensions for teaching practice are at least partly a result of interpretations by school professionals about the nature of science. Those perspectives, while likely influenced by a number of institutional school structures including the language of academic standards and normative patterns for discursive practice, run counter to the views of science reflected in the practices of professional science communities and furthermore, are inconsistent with the approach to participating in school science promoted by NGSS. To illustrate the claim that affording students increased discursive agency directly contributes to their ability to productively construct authentic scientific practice as promoted by the NGSS, I provide an account of first graders engaging in contrasting science discussions. This research bears relevance to the continuing conversation about the relative authenticity with which science is communicated and enacted in school and the influence, effects, and demands of the NGSS framework on approaches to teaching and learning science.

Chapter Four

In this chapter, "Transdisciplinary STEM and Teacher Beliefs: Exploring the Interplay of Epistemology and Constraints," I report on a case study analysis of the perspectives of a sample of five participants in a Teacher Leadership in STEM Education graduate degree program at a large Mid-Atlantic University. The program is designed to support teachers in making a shift toward more constructivist-driven, integrated and transdisciplinary approaches to teaching and learning. These systems and methods of teaching are often referred to as *trans*disciplinary in that they seek to move beyond isolated learning framed primarily for purposes of meeting academic goals toward holistic, real-world relevant approaches. *Transdisciplinary* approaches contrast with traditional, 'siloed' approaches to schooling in which knowledge and practices of disciplines are represented as both bounded and separate. It emphasizes the reflexive value of the interdisciplinary construction and application of knowledge through contextualized practice (Bybee, 2010a; Bybee 2013; Vasquez, 2015; Vasquez, Schneider, & Comer 2013).

For teachers, the adoption of transdisciplinary approaches to STEM education may require considerable shifts in the ways that they understand, view, and approach their practice (Bybee, 2013; Czerniak & Johnson, 2007; Sanders, 2008). While I initially sought to explore the factors that mediate the capacities and inclinations of these teachers for embracing the shift more generally, early phases of data analysis indicated that 'barriers to implementation' was a prominent theme for all teachers and that *epistemological beliefs* were particularly salient within descriptions of these constraints. My refined research question thus became, *how do teachers' epistemological beliefs affect their perceptions of the locus of perceived barriers and the extent to which those barriers may be overcome?*

This research provides new insights to understandings about the role that teachers' epistemological beliefs may influence and interact with the way that they consider challenges to constructivist-driven, transdisciplinary education reform, which, in turn, may work to productively shape approaches to teacher professional learning programs.

Chapter 3: Exploring Relationships Between Discursive and Epistemic Agency and Authentic Enactments of School Science

Abstract

This paper reports on a study in which discourse is used as a primary medium for understanding the relationship between agency and scientific authenticity within disciplinary learning. I argue that an epistemological misalignment between perspectives underpinning traditional approaches to science in school and those of professional science contribute to tensions regarding the amount of control that students should be given over the nature, style, and participatory patterns of classroom discourse in order for scientific activities to be both productive and authentic. Using the Next Generation Science Standards as representative of authenticity, I explore and respond to a dilemma faced by many science educators of whether students must relinquish discursive agency in order for their participation in science to be considered authentic. I specifically confront the perspective that in order to maintain the integrity of science in school, teachers must explicitly direct the ways students use language in science contexts. To draw inferences about discursive agency, I conduct a structural analysis of discourse used in-context of both a whole-group 'science talk,' in which the teacher maintains control of the discourse, and a contrasting small-group sense-making discussion, for which agency is shifted to the students. The results indicate that discursive agency empowered these students to more authentically engage in the scientific practices that lead to knowledge construction and meaningful learning. This study supports the theoretical argument that engagement in authentic science practices (as defined by NGSS) both permits *and* invites

children to take agency over the discourse and associated linguistic resources they engage and apply while further contributing to increased cognitive agency required for learning.

Introduction

Many proponents of education reform within and across the STEM disciplines emphasize that goals of expanding student engagement and achievement in science to meet the demands of 21^{st}-century society are best met when students not only learn about the results of professional practice, but also authentically participate in the activities of scientists, engineers, and mathematicians. That is, students should not merely *experience* disciplines in school but should be seen and see themselves as active agents in the ways in which those disciplines play out in the classroom. This perspective holds that “in order to learn these subjects (and not just to learn about them) students need much more than abstract concepts and self-contained examples. They need to be exposed to the use of a domain's conceptual tools in authentic activity” (Brown, Collins, and Duguid, 1989, p. 34). In other words, enculturation through authentic activity is critical for students to be able to engage in meaningful sense-making around core ideas and thus leads to more productive learning.

Education communities have long-supported goals of engaging students as active agents in the authentic activities of disciplines. However, arguments regarding the manner and degree to which students can and should be involved in the practices through which scientific knowledge develops depend largely on underlying perspectives about what “counts” as authentic scientific activity in the first place. These perspectives fuel pedagogical approaches to teaching and learning in school science, particularly with regard to the extent to which a student's natural, everyday ways of drawing on resources to interact with and make sense of the world should be adjusted or refined to align with those of science.

My research focuses on discourse as a primary medium for making sense of the relationship between agency and authenticity within disciplinary learning and for conceptualizing scientific practice and student engagement therein. According to Brown, Collins, and Duguid, "authentic activities…are most simply defined as the ordinary practices of the culture" (1989, p. 34). There are numerous ways to characterize the "ordinary practices" of the culture of science; however, central to all characterizations is the recognition that the practices of science drive and are driven by perspectives on the nature of the discipline. The *Next Generation Science Standards* signify what the National Research Council (NRC) has determined that students in grades K-12 should know regarding the practices, values, and products of the enterprise of science (NGSS Lead States, 2013). Based on *A Framework for K-12 Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012), the NGSS represent a synthesis of seminal scholarship on science and learning and have been developed as benchmarks of quality and excellence in school science. Thus, I use the NGSS' three dimensions of proficiency, often referred to as the "3-dimensional" or "3-D" model, as representative of the 'ordinary practices' of science as they ideally play out in educative contexts and, accordingly, as standards for authentic engagement within the discipline.

In this paper, I explore and respond to a dilemma faced by many science educators of whether students must relinquish discursive agency in order for their participation in science to be considered authentic. Specifically, I confront the perspective that in order to maintain the integrity of science in school, teachers must explicitly direct the ways students talk and interact (discursive participation). I argue that this view reflects a tension that stems from what Windschitl (2002) and others have described as 'the problem with constructivism in practice.' From a pedagogical perspective, allowing students to use the linguistic and cultural resources of their choosing-- resources that may or may not align with those used in traditional academic contexts-- to construct, critique, and validate their own knowledge displaces authority from the 'science' to that of the student, which could potentially jeopardize its validity. In essence, they may not "get it right" (Ball, 1993; Ford, 2008; Henderson, MacPherson, Osborne, & Wild, 2015; Windschitl, 2002). However, by requiring that scientific accounts be discussed in particular 'academic' styles of language, the teacher risks "precluding student authority and perhaps understanding" (Ford, 2008, p. 405).

I argue that these tensions are at least partly a result of interpretations by school professionals of the nature of science, which, while likely influenced by a number of institutional school structures including the language of academic standards and normative patterns for discursive practice, run counter to the views of science held by professional science communities and, furthermore, are inconsistent with the approach to doing and understanding science in school promoted by NGSS. I claim that when students are given agency over their own discursive participation, the discourses that they construct represent authentic scientific practice as promoted by the NGSS. I further claim that discursive agency empowers students to more authentically engage in the scientific practices that lead to knowledge construction and meaningful learning. This does not mean that the teacher's agency need be reduced – merely that increased discursive agency for students may contribute to increased cognitive and epistemic agency, and thus more productive and meaningful learning. To illustrate this claim, I provide an account of first graders engaging in contrasting science discussions. As first graders, the participants in this episode are in the early stages of formal schooling, and, consequently, have had relatively limited exposure to traditional patterns of school discourse. Therefore, if given increased discursive agency, they are potentially more likely to incorporate natural, everyday ways of thinking and speaking into their participation. The example represented by these students works to illustrate some of the ways in which student agency over discourse allows for authentic engagement in scientific practice and productive meaning-making.

Theoretical Framework

Scholars and stakeholders have long argued that there are significant differences between the way that professionals engage in the enterprise of science and the ways that the science disciplines are presented in school (Berland, Schwarz, Krist, Kenyon, Lo, & Reiser, 2016; Ford, 2008; Ford & Forman, 2006; Forman & Ford, 2014; NRC, 2007; Shulman, & Quinlan, 1996; Stevens, Wineburg, Herrenkohl, & Bell, 2005). One of the more significant differences is frequently found in the epistemological perspectives underpinning the practices of professional science and those of school science. Problematically, a misalignment between these perspectives on the nature of knowledge, its production, and validation results in a complex, two-pronged dilemma: it communicates harmful attitudes about the relationship between science and the human experience, which may work to alienate individuals and groups from the discipline, and it inhibits authentic enactments of science by restricting student agency-- which, in turn, hinders meaningful learning. A closer alliance of science in school to professional (formal) science thus bears several advantages. As Duschl explains, "New perspectives and understandings in the learning sciences about learning and learning environments, and in science studies about knowing and inquiring, highlight the importance of science education teaching and learning harmonizing conceptual, epistemological, and social learning goals" (2008, pp. 268-269). The Next Generation Science Standards, a modern reform initiative based on the *Framework for K-12 Science Education* developed by the National Resource Council, not only acknowledge the importance of epistemology and the nature of science in school, but may also work to effectively remedy both aspects of the dilemma of epistemological misalignment and, essentially, 'harmonize' professional and school science by providing a coherent framework for teaching school science in ways that support learning through authentic representations of the practices of the discipline.

The NGSS offer a science education structured to increase student engagement in authentic scientific practice; in other words, NGSS emphasize what students should *do* in order to *understand* science rather than what students need to *know* in order to *do* science. Furthermore, the NGSS explicitly identify 'helping students understand the nature of scientific knowledge' as a goal of science education and emphasize the importance of connecting the pursuits and products of the discipline to human enterprise. The standards describe science as "the pursuit of explanations of the natural world," and further explain that "technology and engineering are means of accommodating human needs, intellectual curiosity, and aspirations" (NGSS Lead States, 2013b) For further clarity, the NGSS offer a matrix of the basic understandings about the nature of science in the standards:

- Scientific Investigations Use a Variety of Methods
- Scientific Knowledge Is Based on Empirical Evidence
- Scientific Knowledge Is Open to Revision in Light of New Evidence
- Scientific Models, Laws, Mechanisms, and Theories Explain Natural Phenomena
- Science Is a Way of Knowing
- Scientific Knowledge Assumes an Order and Consistency in Natural Systems
- Science Is a Human Endeavor
- Science Addresses Questions About the Natural and Material World

NGSS thus provide explicit attention to the nature of science that, together with the messages for how students should engage in scientific activity in school, are important tools for helping teachers approach their practice in ways that invite authentic understandings of and engagements with the discipline. As Lemke (1990) and others note, the language of science class is often the primary medium through which epistemological messages about professional and school science may communicated and reinforced (Ballenger, 1997; Berkenkotter, & Huckin, 2016; Kelly, 2014; Kress, Jewitt, Ogborn, & Tsatsarelis, 2001, Lemke, 1990, 2005; Warren, & Conant, 1992). It is therefore critical that the language of the curriculum, standards, and accompanying resources present clear, authentic messages about the nature of and what it means to engage in science-- in *all contexts*. The language of *Framework*, standards, and accompanying resources work individually and collectively to communicate particular epistemological perspectives on the nature of science as a human enterprise and promote a discourse within and around the classroom in which student agency is strengthened in service of authentic enactments of the discipline.

Nature of Science, Epistemology, & the Discourse of School

Researchers have observed unique patterns for the ways that teachers and students participate in the discourse of science for decades (Christodoulou& Osborne, 2014; Driver, Newton, & Osborne, 2000; Halliday & Martin, 2003; Kelly & Chen, 1999; Moje, 1995; Mortimer & Scott, 2003; Walsh, 2006). These patterns emerge from implicit and, in some cases, explicit rules for the ways individuals use language to interact with each other as well as for the style and types of language used in those interactions. Lemke (1990) notes that, while teachers strive to help students enjoy science and appreciate its achievements, the 'talk' of school science often reinforces a "special mystique of science, a set of harmful myths that favor the interests of a small elite" and tend to "pit science against common sense and undermine students' confidence in their own judgment" (p.129). Problematically, such separation of science from the lives and experiences of 'everyday folks' may result in tension between the agency over particular behavioral and cognitive processes given to students and what qualifies as authentic engagement in science as a discipline.

Language is an important tool in that it supports communication, but it also has influence over the very nature of the activity and the ways in which individuals interact. Socio-linguist James Gee has described language as functioning to provide support and structure to human activity as well as to support our associations to and connections within cultures, social groups, and institutions (Gee, 1999). Gee goes on to describe *discourse* as a "socially accepted association among ways of using language and other symbolic expressions, of thinking, feeling, believing, valuing, and acting, as well as using various tools, technologies, or props that can be used to identify oneself as a member of a socially meaningful group or 'social network,' to signal (that one is playing) a socially meaningful 'role' or to signal that one is filling a social niche in a distinctively recognizable fashion" (Gee, 2012, p. 158). Talk in science class can thus be viewed as particular types of language being used in conjunction with other structures to create the social discourse of science, which, in turn, works to craft the nature of and epistemic beliefs about the discipline as it plays out in particular contexts. In this sense, language is a medium through which the normative values and appropriate behaviors of the culture of science and scientific enterprise are shaped for and developed by students. In other words, we can look to the words, structures, and patterns of the discourse of science classes for clues about the perspectives of the nature of science and what 'counts' as authentic engagement therein.

Many scientists, science educators, and science education organizations agree that helping students to develop informed understandings of epistemic tenets that underpin science as a human enterprise and authentic enactments of the discipline is a worthy objective for K-12 education (American Association for the Advancement of Science, 1989; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Rutherford, & Ahlgren, 1990; Sandoval, 2005). While scientific communities may disagree about specific definitions, *nature of science* is a phrase that refers to the epistemology and sociology of science, in other words, the values and beliefs inherent to scientific knowledge as well as sources and ways of validating such knowledge and the processes through which it is constructed. (Elby & Hammer, 2001; Lederman, et al., 2002; Sandoval, 2005). Within definitions of the nature of science is the notion that scientific knowledge is “tentative and evolving, rather than certain and unchanging; subjectively tied to scientists' perspectives, rather than objectively inherent in nature; and individually or socially constructed rather than discovered” (Elby & Hammer, 2001, p. 554). Thus, human creativity, cooperation, and collaboration play integral roles in the enterprise of science. Lederman, et al., further point out that “the distinction between observation and inference, the lack of a universal recipe-like method for doing science, and the functions of and relationships between scientific theories and laws” are additional aspects of the nature of science that are important for students and teachers to understand (2002, p. 499). As Ford simply points out, “a proper understanding of a scientific idea requires that one also know something about the architecture of that knowledge—that is, how it is constructed. Students generally do not understand scientific ideas when they are merely committed to memory” (2007, p.404). Furthermore, understanding the processes by which scientific claims are built is important not only for mastery of science concepts in school but also for participation in civic life. As Sandoval explains, “In contemporary democratic societies, lay citizens need to understand the nature of scientific knowledge and practice in order to participate effectively in policy decisions and to interpret the meaning of new scientific claims for their lives” (2005, p. 637). Thus, it is imperative for both learning and for society that science education programs explicitly teach and model authentic representation of the nature of science.

Scholars have observed that in school, teachers implicitly communicate perspectives on science regardless of whether the ‘nature of science’ ‘is the topic of discussion. For example, Lederman and Zeidler (1986) found that teachers' conceptions of the nature of science were frequently communicated through ordinary discourse in the presentation of subject matter and other contexts that “teachers used to express themselves, scientific information, and concepts” (Zeidler & Lederman, 1987, p. 4). Many discursive practices, structures, and patterns typical of schooling in general as well as of science class, however, work to reinforce epistemological perspectives that contradict those of professional science and contribute to the tension that educators encounter between agency and authenticity in the classroom. Instruction is traditionally approached through conventions of transmission, “with teachers showing and telling students what they should know and then testing them to ensure that they have learned it” (Wells & Arauz, 2006, p. 379). As a result, ‘default patterns’ of classroom discourse emerge, in which the teacher holds an incredibly disproportionate amount of control over rights to speak, initiating prompts and evaluating student answers (Berland, Schwarz, Krist, Kenyon, Lo, & Reiser, 2016; Cazden, 1988, 2001; Cazden & Beck, 2003; Henderson, MacPherson, Osborne, & Wild, 2015). In other words, in conjunction with the curriculum, the teacher maintains primary control over the ways students talk about and interact with ideas and activities in science.

Problematically, discourse patterns that restrict student agency over the participatory rights of students engaging in the discipline jeopardize the authenticity of their engagement in scientific practice as well as students' practical epistemologies, described by Sandoval (2005) as "the epistemological ideas that students apply to their own scientific knowledge building through inquiry" (p. 635). It is not, however, only norms for discursive participation that influence the authenticity of science in school. Lemke, for example, observed that both teachers and students claim that in science, there are standards for the "correct and serious" *talk*, itself. These standards include verbal explicitness, the use of technical language and terms over the colloquial, the avoidance of metaphorical and figurative language, the use of causal forms of explanation over "narrative and dramatic accounts," and the avoidance of "personalities and reference to individual human beings and their actions" (1990, p. 133). Resources that are considered appropriate for *scientific* activity are thus characterized by particular qualities including "rationality, precision, formality, detachment, and objectivity" (Warren, Ballinger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001, p. 530). Since the cultural and linguistic resources of children's' *everyday* experience may be characterized by such qualities as "improvisation, ambiguity, informality, engagement, and subjectivity" (Warren et. all, 2001, p. 530), their relevance to participation in school science falls under question. As Lemke explains, "the language of classroom science sets up a pervasive and false opposition between a world of objective, authoritative, impersonal, humorless scientific fact and the ordinary, personal world of human uncertainties, judgments, values, and interests" (pp. 129-130) thus perpetuating the view that science is a specialized process of empirical discovery rather than a collaborative and creative human endeavor and is thus incompatible with everyday experiences, linguistic resources, and ways of interacting with the world. As Brown, Collins, and Duguid further note that, "prevalent school practices assume, more often than not, that knowledge is individual and self-structured, that schools are neutral with respect to what is learned, that concepts are abstract, relatively fixed, and unaffected by the activity through which they are acquired and used and that [the behavior of 'Just Plain Folks'] should be discouraged" (1989, p. 37).

The extent to which everyday resources may qualify as congruous or compatible with science depends largely on conceptualizations of the disciplines and what it should mean to participate in science in school. These perspectives have significant pedagogical implications, particularly for children from culturally and linguistically diverse backgrounds, in that they bear an underlying supposition that there is a "singular 'culture of science' that would-be scientists must acquire" and further "assumes, implicitly or explicitly, that the culture of science does not reflect the cultural values that people bring to science" (Bell, Lewenstein, Shouse, and Feder, 2009, p. 212). Representing science as a culturally neutral endeavor suggests that in order for average, 'non-scientists' (e.g. students) to participate, they must *acquire* particular habits of mind and practice that may or may not align with those of their 'every day.'

In school, science is represented as a formal, specialized activity, the discourse of which is, by default, controlled by experts (the teachers, texts, curriculum, etc.). What's more, science is often presented as dialectically opposed to everyday ways of thinking, speaking, and interacting with the world. Rules for student participation in scientific practice, those activities that help reinforce practical epistemologies regarding the nature of the discipline, are strictly regulated by norms and values that are -- to varying degrees -- inconsistent with epistemic perspectives of science reflected in professional communities that approach the practice of science as individually and socially constructed, culturally negotiated sense-making endeavors. Furthermore, such discursive patterns often lead to pedagogical perspectives that conclude the linguistic resources of children, particularly children from culturally diverse backgrounds, are inherently incongruent with scientific activity to the extent that the language of instruction should be "mediated" in order to provide scaffolding for students from non-English language backgrounds to acquire it (Lee & Fradd, 1998). In other words, particular pedagogical interventions and strategies are required in order to "enable" students from diverse backgrounds to develop the literacy required to learn science (Lee, 2002).

Many researchers and scholars in the field of science education, however, draw purposeful attention to how children's everyday language, personal experiences, and resources for interacting with the world may be productive tools for helping them achieve proficiency in science class (Ballenger 1997; Berland, Schwarz, Krist, Kenyon, Lo, & Reiser, 2016; Hammer & van Zee, 2006; Fenichel & Schweingruber, 2010; Levin, Hammer, Elby, Coffey, 2012; Rosebery, Warren, & Conant, 1992). My work contributes to these conversations as well as to those claiming the ways that students are permitted and encouraged to participate in science are intimately linked to epistemic perspectives on the nature of the discipline. I argue that multiple linguistic resources, especially those negotiated in-situ by student participants, may be productive for scientific inquiry and that student agency over discourse is not only productive for scientific practice but is *required* for truly authentic engagement and necessary for the appropriate representation of the discipline. In order for students to build conceptual understandings through authentic practice and thus develop more sophisticated understandings of the nature of science, curriculum and instruction must explicitly work to unsettle assumptions about norms for discursive participation in science.

The Next Generation Science Standards: A New Approach to Student Agency within Scientific Activity

In addition to verbal discourse, the language of curriculum standards, the frameworks used by states, school districts, and teachers that define the knowledge and teachers, are powerful sources of messaging around what constitutes appropriate engagement in classroom science. knowledge and authority of these outside sources rather than make their sense of it, themselves. Grounded in the NRC's *Framework for K–12 Science Education* and developed by the NRC, the National Science Teachers Association (NSTA), the American Association for the Advancement of Science (AAAS), and Achieve Incorporated, the NGSS support "21st century science for all and emphasize the importance of "developing students' knowledge of how science and engineering achieve their ends while also strengthening their competency with related practices" (NRC, 2012, p. 41). The NGSS present a "3-dimensional" of vision science proficiency that "…rests on a view of science as both a body of knowledge and an evidence-based, model and theory building enterprise that continually extends, refines, and revises knowledge" (NGSS, 2013e).

The *Framework* emphasizes the perspective that science is a social enterprise that depends on collaboration within a community and that "this community and its culture exist in the larger social and economic context of their place and time and are influenced by events, needs, and norms from outside science, as well as by the interests and desires of scientists" (p. 27). The *Framework* further claims that simultaneous coordination of knowledge and skill fosters a meaningful understanding of the way that knowledge is developed and will help students to become more "critical consumers" of scientific information (p. 41). Thus, the NGSS identify the nature of science proficiency as being comprised of three dimensions: *practices*, "behaviors that scientists engage in as they investigate and build models and theories about the natural world," *crosscutting concepts*, which have relevance and applicability across disciplines, and *disciplinary core ideas* within each of four domains: the physical sciences; the life sciences; the earth and space sciences; and engineering, technology and applications of science (NGSS, 2013e).

When it comes to discourse, the *Framework* explains that scientific literacy requires that individuals be able to read, understand, and share scientific ideas and identifies *Obtaining, Evaluating, and Communicating Information* as an explicit practice of science. The authors recognize that reading in science can be particularly challenging for many students given the preponderance of "jargon" and complex sentence structures (p. 74); however, neither the *Framework* nor NGSS suggests that these or any other particular linguistic styles are required or even necessary for participation in science. The authors acknowledge that the discourse of science can be challenging, but do not posit claims as to whether or not it *should* be. The *Framework* does not specify which types of linguistic resources are appropriate for participation in science, but rather emphasizes the need for individuals to be able to communicate ideas and results of inquiry “orally, in writing, with the use of tables, diagrams, graphs, and equations, and by engaging in extended discussions with scientific peers” (NRC, 2012, p. 53). Given that the ability to share and derive meaning is a primary goal of communication in science, participants who are engaged in collaboration within scientific activity in any given moment should hold the authority to negotiate the linguistic structures, resources, and discursive patterns that are required for successful communication. If external authorities (for example, teachers) dictate the mechanisms by which collaborators participate in the discourse of science, as suggested by the *National Science Education Standards* of 1996, the productivity of the communication and thus the authenticity of the practice, are in jeopardy. This is not to say that “experts” such as the teacher or curriculum should not play a role in discursive negotiations, particularly for purposes of helping students develop more sophisticated and/or more successful mechanisms of communication. Explicit instruction on how to interpret the complex language of scientific (and other disciplinary) texts may be considered *a* goal of science education or even an interdisciplinary goal shared with English/language arts education; however, it should not be *the* goal.

Thus, students must be able to maintain agency over their own discursive participation, in order for the discourses that they construct to authentically represent scientific practice as promoted by the NGSS and it is this authentic activity that leads to knowledge construction and meaningful learning. In other words, increased discursive agency contributes to increased epistemic agency, and thus more productive and meaningful learning. The following report works to illustrate these claims through accounts of contrasting examples of discourse used in a first-grade classroom.

Methodology

This study seeks to illustrate the epistemic tensions that underpin ways that discursive and participatory agency and authentic engagement in scientific practice. The episodes below are intended to serve as evidence to illustrate the claim that discursive agency empowers students to more authentically engage in the scientific practices that lead to knowledge construction and meaningful learning. To be clear, the data and analysis presented below do not provide empirical support for the generalizability of my claims. The data and analysis instead illustrate the type of evidence that empirically supports the claims, thereby clarifying the substance of the claims themselves, which may be tested in larger-scale studies in the future.

Subject Selection, Setting, Data Collection

Mr. Owen teaches first grade in a school that services kindergarten, first, and second grades within a large public-school system in the Mid-Atlantic United States. In addition to approval by the University's International Review Board, a rigorous protocol was required by the school district in order for me to conduct this research in the classroom. This protocol included written and signed consent from both the parents and the students. All methods and instruments were submitted ahead of time to the district's

Office of Accountability. I obtained verbal and written permission from Mr. Owen, whom I had met in a graduate-level physics education course a few years prior, as well as the principal of the school for several visits to Mr. Owen's class during the fall semester. The dates and at times were chosen by Mr. Owen such as to minimize the risk of disruption and maximize the opportunities for me to observe science activities.

It was critical that I select subjects and a setting that would best inform my research question and enhance understanding of the influence of everyday discursive practices on the authenticity of scientific practice (Creswell, 2009; Kuper, Lingard, & Levinson, 2008). It was, therefore, important to be able to observe students in situations in which they might and might not be granted the agency over the discussion. In order to observe the relationship between agency and authentic practice in *school* science—in other words, scientific practice that is intended to meet standardized goals for learning within academic contexts—participants who would best inform my research question and enhance understanding would be students in a position to discuss a scientific problem or phenomenon connected to a lesson in the formal context of school.

Mr. Owen is responsible for teaching all academic subjects to his first graders, including reading, language arts, mathematics, and social studies, however, he is particularly passionate about teaching science. During one of my early visits to his classroom, Mr. Owen informed me that he had acquired much of the "science stuff" in his classroom as a result of his prior experience running the science lab at the school and that many of the supplies and materials are utilized by the entire school.   A wasp nest hangs from the ceiling in the center of the room, the vocabulary 'word-wall' is positioned above a table exhibiting a miniature-sized replica of a human skeleton, bits of coral, conch shells, geodes, a lucite-encased snake skeleton, a case of fossilized shark teeth, and much more. A pendulum rests on its stand on the ledge above the student cubbies next to a kaleidoscope, a model of the earth and moon, and a bird's nest.

Complementing the assortment of realia are several representatives of materials that are traditionally associated with academic or "school" science. The bulletin board displays posters illustrating whale taxonomy, the classification of rocks and minerals, an informative poster on jellyfish, and an illustration of an iceberg. The bookcase shelves under the window are filled with buckets of labeled rocks, magnets, and science-themed books on weather, the seasons, and more.

Mr. Owen shared that while he appreciates the richness the materials bring to his space, it's important that their inclusion does not come at the expense of the room appearing cluttered and that it is important to him that the classroom space is both engaging and productive. He prefers that everything on the walls either be interesting or useful and that when it comes to the set-up of his classroom he strives for efficiency, workability, exposure, and interest.

I observed and recorded several discursive contexts in which groups of these first graders were situated. A frequent context was whole-group, teacher-led science "talk." During these types of discussions, the students are called to leave their desks and sit on a large carpet at the front of the room facing Mr. Owen (who usually stood). I was also able to observe and, at times, interact with students in small groups and while they worked independently or with partners at their desks.

It is important to note that the episodes reported below occurred before the NGSS had been adopted by the state and were very much unfamiliar to teachers. Mr. Owen's approach to teaching is closely aligned with the strategies put forth by the curriculum standards that he was responsible for teaching at the time.

I recorded the classroom discourse with both video and audio during each of my visits to Mr. Owen's classroom. All recordings were subsequently transcribed using transcription software. In addition to the recordings, I took extensive field notes of my observations. These notes included descriptions of the layout of the classroom, my initial reactions to interactions among the students and between the students and teacher. In the analyses that follow, I report on a whole-group science talk led by Mr. Owen as part of his approach to integrating a social studies lesson with language arts and science. I then present an analysis of a small-group, follow-up discussion that I facilitated in order to engage students in deeper sense-making around one of the topics that came up in the whole-group session. Taken together, these episodes are intended to illustrate effects of contrasting epistemological approaches to teaching science on the authentic enactment of the discipline with regard to discursive agency, relative to current conceptions of authenticity promoted by the NRC in NGSS.

Data Analysis

In order to draw inferences about discursive agency, I first conducted a structural analysis of discourse used in-context of both the whole-group 'science talk' and the small-group sense-making discussion. I then "coded" the discussion for evidence of NGSS practices, cross-cutting concepts, and disciplinary core ideas to make inferences about the scientific authenticity of the discourse, relative to NGSS. Together, these analyses allow me to check for co-occurrence of students' discursive agency and the scientific authenticity of their discourse, which then positions my arguments for the causal connectedness of agency and authenticity.

As Gee (1985) suggests, "One of the primary ways--perhaps *the* primary way– human beings make sense of their experience is by casting it in narrative form" (p. 11). I thus present my data with and through thick descriptive narrative, with the intent to strengthen the likelihood that this case study may be, as Stake (1978) described, "epistemologically in harmony with the reader's experience and thus to that person a natural basis for generalization" (p. 5). Accordingly, rather than simply summarizing my results in subsequent sections, I provide copious examples of the coding processes as part of my analysis. Presenting the "coding" examples in context works to make the coding decisions easier to understand while also helping readers to evaluate the appropriateness and productiveness of the codes/inferences given the contextual cues and conversational flow.

Results & Discussion – Narrative Analyses

Whole Group Science "Talk"

While conducted in a more informal space away from desks and chairs, whole-group science "talks" often typify traditional discourse patterns in which the teacher maintains the majority of control over the talk. The students are systematically 'led' through the discussion in organized sequences to reach the conclusions that Mr. Owen believes are the most appropriate for each inquiry.

The week before the talk presented below, each student had been charged with bringing in an "artifact" that represents his or her family's cultural heritage and the science talk focused on giving the students opportunities to share their artifacts with the class. The objective was for each student to present his or her artifact "show-and-tell" style to the group and explain what it was and why it was special. The lesson was primarily intended to focus on social studies learning indicators, however, the integrated nature of the primary grades curriculum allowed for the incorporation of content, skills, and practices from other subjects into the activity. Mr. Owen subsequently added a science component to the lesson by asking each student to "think like a scientist" and try to determine what his or her artifact was made of and how it had been constructed.

Several students were given the opportunity to first share the cultural and personal relevance of the artifact before some portion of their time was devoted to talking about the "science." Mr. Owen began the activity by calling all students to the carpet and asking them to face the same direction. He then placed a student chair in front of the "audience," establishing a clear space from which each "shower" could "tell."

Amani, one of the students who would join me in the small-group discussion following the whole-group talk, was first. Mr. Owen brought up her artifact: a brightly colored basket, which she explained was for holding and carrying fruit. After a few moments devoted to eliciting personally relevant details about the basket, Mr. Owen indicated a change in focus by stating:

> …and the last thing to think about: what do you think it's made of, what pieces, what materials do you think it's made of, what small parts does it have, and how does that help it work?

The question was directed solely at Amani and both initially and upon subsequent analysis, I was unsure if he provided multiple variations of the question to make the general request as comprehensible as possible through rephrasing, or to indicate there were multiple ways to think about the materials and how they come together. The move seemed to be an attempt at providing support for the dialogue however, it was unclear whether the primary purpose behind it was for clarity of communication or conceptual thinking.

Amani responded to the prompt with a nearly inaudible answer, "raffia," which the teacher repeated with what I interpreted as genuine interest. He asked if she believed that that was the material and, upon receiving a nod of confirmation, he asked her, "How do you think it's put together? How do you think they made it? Can you look closely at the parts and see how they might have made it?" Again, the rephrasing of the question might have been intended to either make his request clearer or to give her multiple avenues with which to think about the basket and its construction.

Following several seconds of wait time, while Amani seemed to study the basket in her lap, Mr. Owen then leaned in, turned the basket over and said, "I see some things that go over-under, over-under." He turned to the class and asked, "Do you know what that, does anyone know what that's called when you go over-under, over-under? Does anyone know what that's called?" When members of the class didn't indicate attempts to respond, Mr. Owen turned his attention back to Amani and gently asked her if she knew what it was called. When she responded, "weaving," Mr. Owen repeated the word, weaving, and elaborated by stating, "So it looks like whatever material they used, they put it together by weaving."

The questions put forth indicated that Mr. Owen intended the students to think about the parts of the basket and how it was made, however, the interaction regarding the construction suggested that Mr. Owen was taking advantage of the moment to activate and reinforce the students' vocabulary by discussing the word "weaving" and its meaning. He employed many strategies for supporting language including rephrasing, restating the word several times, using 'over-under' hand gestures to accompany his description of the pattern, and bringing the word, *weaving*, and its definition back together with and relating it the "science" of examining how the parts of the basket came together to make the whole. It was evident that in this moment, Mr. Owen was privileging language support for purposes of communication and enhancing general literacy skills over providing support for purposes of making sense of the parts of the basket. The “science” to be understood was retained primarily in a particular vocabulary word. Furthermore, the students’ roles in this portion of the discussion were limited to responding to prompts initiated by Mr. Owen. The three-part ‘Question-Answer-Evaluation discourse patterns what Lemke (1990) calls “triadic dialogue” through which “teachers get to initiate exchanges, set the topic, and control the direction in which the topic develops” (p. 11) thereby very much limiting student agency.

Throughout the discussion, Mr. Owen continued to orchestrate the talk in ways that conform to the “stylistic norms” observed by Lemke and others. Messages that appropriate talk in science requires verbal explicitness such that technical terms are privileged over colloquial phrases or nonverbal gestures “serious and dignified in all expressions of scientific content,” and that personal expressions should be avoided (Lemke, 1990, p. 146) were consistently communicated. Mr. Owen would explicitly indicate a shift in the activity of each presentation toward science (usually in directing the students’ attention to thinking about the properties of the objects) yet the *function* of the dialogue seemed to remain relatively consistent with formal, traditional perspectives. The specific references Mr. Owen made to thinking and talking about the “science” indicate that science is a specialized activity to be separated from the personal or cultural aspects of the artifacts. Student participation seemed to be restricted to communicating predetermined responses to teacher-initiated prompts. Mr. Owen specifically described the activity as scientific, however, in the absence of discursive participatory agency, it was difficult to determine the extent to which *the students* were engaged in scientific practice.

Abel, for instance, brought in a foot-long chunk of sugar cane. Mr. Owen's enthusiasm for the science potential of the artifact was clear in the way he opened the space for Abel to share:

> You know, I love the fact that these come from so many different cultures but I've done this project before but I've never talked about these artifacts like a scientist until this year so this is the first time I've done this. And I'm looking at all the different things and I'm thinking there's so much science to talk about. Really cool. OK go ahead, take it away. What are we talk-what are we looking at?

Abel shared that his artifact was a sugar cane plant from his mother's country, Guyana and that it is used to make sugar. He said that he brought it in because he liked it and when Mr. Owen asked him what the plant made him think about Abel replied that it made him think "about how did they make it, how do they make the sugar with it?" Mr. Owen immediately used Abel's question to segue into a "scientific" discussion. He repeated the question, "How do they make the sugar with that," and mused aloud, "That's sort of like a science question isn't it? Sure is! Now let's, let's continue to think like a scientist for a second, Abel, what parts help make that what it is? What pieces are inside of it?" When Abel didn't respond, Mr. Owen assisted by prompting him to "look at it, what do you see? How would you describe what you see? That's what scientists spend a lot of time doing."

Abel mused that he saw “black dots like from a tree.” Mr. Owen repeated and affirmed this observation and encouraged the student to look at the ‘inside’ of the plant that was visible as a result of the stalk being cut for more clues. Abel responded that he saw ‘black things’ which prompted Mr. Owen to offer further guidance.

> **Mr. Owen:** More black things? Sometimes when you have a hole in something, it's dark inside and it looks like black even though it's the same color as the inside, what color is most of the inside that you can see?
>
> **Abel**: Pretty much...white?
>
> **Mr. Owen**: White. So there's a white inside, what color is the outside?
>
> **Abel:** [inaudible]
>
> **Mr. Owen**: green and black. [to the group] What color is sugar?
>
> **Group**: White
>
> **Mr. Owen**: Where do you think the sugar comes from? The outside or the inside?
>
> **Some members of the group**: the inside
>
> **Abel**: inside.
>
> **Mr. Owen**: The ***in***side. Sounds good to me. Anything else to say? About the science part or the culture part of that artifact? OK. Any questions or comments for Abel? Abel, you can call on two people.

Much like in the discussion about Amani’s basket, the structure of the discourse and support strategies Mr. Owen employed seemed to work productively to give the students opportunities to practice using discourse for participation in scientific activities in ways that align with a perspective of science as almost inflexibly academic. He was clearly and carefully delimiting the science discourse from discourse in which students were free to use linguistic resources of their choosing to describe and discuss what they found compelling about the objects. Even though the students were [seemingly] able to offer the vocabulary words of their choice ("white," "inside,"), the specificity of Mr. Owen's questions and the way he posed them in intentional sequences suggested that there were specific words he had in mind as appropriate answers and the students were very much constrained to answering Mr. Owen's questions, rather than pursuing their own.

This discussion likely well satisfied many of the district's curricular objectives for first-grade science prior to formal adoption and integration of the Next Generation Science Standards. It also reflects many of the epistemological perspectives communicated through the standards of 1996. Mr. Owen was using "different strategies to develop the knowledge" (NRC, 1996, p. 23) by using discourse to make observations and use those observations to reach straight-forward conclusions. State and local districts have required that student learning objectives are conceptualized in terms of quantifiable, measurable actions such as *explain, identify, state, observe, describe*, for decades and the talk of this whole-group session clearly reflects a commitment to meeting these requirements. Unfortunately, when coupled with traditional assumptions about appropriate talk in science classes, these approaches reflect epistemologies that contrast with constructivist approaches that underpin formal science, reflecting inaccurate and potentially harmful (Lemke 1990; Schulz, 2014) messages about what it means to construct knowledge and to "know" in the discipline. As illustrated in this discussion, this approach may also restrict student agency which jeopardizes both opportunities for meaningful learning as well as authentic engagement, relative to NGSS.

The nature of science and of *learning* science promoted by the NGSS require a shift toward learning objectives that measure performance through representations of core ideas and concepts that students construct through collaborative participation in scientific practices. The analysis that follows reports on a discussion intended to shift more discursive agency to the students to draw interferences about the relative authenticity of their subsequent engagement.

Small-group Sense-making Discussion

I approached Mr. Owen immediately following the whole group session about pulling a few students for a discussion and he willingly consented. We decided that I would ask a small group of students to come sit with me at the back of the room to talk a little more about the "science" involved in Abel's sugar cane artifact. Many of the students had seemed particularly interested in the sugar in this object and thus I predicted it would be a fruitful topic for this discussion.

It was my intention to select students for whom this discussion would provide minimal disruption, though I did think it would be valuable to select at least one student who had held a lead role in the whole group discussion in order to be able to contrast participation for at least one individual. Isabel, Camille, Mia, and Amani, who had shared the raffia basket with the class in the whole group discussion, were sitting near each other at a table near the back corner of the room and had not yet started writing in their journals. I invited them to come sit back on the floor with me to talk a little more about the artifacts and they enthusiastically agreed. During the whole group lesson, Amani had shared that she had made sugar from sugarcane but wasn't quite able to explain how. This seemed like a productive entry point into the conversation and thus I asked the girls if they would try to figure out "how [getting sugar out of the sugar cane plant] works." Immediately Isabel raised her hand to attempt to answer and I whispered to her not to ask *me*, but to tell each other. I asked Amani to scoot over in front of me in an attempt to reinforce the idea that I was not in control of the conversation. I once again charged the girls with "figuring it out," and sat a few inches back from the group as they began talking.

It was my intention that the students would have control over their own participation including governance over turn-taking and thus I expected this discussion to more closely resemble everyday ways of engaging in conversation. My role as the facilitator would be to support and contribute to the conversation, rather than direct it. The students were being asked to talk about ideas, many of which were being constructed at that moment and there were thus several instances in which the girls spoke simultaneously, interrupted each other's sentences and ideas, and often took up the words of one another and latched them onto their own sentences without a break in speech. The discussion thus reflects what Rogers (2004) describes as the "*co-construction of dialogue* by multiple participants" (p.87). My contributions primarily centered on encouraging participation and seeking clarification.

Over the ten minutes of this discussion, I would observe these students employing many strategies to support their use of language toward scientific understandings. Some were similar to those that Mr. Owen had applied in service of the previous whole group discussion, and some I had not previously observed. My method and motivation for analysis of the small group session would be similar to that of the whole group activity. In the moment and later during analysis of the transcription, I was attending to the ways the girls used linguistic support strategies to support the communication of ideas and sense-making, generally. I concentrated on how the talk and corresponding support would compare to academic situations like the artifact-sharing discussion in which portions of the activity were framed both explicitly and implicitly as *scientific*. While I didn't expect the students to bring overt goals of enhancing language literacy or behavior maintenance to the discussion, I did wonder if there would be similarities to the whole group discussion in how they employed language for certain purposes.

The first few moments of the conversation centered on the physical process of getting sugar from the inside to the outside of the plant. My impression was that these initial ideas were a result of the whole group conversation that had culminated in the straightforward conclusion that the sugar came from the inside of the plant. Isabel began by describing her ideas for the sequence of steps that would be required to extract the sugar. She stated, "I think they take the green stuff off, um, peel the green stuff off and then, and then they cut up the white stuff and then that makes sugar... but then they put a little water in it." Whether intentional, her clarification of the process by which the green stuff is removed, from "take" to "peel" was a move to support the words being used to express her thinking. It served to make her idea of how the green stuff was removed more explicable for the group and potentially also for her. The word “peel” conjures up a more specialized type of removal than “take,” and indicates she is working on determining a mechanical or practical, rather than an imaginary or fantastical solution. Furthermore, Isabel’s ability to “talk through,” her thought without direct intervention, allowed her to refine how she talks about the process (taking the green stuff off became peeling the green stuff off), helping to support her own individual understanding as well as that of the group.

Camille responded with a similar attempt to refine the phrase “white stuff*”* for more productive use. “But, the white stuff, that's the sugar inside of it, which um, the sugar comes from the plant, so it's inside of the stem, Isabel. Probably. I wonder if [the piece Abel brought in] was the stem, or if that was the whole plant.” It seemed important for Camille to note that the “white stuff” they had observed on the inside of the stalk was, in fact, the “sugar.” Thinking about the “white stuff” specifically as *sugar* likely influenced the way in which Camille was considering the question of how the sugar was removed from the plant. It also seems to lead her to wonder about what part of the plant they are viewing, suggesting she is applying prior or existing understandings of plants, plant parts, and perhaps even plant sugar to making sense of the phenomenon. Here, Camille has retained discursive agency which allows her to not only move toward a more specific (and thus productive) way of talking about the “white stuff,” but also to wonder out loud about the object itself in such a way as to pose a rhetorical question to the group. Traditional, teacher-controlled patterns of discourse, do not typically allow for students to respond with their own questions (Berland, Schwarz, Krist, Kenyon, Lo, & Reiser, 2016; Cazden, 1988, 2001; Henderson, MacPherson, Osborne, & Wild, 2015), yet here, Camille has done just that in a way that seems to prompt further productive sense-making about the *sugar* inside the plant, indicating that the agency is contributing to authentic progress toward scientific proficiency.

A few more moments of discussion around the removal of the ‘green stuff’ to get to the sugar led into Camille once again posing a question to the group, “Um, but, where did the sugar come from before it was in the plant?” Again, the discursive context here has empowered Camille to ask her own questions in the service of understanding, which Mia then takes up by offering that maybe the “sun and the water and stuff” could help the plant “get the, um, sugar.” The students had spent some time earlier in the year discussing how plants made their own food and the “food” was often referred to specifically as sugar. Weeks earlier, I had observed a lesson in which the class discussed where the sugar listed in the nutritional information on white milk might have come from. By the end of the lesson, many of the students had come to agree that the sugar originates in the grass and is transferred to the milk after the cow eats the grass. Whether the girls were tapping into information constructed during those lessons or from other experiences, the notion that plants ‘make’ *food* –which is also known as *sugar*--seemed to be at play. It is important to note here that the discursive context of this discussion allowed the students to tap into these prior understandings at a point in the discussion in which *they* felt that it was valuable, using them as evidence to support ideas and contribute to understanding.

Camille responded that if the plant had had leaves it might be a clue. Amani added, "'Cause the leafs [sic] make their own sugar and then, it could, the leaves of the sugar cane could, um, go...they go through the stem then the stem…it could go through the stem, it could be, some of it could get stuck in the plant." Her idea seemed to be that the leaves make sugar for the plant and that sugar could move from the leaves to the stem whereupon some of it would become "stuck." The fact that the piece Abel brought in did not have any discernable leaves seemed to be problematic for their reasoning, evidenced by the subsequent few moments of discussion.

> **Camille:** Well I think that with the stems he showed us, because if the leaves are, the stem brings up all the sugar and it's right inside of it, so they could have chopped it all off before like went to the leaves.
>
> **Isabel:** Or maybe if it didn't have any leaves then maybe the stem could act like IT was a leaf
>
> **Camille:** [*inaudible]*
>
> **Me:** How, what do you mean?
>
> **Camille:** Well the stem could have its sugar or stuff like the food, carrying the food instead of the leaves if it didn't have leaves
>
> **Isabel**: ahh yeah or maybe or maybe it could still have leaves but the leaves were just so tiny that that was the green part.
>
> **Me:** What did she just say?
>
> **Camille:** Oh, she said maybe the leaves were just so tiny? Or something?

Isabel: That, that, that might appear far away from us as the green part, but… [shrugs]

Mia’s reference to the “sun and the water and stuff” being involved seemed to trigger the girls to attempt to fit understandings of the mechanisms of photosynthesis to the situation—at least that plants house their food internally somehow-- and, as a result, *food,* came to replace *white stuff* as the alternative way of referring to ‘the stuff’ under consideration. The choice of the word seems to be purposeful in helping the girls work out how the sugar came to be inside the plant. At this stage, it is not clear whether all four students recognize that a plant’s food not only is internal but that the plant ‘makes’ its own food. This is understandable given their young age and relative inexperience with concepts of food production of any sort. It does suggest that they are accessing and applying a portion of the phenomenon to their thinking, which seems to be working productively for them in this moment.

The issue of whether the plant at one point had leaves was clearly problematic for the girls and it soon prompted them to turn to clues in the name, itself. Camille mused aloud several times that it was called a sugar *cane* which prompted Isabel to bring up another type of “cane”.

Camille: Well if it's a sugar CANE, a cane doesn't usually have leaves by itself so...

Isabel: I know!

Camille: I guess there wouldn’t be leaves in there by the …

Isabel: Yeah like one of those Christmas candy canes, they don't have leaves.

The girls seemed to be turning to the word name of the object for clues about the nature of the object, itself. The canes of their experience, in this case, Isabel offers *Christmas candy canes* as an example, don't typically come with leaves. It would be logical to conclude that if *canes* in other contexts don't have leaves, perhaps the same is true for the sugarcane and such a conclusion could certainly be productive in making sense of how the sugar came to be inside the plant.

Each of these moves-- Isabel's refinement of "take" to "feel," Camille's clarification of "white stuff" as "sugar" -- and the exploration of the name sugar*cane* in other contexts all contributed to a pattern of refining language for purposes of refining meaning. Unlike the whole group activity, the students had considerable control over the patterns of discussion and the types of language used and the talk seemed largely to work toward clarity of communication such that the girls could more effectively to use their own and each other's ideas to collaboratively make sense of the phenomenon.

Coding for Evidence of Scientific Practice – Summary of Results

The narrative analyses of the whole and small-group discussions support an inquiry into the question of the connections between discursive agency and scientific authenticity. These analyses indicate that students did, indeed hold more control over the discourse and its use during the small-group discussion, that the students used more 'everyday' ways of talking and followed fewer of the 'stylistic norms' for appropriate science talk that Lemke and others have observed (Ballenger, 1997; Berkenkotter, & Huckin, 2016; Kelly, 2014; Kress, Jewitt, Ogborn, & Tsatsarelis, 2001, Lemke, 1990, 2005; Warren, & Conant, 1992). The next stage of analysis now required that I evaluate the nature of this discussion for evidence of authentic scientific practice. What follows is a report of the coding scheme I applied to this discussion in order to make inferences about the authenticity of the discussion relative to the NGSS as representative of the ‘ordinary practices’ of science in school.

As noted above, the nature of my research question, particularly the specificity of connecting student talk with the NGSS, led me to apply an analysis in which I was coding utterances for claims of authentic enactments of science. The NGSS outlines three dimensions of science proficiency: *Practices, Cross-Cutting Concepts,* and *Disciplinary Core Ideas*. I used these three dimensions as the first-level in the hierarchy of my coding scheme. *Practices* were represented by the letter, ‘A,’ *Crosscutting Concepts* were represented by the letter, “B,” and *Disciplinary Core Ideas* by the letter, “C.” There are multiple sub-elements within each of the three broad dimensions and I have included them as second-level categories in my scheme[1]. Table1, below, illustrates the application of these codes to a section of transcript.

[1] See Appendix A: *‘Progress Toward NGSS Proficiency’-3-D Coding Scheme*, for detailed information on the coding levels.

Table 1: Sample Coding for NGSS Dimensions

Code(s)	Utterance
A.6.a [Practices: Constructing Explanations] **A.8** [Practices: Obtaining, Evaluating, and Communicating information] **B.5** [Crosscutting Concepts: Energy & Matter] **CLS1.B** [Core Ideas: Life Sciences: Growth & Development of Organisms]	**Isabel:** Maybe, maybe when it was a seedling, the sugar actually GROWS in the plant!"
A.6.a [Practices: Constructing Explanations] **B.2** [Crosscutting Concepts: Cause & Effect]	**Mia:** …maybe that the sun and the water and stuff help how to get the, um, sugar…
A.6.a [Practices: Constructing Explanations] **A.8** [Practices: Obtaining, Evaluating, and Communicating information] **B.2** [Crosscutting Concepts: Cause & Effect **B.5** [Crosscutting Concepts: Energy & Matter]	**Camille**: Well, but, if-well, if it did have leaves, you probably could tell how it would happen…If it had leaves, you could because the leaves have sugar with them. But you could've just chopped off all, everything…
A.6.a [Practices: Constructing Explanations] **A.8** [Practices: Obtaining, Evaluating, and Communicating information] **B.5** [Crosscutting Concepts: Energy & Matter] **CLS1.B** [Core Ideas: Life Sciences: Growth & Development of Organisms]	**Amani:** Cause the leafs make their own sugar and then, it could, the leaves of the sugar cane could, um, go...they go through the stem

In my analysis of the small group discussion, I studied each utterance for ways in which it was or was not consistent with the three dimensions of science 'proficiency' outlined by the NGSS: *Practices, Crosscutting Concepts*, and *Disciplinary Core Ideas*. The utterance did not need to reflect complete "mastery" of the science idea, concept, or practice; rather it needed to reflect evidence of the activation and/or application of some element or aspect of the dimension. In other words, I was looking for evidence of 'progress toward proficiency.' Of the student utterances analyzed, 55.7% were found to reflect one or more of the dimensions for a total of 63.2% of the student talk time. It is important to note that of the 44.3% of utterances not coded as being reflective of the dimensions of science proficiency outlined by the NGSS, none were found to be *un*scientific. Rather, they were statements that contributed to the organizational patterns of the conversation such as "…you're talking too fast," and "I have an idea." Other utterances not found to be representative of elements of science proficiency were incomplete statements or ideas such as "the plant…" and "maybe something…"

Figure 1: Discourse Participation (total observed time: 509 seconds)

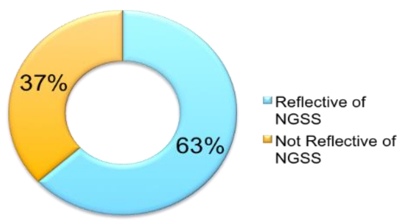


Figure 2: Percentages of Student Talk found to reflect Progress Toward NGSS Proficiency

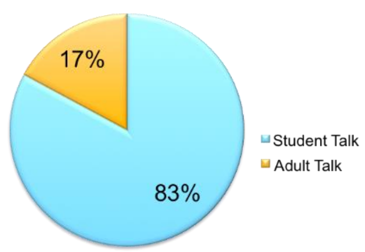
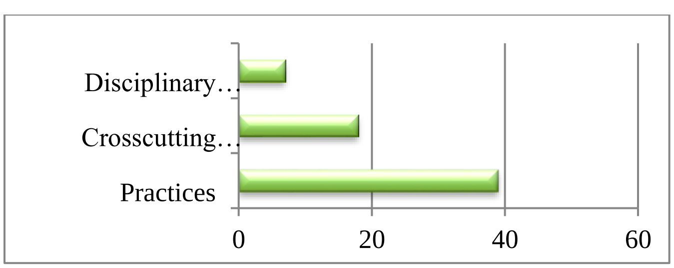


Figure 3: Number of Student Utterances Found to be reflective of Progress Toward NGSS Proficiency (Total utterances: 39)



Within the utterances that were found to be consistent with the NGSS, the dimension *Practices* was the most frequently evident and was apparent in every utterance that was coded as reflecting progress toward proficiency. Crosscutting concepts were also present in the student discussion, reflected in 25.7% of the utterances. Disciplinary Core ideas, perhaps predictably given the grade level, was the dimension found to manifest the least, being reflected in 10.0% of the talk. The following represents findings of the analysis of the first four minutes of the discussion.

Discursive Agency & Authentic Scientific Practice – Detailed Illustrations

Evidence of progress toward scientific proficiency and authentic scientific practice according to the NGSS was present throughout the girls' small-group discussion of the sugarcane. The detailed examples that follow illustrate nuanced, yet significant ways that the increased discursive agency that the girls maintained directly contributed to the scientific activity and meaning-making. Following each description, I have used bold-print to emphasize my claims for how each contributes to my overall argument.

In the girls' discussion of sugarcane, *Practice 6, constructing explanations*, was often evident.

The initial portion of the dialogue focused on the physical process of extracting the sugar from the sugarcane. Isabel began by describing her ideas for the sequence of steps that would be required to extract the sugar. She stated, "I think they take the green stuff off, um, peel the green stuff off and then, and then they cut up the white stuff and then that makes sugar...but then they put a little water in it." According to the NRC

(2012), “A scientific hypothesis is neither a scientific theory nor a guess; it is a plausible explanation for an observed phenomenon that can predict what will happen in a given situation” (p. 67). In this utterance, Isabel is providing an explanation in the form of a hypothesis for how the sugar may be removed based on her observation of the colors of the inside and the outside of the stalk and is thus reflects the NGSS practice of constructing explanations. It is important to note that using the word “hypothesis,” and/or explicitly framing an explanation as such is not a prerequisite for classification as this Practice. Isabel’s opening explanation is also an example of Practice 8: “obtaining, evaluating, and communicating information.” In the *Framework for K-12 Science Education,* the NRC (2012) notes that “Communicating in written or spoken form is another fundamental practice of science; it requires scientists to describe observations precisely, clarify their thinking, and justify their arguments” (p. 74). Isabel’s refinement of the process by which the green stuff is removed, from “take” to “peel” was a move that functioned to clarify her idea for the group, and perhaps also for herself. It served to make her idea of how the green stuff was removed more explicable for the group and potentially also for her. The word “peel” conjures up a more specialized type of removal than “take,” and better helps communicate her thinking. **Thus, in this moment, Isabel’s discursive agency to use her own words made it possible for her to refine her word choice, from “take” to “peel,” in an attempt to communicate her scientific idea more clearly—to authentically engage in hypothesis formulation and oral communication of ideas.**

A few moments further into the discussion, Camille shifts the direction of the conversation toward contemplating the phenomenon of sugar being in the sugar cane when she asks, “Um, but, where did the sugar come from before it was in the plant?” Clearly this is an example of asking a question, but according to the NRC (2012), students should be able to “Ask probing questions that seek to identify the premises of an argument, request further elaboration, refine a research question or engineering problem, or challenge the interpretation of a data set” as part of the NGSS practice of asking questions and defining problems (p.55). Camille is asking a question about the phenomenon, which helps to *formulate* and *refine the problem*. Her question prompts the girls to move away from discussing the extraction of the sugar and focus instead on how the sugar came to be in the plant in the first place. **In brief, Camille’s discursive agency to shift the direction of the discussion made it possible for her to engage in the authentic scientific practice of formulating and refining a problem.**

Camille follows up her question with the suggestion that the sugar could have come from an outside source such as a purchased candy bar and put into the plant. It is neither unreasonable nor unscientific for first graders to consider the idea that sugar could have come to the sugarcane from an outside source and while this idea is clearly inaccurate, it is a valid explanation and sets up space for the girls to consider the alternative solution that the sugar grows from within. I asked the girls whether they believed that the plant had “bought [the] sugar,” which the girls recognized as not only unlikely but silly as evidenced by their giggles and cries of “no!” This is particularly noteworthy in that it indicates that the students aren’t, in this moment, willing to accept explanations based on fictional or fantastic evidence, a key element of science proficiency.

I nudged the discussion further by asking how the sugar got inside the plant. Isabel instantly took up the notion of the sugar developing within by enthusiastically offering, “Maybe, maybe when it was a seedling, the sugar actually GROWS in the seedling plant!” This statement is reflective of the NGSS practices of “constructing explanations” and “obtaining, evaluating, and communicating information.” Her causal, mechanistic explanation is likely inspired by a previous science unit in which the whole class had discussed the idea that plants make their own food. She is applying knowledge constructed in other contexts to a new situation, an element of science proficiency addressed by the NRC. Isabel is also applying a specialized word, *seedling,* in her explanation. This move helps communicate her hypothesis by reinforcing the idea that the sugar develops inside the cane as the plant grows. In addition to being representative of two NGSS practices, Isabel’s statement also reflects the beginnings elements of the second dimension, *Crosscutting Concepts,* which the NRC (2012) describes as those whose explanatory value helps to “bridge disciplinary boundaries” (p. 83). The crosscutting concept, “cause and effect: mechanism and prediction,” describes the notion that any causal hypothesis “requires a model for the chain of interactions that connect [the cause] and [the effect]” (NRC, 2012, p. 87). Isabel recognizes that there must be an underlying mechanism for the sugar to come from within the plant and suggests that it develops as the plant grows. Her explanation also suggests that Isabel is employing fledgling aspects of several elements of the third dimension, *Disciplinary Core Ideas,* particularly those of life sciences, which hold that plants and animals grow and develop in predictable ways. Isabel's idea that the sugar grows inside the plant speaks to these notions. **Here, Isabel maintained the agency to introduce a new idea using her own, 'specialized' word (seedling), which subsequently allowed for her to more authentically communicate her thinking toward the development of a causal, mechanistic explanation that reflects evidence of core scientific ideas.**

As a whole, the presentation and discussion of data in the preceding paragraphs serves to simultaneously illustrate my approach to coding the transcript along the three NGSS dimensions of scientific proficiency and provide examples of ways that the students' discursive agency in particular moments led to or supported their engagement in authentic science practices (as defined by NGSS) in those moments.

Conclusions and Implications

This research indicates that allowing these students to take control of the discourse used in the service of science co-occurred with engagement in NGSS-authentic scientific practice. Furthermore, the example pieces of discourse given above suggest that the ability to use the words, linguistic structures, and participatory patterns of their choosing directly led to productive sense-making and progress toward proficiency. The seemingly 'sporadic' patterns of 'turn-taking' resulted in the students building off the ideas embedded in each other's talk in scientifically productive ways. They were able to ask questions of each other using their own words, phrases, and expressions -- many of which prompted deeper thinking -- to respond in ways that more naturally served their understanding, and to apply previous or existing understandings in moments of their choosing. And, as illustrated by the boldfaced mini-summaries above, the students' discursive agency directly led to their engagement in scientific practice in those moments.

We use language to construct and scaffold social activities and our identities within them. As such, disciplinary learning in science is shaped by the discourses we create in school contexts. Through language, we indoctrinate children into a conception of the discipline of science. It is necessary, as Gee explains, to "get one's body, clothes, gestures, actions, interactions, ways with things…values, attitudes, beliefs and emotions 'right,'" but it is also crucial to get the words 'right' as well (1999, p.7). Very often the message that we send is that "getting it right" in science means abandoning the everyday ways of thinking, valuing, believing, and, most importantly speaking that is characteristic of our interactions in our lifeworlds. This message contradicts professional consensus on the nature of science as a human enterprise in which the construction and validation of knowledge are socially and culturally mediated. This epistemological misalignment between school science and formal science is evident in the language demands and normative discursive practice in traditional classrooms. Problematically, the epistemological misalignment between school and formal science-which manifests in the language demands and normative discursive practices of the classroom--reflect and promote potentially detrimental perspectives on the nature of science. Furthermore, by constricting discourse and language use, we also limit the extent to which students are able to make their own choices and pursue inquiries in ways that are most productive for their individual and unique learning needs.

This report is intended to illustrate the theoretical argument that engagement in authentic science practices (as defined by NGSS) not only invites but specifically allows children to take agency over the discourse and associated linguistic resources they bring to bear. As the 'teacher' in the small-group episode, I facilitated and supported the discourse, rather than directed it. The result was the students applied more natural, everyday ways of talking and interacting with each other and with the ideas and, while they didn't develop a scientifically pristine explanation of photosynthetic processes and products, their activities still indicated substantial progress toward authentic scientific practice and appropriately "accurate" understandings. They maintained agency and were still able to make progress toward 'getting it right.' Furthermore, the discursive agency that led to more authentic scientific practice, allowed these students to more have more control over their own cognitive sense-making, an essential component of learning.

The episodes reported here are certainly limited by their size and scope. It would be valuable to explore the claims made here in extended applications of discursive shifts in agency (for example, in entire class periods, over entire curricular units) to understand how progress toward proficiency moves toward mastery in certain contexts. It would also be valuable to conduct research that explores how discursive agency plays out with students in more advanced academic grades and contexts. It is important to note that I am not suggesting that increasing student discursive agency requires that teachers abdicate their own control over the organization, flow, or content of their lessons. Moreover, I am not arguing that *discursive* agency need be taken from teachers. Teachers still play a vital role in facilitating and supporting the learning processes of their students and it is essential that they maintain the ability to do so. My argument merely suggests that a shift in approaches to language use in science that allow and empower students to have more control over their discursive participation can lead to more authentic and productive ends. It would be valuable for future research projects seeking to understand the relationships between agency and authenticity in disciplinary learning to attend closely to the role and perspectives of teachers.

Chapter 4: Transdisciplinary STEM and Teacher Beliefs: Exploring the Interplay of Epistemology and Constraints

Abstract

This research represents a case study analysis of the perspectives of a sample of five participants in a Teacher Leadership in STEM Education graduate degree program at a large Mid-Atlantic University. The program is designed to support teachers in making a shift toward more constructivist-driven, integrated, and transdisciplinary approaches to teaching and learning. Though my initial research question sought to generally explore which factors mediate these teachers' capacities and inclinations for embracing such a shift, early phases of data analysis indicated that attention to implementation barriers was not only a prominent theme for all teacher participants but that their epistemological beliefs were particularly salient within descriptions of these constraints. The research question thus became, *how do teachers' epistemological beliefs affect their perceptions of the locus of perceived barriers and the extent to which those barriers may be overcome?* Results of this study support the conclusions drawn through previous research programs that teacher training programs may benefit from accessing teacher beliefs and, furthermore, that authentic and productive alignment between personal epistemologies and those of the reform may be connected to success. Additionally, the findings of my research add a new perspective to the discussion: epistemological beliefs may be intimately entangled with teachers' perceptions of constraints to implementation of reform, rather than function soley as a distinct factor influencing buy-in and implementation. Thus, examining the ways teachers describe and respond to constraints

may be particularly productive for accessing beliefs and, rather than treating constraints as ‘technical’ problems for which there are straightforward solutions, teacher educators should consider whether and when constraints are more of an epistemic challenge.

Introduction

In recent decades, the extent to which public school systems successfully prepare students with the knowledge and skills necessary for post-secondary education, careers, and citizenship in the 21st century has been progressively scrutinized. Many argue that the evolving workforce is demanding new generations of graduates to be independent thinkers, problem solvers, and decision makers. As such, many stakeholders in modern education reform increasingly advocate for considerable paradigm shifts within approaches to disciplinary teaching and learning, particularly within science, engineering, mathematics, and technology.

As with many education initiatives, STEM education reform focuses largely on goals of strengthening both the products and processes of schooling and, as Duschl and Gitomer note, such goals ultimately target “problems of practice,” described as “problems of appropriate curriculum designs and instructional dynamics” (1997, p. 38). Thus, efforts for change must address both *what* we teach and *how* we teach it. For many advocates of modern reform within STEM education, problems of both ‘appropriate curriculum design’ and ‘instructional dynamics’ may be traced to a misalignment between epistemology and nature of science in school and that of professional science communities.

Some recent reform initiatives such as the *Next Generation Science Standards* (NGSS) invite and afford a simultaneous solution to the epistemological, curricular, and pedagogical issues of modern schooling by situating learning within life-relevant contexts, phenomena, challenges, or problems that allow students to build knowledge through the explicit and purposeful integration of multiple disciplines. These systems and methods of teaching are often referred to as *trans*disciplinary in that they seek to move beyond isolated learning that is framed primarily for purposes of meeting academic goals toward holistic, real-world-relevant methods. Transdisciplinary STEM seeks to offer a cohesive, interdisciplinary, and applied approach to learning in academic contexts and contrasts many traditional, 'siloed' approaches to schooling in which knowledge and practices of disciplines are represented as both bounded and separate. It emphasizes the reflexive value of the interdisciplinary construction and application of knowledge through contextualized practice (Bybee, 2010a; Bybee 2013; Vasquez, 2015; Vasquez, Schneider, & Comer 2013).

For teachers, the adoption of transdisciplinary approaches to STEM education may require considerable shifts in the ways that they understand, view, and approach their practice (Bybee, 2013; Czerniak & Johnson, 2007; Sanders, 2008).Research has indicated that teachers' beliefs-- including epistemological beliefs about the nature of knowledge and knowing-- influence the choices and strategies they use in their instructional practice (Brickhouse & Bodner, 1992; Chan & Elliot, 2004; Czerniak & Lumpe, 1996; Haney, Czerniak, & Lumpe, 1996; Hofer, 2001; Hofer & Pintrich, 1997; Pajares, 1992, Schommer et al., 1992; Stipek, Givvin, Salmon, & MacGyvers, 2001; van

Driel, Beijaard, & Verloop, 2001). Thus, given that the success of pedagogical strategies is closely connected to teacher beliefs, values, and buy-in, *and* that teachers are ultimately the ones responsible for implementation, it is valuable to collect data on their interpretations and perspectives (Battista 1994; Bybee, 19936; Czerniak & Lumpe, 1996; Keys and Bryan, 2001, Pajares, 1992).

The goal of this research is to better understand how teachers view transdisciplinary STEM education and how those views might facilitate or hinder classroom implementation. I explore the perceptions and experiences of a sample of teachers currently enrolled in a graduate degree program in STEM Teacher Leadership. Initially, I sought to address the broader question, *what factors mediate these teachers' inclinations and capacities for embracing a shift toward transdisciplinary education within STEM disciplines?* Yet as my data collection and analysis progressed, I noticed not only frequent evidence of beliefs and of barriers to implementation--two factors that are commonly identified in the literature as mediating successful education reform—but I also noted salient evidence of the *relationships* between epistemological perspectives and perceptions of barriers as having significant influence over the teachers' considerations. Given that previous research and scholarship has typically treated teacher "beliefs" and constraints as *discrete* factors that affect buy-in and implementation of reform (Brickhouse & Bodner, 1992; Czerniak, & Lumpe, 1996; Ertmer & Ottenbreit-Leftwich, 2010), a focus on how these two factors may be related seemed worthy of investigation. I therefore focus more closely on ways in which these teachers' epistemologies seem to be influencing their perceptions of transdisciplinary STEM, particularly on how they view implementation barriers and constraints and focus my inquiry on the narrower research question**,** *how do teachers' epistemological beliefs affect their perceptions of the locus of perceived barriers and the extent to which those barriers may be overcome?*

Guiding Perspectives

STEM Education: Constructivist Teaching for Authentic Learning

In recent decades, transdisciplinary STEM education has emerged as a model for addressing 21st-century demands for public schooling that better prepares students for productive post-secondary careers and civic life through enactments of the disciplines that more closely reflect the epistemological perspectives of professional communities (NRC 2007, Sandoval, 2005). As Sandoval explains, "In contemporary democratic societies, lay citizens need to understand the nature of scientific knowledge and practice in order to participate effectively in policy decisions and to interpret the meaning of new scientific claims for their lives" (p. 637). Furthermore, understanding the structure and nature of science enhances students' ability to both participate in and learn science in that "if students come to see science as a set of practices that build models to account for patterns of evidence in the natural world, and that what counts as evidence is contingent on making careful observations and building arguments, then they will have greater success in their efforts to build knowledge (NRC, 2007, p. 169). STEM education reflects and models these perspectives through "an interdisciplinary approach to learning that removes the traditional barriers separating the four disciplines of science, technology, engineering, and mathematics and integrates them into real-world, rigorous, and relevant learning experiences for students" (Vasquez, Schneider, and Comer, 2013, p.

4). STEM education is thus inherently grounded in constructivist epistemologies for learning in that students are at the center of the learning process, knowledge is constructed through collaboration, questions with single ‘right answers’ that are provided or confirmed by an external authority (teacher or textbook) are deemphasized in favor of investigations into complex issues and phenomena, thinking skills and “habits of mind” are integral to project work, and digital technologies are used to support and enhance learning. STEM seeks to intentionally integrate the concepts and practices of multiple disciplines through experiences in which learning is situated within immediately applicable contexts. These contexts may include authentic technological or engineering design-based problem solving (Sanders, 2008, 2012), real-world challenges to address, or phenomena to explore (Bybee 2013; Vasquez, Schneider, & Comer, 2012). Central to the ‘nature of scientific knowledge’ within transdisciplinary STEM is a coherent understanding of the processes by which scientific claims are built. As Ford points out, “a proper understanding of a scientific idea requires that one also know something about the architecture of that knowledge—that is, how it is constructed. Students generally do not understand scientific ideas when they are merely committed to memory” (2007, p.404). The explicit instructional emphasis on the practices by which knowledge is constructed in STEM fields represents what Ford and Foreman describe as a ‘practice-turn’ in sociocultural learning theory.” The authors describe this shift toward practice as a response to the frequently asserted reformist concern that “students should be engaged in the activities of historians, mathematicians, scientists, or literary analysts rather than just learning about the results of those practices” (2006, p.1). With regard to schooling, the perspectives underpinning this shift align more closely with the constructivist theoretical commitment that learning is not a result of direct transmission from one knower to another, but rather is actively constructed through individual and social processes (Bransford, Brown, Cocking, 2000; Driver, Asoko, Leach, Mortimer, & Scott, 1994). Furthermore, these approaches call for students to become active agents in the processes of constructing and justifying knowledge. In other words, transdisciplinary STEM education should not only allow students to be consumers of the knowledge constructed by professionals, and, likewise should not merely learn about the practices of the disciplines, but should, themselves, meaningfully engage in the practices through which professional science, engineering, technology, and mathematics achieve their ends.

Teacher Beliefs

An ultimate goal of transdisciplinary STEM education reform is high quality constructivist curricular and instructional practices that augment student understanding of core ideas, practices, and authentic perspectives on the nature of knowledge and knowing within and among formal disciplines. However, research suggests that there are many factors within the structures of schooling and, in particular, within features of classroom discourse that may influence the ways in which students access and interpret these ideas in school (Lampert & Blunk, 1998; Lemke, 1990). If, as Maggioni & Parkinson explain, "the way in which teachers conceptualize the nature and justification of their subject-matter knowledge and their ideas about students' learning influence the features of classroom discourse," (2008, p. 446), then it is reasonable to conclude that teacher belief systems affect students' knowledge and epistemological outcomes.

Handal and Herrington, synthesizing the work of others (Holder & Pintrich, 1997; Lovat & Smith, 1995; Pajares, 1992) have written, “Teachers’ belief systems reflect personal theories about the nature of knowledge and knowing that, in turn, influence teachers’ curriculum decision-making and teaching approaches” (2003, p. 59). Indeed, academic communities have long acknowledged and studied the impact that teacher beliefs have on the ways that they approach their profession and, connectedly, the ways in which they ‘take up’ professional development aimed at reform (Ball, 1988; Battista, 1994; Darling-Hammond, 1990; Richardson, 1996; Roehrig, Kruse, Kern, 2006; Prawat, 1992; Stipek, Givvin, Salmon, & MacGyvers, 2001; Tobin & McRobbie, 1996; Windschitl & Sahl, 2002). Understanding and influencing teacher belief systems may thus be critical to the success of reform efforts. Furthermore, as scholars have argued, an implemented curriculum may be viewed as representing a set of beliefs put into action (Short & Burke, 1996, 1990) and thus it is reasonable to theorize that the relative congruence between teacher beliefs and the beliefs underpinning efforts to innovate education will influence the success of the reform (Handal & Herrington, 2003). In other words, teachers’ understandings and belief-influenced interpretations often determine the relationship between the intended curriculum and the enacted one.

Within modern inquiries into the influence of teacher beliefs on teacher practice, the study of *epistemological* beliefs is becoming of particular interest. As Hofer (2001) explains, research on personal epistemology addresses “thinking and beliefs about knowledge and knowing, and typically includes all or some of the following elements: beliefs about the definition of knowledge, how knowledge is constructed, how knowledge is evaluated, where knowledge resides, and how knowing occurs." In many research programs that focus on mathematics and science education contexts, teachers' beliefs are frequently associated with two primary and often contrasted learning models: traditional or transmissive and progressive or constructivist (Chan & Elliott, 2004; Hashweh 1996; Maggioni & Parkinson, 2008; Tsai 2006; Yerrick, Pederson, & Arnason, 1998). When viewed and studied as dichotomous, traditional/transmissive perspectives are typically characterized by a view of the teacher, subject matter, or curriculum as the source of knowledge and students as passive recipients whereas the progressive-constructivist perspective emphasizes active learning, critical thinking, and the collaborative construction of knowledge. In recent years, theoretical and empirical discussions regarding personal epistemology have expanded beyond a 'one-or-the-other' classification system to include conceptions of flexibility and context-dependent beliefs. Hammer and Elby (2002), for example, argue that most researchers presume an ontology of beliefs as "essentially unitary components of essentially stable epistemologies," meaning "each belief corresponds to a unit of cognitive structure, which an individual either does or does not possess" (p.1) and that such epistemological stability does not account for the influence of context. The authors, whose work focuses on epistemology in the context of science teaching and learning, propose that personal epistemologies are more productively viewed in terms of contextual epistemological resources and claim that "when judging the sophistication of a particular epistemological resource and of the behaviors it helps to drive, we must attend to the overall frame of which it is a part" (2002, p. 19). Elby and Hammer further challenge the assumptions regarding the ‘substance’ and makeup of so-called sophisticated epistemologies. These authors push to recognize a distinction between *correctness* and *productivity* of epistemological beliefs given the context in which they are being applied. A view of epistemology as a construct of context-dependent *resources* rather than “beliefs” or “conceptions” allows flexibility for naïve perceptions, such as realism for example, to be considered productive for helping students learn, and thus *valuable*, in certain contexts (Elby & Hammer, 2001) and perspectives that are commonly viewed as sophisticated, such as relativism, to be less productive. Such a view contributes to a perspective that, rather than consisting of blanket generalizations that apply to all knowledge in all disciplines and contexts,” a “sophisticated” epistemology incorporates contextual dependencies and judgments” (2001, p. 21). In other words, sophisticated epistemologies are not determined by consistent markers on one end of a dimensional spectrum, but rather the flexibility to move back and forth along the spectrum as context demands.

Despite the increasing attention to epistemology as a potentially significant influence on teacher practice, much of the current research into the factors that impact pedagogical *reform* focuses on teacher beliefs --whether inclusive or not of considerations of epistemology-- as being one factor in a collection of relatively autonomous structures of constraints and opportunities. In other words, institutional, school, classroom, and other personal constraints such as considerations for student reactions (Brickhouse & Bodner, 1992) and self-efficacy (Ertmer & Ottenbreit-Leftwich, 2010) are positioned alongside yet kept relatively separate from beliefs--particularly from epistemological beliefs. Rather than considered as a factor that might be entangled with and influencing other constraints, beliefs are typically considered—and studied--alone. In the research presented here, I explore ways that epistemological beliefs may both influence and be revealed by teachers' perceptions of constraints to education reform.

Research Design and Methods

This research represents a pluralistic exploratory and explanatory case study analysis (Yin, 2013) of the perspectives of a sample of five teachers who are current participants in a STEM Teacher Leadership degree program at a large Mid-Atlantic University. The initial research question, driving my data collection and early analysis, asks, *what factors mediate these teachers' capacities and inclinations for embracing a shift toward transdisciplinary education within STEM disciplines?* As I began to systematically review the data, however, I noticed that the attention to implementation barriers was not only a prominent theme for all teacher participants but that their epistemological beliefs and views were particularly conspicuous within the nuanced consideration and descriptions of these constraints. Therefore, I focused my analysis from the initial, broader inquiry, to attend more specifically to indications of particular belief systems and structures that may be both influencing and reflected within these teachers' interpretations of STEM as well as their explanations of opportunities for and barriers to implementation. Through my analysis, I could identify certain epistemological beliefs that were particularly salient in discussions of dilemmas, barriers, and/or constraints and manifested as significant factors mediating these teachers' inclinations to embrace transdisciplinary approaches to STEM instruction. Thus, my inquiry has become focused on a narrower research question: *How do teachers' epistemological beliefs affect their* *perceptions of the locus of perceived barriers and the extent to which those barriers may be overcome?*

Rather than exploring beliefs within discrete or 'siloed' disciplinary subjects such as mathematics or science as other research projects have done, I focus my inquiry on *transdisciplinary* approaches in which the core ideas and practices of STEM disciplines are integrated, learned and applied in the service of sensemaking around life-relevant issues, phenomena, or challenges. Furthermore, my research originates and operates from the position that epistemology is influenced by, related to, and enacted *in-context* and thus should be studied that way (Elby & Hammer, 2001; Louca, Elby, Hammer 1994; Hammer, & Kagey, 2004). Therefore, I probe epistemological beliefs in the contexts in which the teachers are drawing upon and applying them, rather than attempting to access them through decontextualized surveys, for example, or direct questioning.

In the sections that follow, I first outline and analyze data of the interpretations of and experiences within transdisciplinary STEM from the perspective of each teacher participant selected for the study (Merriam, 1998; Miles & Huberman, 1994; Smith, 1978) such that the reported experience of each teacher is considered an individual, bounded case. I also offer cross-case analysis that might suggest generalizations about how these teachers understand the nature and implementation of transdisciplinary STEM within their shared local contexts. Through a series of one-on-one interviews, I ask the participants questions designed to reveal clues to how they are making sense of the nature of STEM education, specifically the affordances, and drawbacks of the interdisciplinary, practice-driven, and contextualized learning principles that underpin transdisciplinary

STEM education[2]. I attend closely to their explanations of opportunities for and barriers to implementation for indications of particular belief systems and structures that not only manifest alongside these factors but also for ways in which epistemologies may be influencing and reflected within them.

Background & Context

At the time of data collection, the teachers selected for participation in this study were students in the first cohort of a STEM Teacher Leadership graduate degree program developed by a Mid-Atlantic public research university in partnership with a large local school district. Though the primary development team was comprised of a small group of science and math education researchers, myself included, the program was developed over the course of several years with input and feedback of a cross-departmental steering committee of university staff, teachers and curriculum coordinators from the target school district, and STEM Education representatives from the State Department of Education.

The program was specifically designed to prepare teachers to be ambassadors for the State Department of Education's newly released STEM standards of practice as well as to prepare them to qualify for an endorsement on their teaching certifications as *STEM*

[2]See Appendix B: Transdisciplinary STEM and Teacher Beliefs: Interview Protocol

Instructional Leaders. The team of science, mathematics, and engineering educator-researchers who were responsible for the design of the program and who would also become course instructors, felt that sophisticated understandings of the constructivist principles that underpin the nature of science and the science of learning was a critical component of preparing these teachers with the habits of mind and practice to serve as teacher leaders in STEM. Recognizing that identifying normative accounts of epistemology is critical for supporting epistemological development (Matthews, 2002, xv), we strove to ensure that the program courses both communicated and modeled an epistemological view on the nature of the discipline as "a socially and historically constituted meaning-making enterprise" (Rosebery & Puttick, 1998, p. 672). We support the authors' claim that without this view, "teachers and students…cannot genuinely understand what science is or how scientific ideas emerge" (Rosebery & Puttick, 1998, p. 672) and this perspective underpinned the choice of course readings as well as the teaching strategies employed by the instructors. It is important to note that our goal for the program focused less on moving the individual teacher participants from any participation position or dimension on a spectrum of epistemological sophistication, but rather to facilitate their recognition and understandings of fundamental epistemological assumptions that underlie approaches to sense-making (Kardash and Scholes, 1996).

Each semester of the first year of the program offered a complete, three-credit, content-focused course (physics in the fall semester, biology in the spring semester, and engineering in the summer semester). The three university professors who taught the content courses had extensive experience working in teacher education and were part of the planning process for developing the degree program. In addition to serving as the program coordinator, I co-taught each of the three courses of the first year and was the primary instructor for the *Professional Portfolio* course that was presented in the form of three single-credit-hour strands running *concurrently* with these content courses. This course was designed to provide opportunities for metacognitive reflection on the experiences in the content courses and their professional teaching practice in the context of weekly readings of research and scholarship about the nature of knowledge and how people learn. One of the primary objectives of the course (which was shared with the teachers) was for participants to develop a comprehensive, dynamic, personal philosophy of teaching and learning in STEM education. Philosophies were to be grounded in seminal theory and research on teaching and learning and developed through experiences in the program as well as in the classroom[3].

Subject Selection

The purpose of this research is to better understand how teachers make sense of transdisciplinary approaches to teaching in the STEM disciplines within the context of their professional commitments, as well as within the context of the STEM Teacher Leadership degree program in order to draw conclusions about their capacities and inclinations for embracing a shift toward a transdisciplinary model of teaching. I chose to

[3] See Appendix C: *EDCI 614 Developing a Professional Portfolio (Syllabus)*

specifically apply what Patton refers to as intensity sampling to select “excellent or rich examples of the phenomenon of interest but not highly unusual cases” (2002, p. 234). I sought cases that would yield substantive data, particularly in the form of detailed impressions of and experiences within STEM education (whether positive, negative, or neutral). Thus, the subjects of this case study have been chosen for their potential to provide rich data relevant to the research questions rather than the value they might have for “generalizing from a sample to a population.”

As Patton notes, “Intensity sampling involves some prior information and considerable judgment” (1990, p. 268) and thus I conducted significant exploratory fieldwork in order to develop a preliminary landscape of the variation among the teachers’ reports of their impressions and experiences. As the program coordinator and an instructor in this program, I have had the opportunity to become familiar not only with the resources through which they have been learning about STEM education, but to become acquainted with the teachers, themselves. I, therefore, have access to many resources through which to conduct this introductory fieldwork. For example, many of the assignments that the teachers completed over the course of the first year of the program were essays in the form of blog entries that have been posted on the teachers’ professional electronic portfolios. These assignments required the teachers to reflect on readings and class discussions regarding open-ended topical prompts such as “STEM and How We Learn,” “Engineering in STEM Education,” “Learning Objectives and Assessing STEM,” and “My Own Perspective on STEM.” The teachers were also responsible for designing, implementing, and reflecting on an integrated STEM lesson plan, as well as developing a web-based professional development activity intended to support their colleagues in STEM. Additionally, I was either present or a part of many discussions that the teachers held on these topics and have a general sense of the some of the social structures (particular school climates, personal histories, etc.) that might influence some of the teachers' proclivities when it comes to participating in discussions and activities.

I began my initial fieldwork by creating a detailed spreadsheet in order to systematically organize resources such that I could make explicit and thoughtful decisions on which teachers would yield productive data congruent with the study purpose. This document listed each of the twenty teachers currently enrolled in the program along with general demographic information including the grade level each taught at the time and the number of years each had been teaching. I then visited each teacher's online portfolio and read or reread blog post entries in which they shared their thoughts on the meaning of STEM education. I was attending to entries that seemed to present a relatively substantial amount of the teachers' own personal viewpoints, specific anecdotal experiences, and impressions of major claims made in the literature we had read. I expected that the teachers who were inclined to highlight their own viewpoints and provide supporting evidence would have greater potential to contribute data pertinent to this study than teachers who tended to rely heavily on paraphrased portions of published texts to explain their ideas. For example, in one of her blog posts on her understanding of STEM, one of the teachers, "Gabrielle," discussed the role of using real-world problems in order to help students develop critical thinking skills. This was not a topic that the teachers had specifically discussed in class or covered in course readings but rather seemed to derive from an intersection of her experiences as a teacher and her understandings of STEM. I flagged this excerpt as indicative of this teacher's potential as a productive research subject and this, along with other factors (explained below) led me to choose her as one of the subjects in this research.

I was also seeking intensive cases of subject candidates who, unlike Gabrielle, either did not seem to relate elements of transdisciplinary STEM education closely into their practice or expressed conflicting viewpoints on what it means to enact transdisciplinary pedagogies. This choice was made to avoid a participant sample that was heavily weighted toward energetic enactors of STEM. An initial exploration into blog posts submitted by another teacher, "Meg," indicated that from her perspective, the challenges to transdisciplinary implementation strongly influence her conceptualization of STEM. In other words, barriers to implementation were an intimate part of her understanding of STEM. Her writing also suggested that she did not consistently view transdisciplinary STEM as distinctive from what her district, which has been rolling out a new, more integrated elementary curriculum, already requires her to teach. Her propensity to write at length about how the concept of transdisciplinary STEM intersects with and even contrasts her views on classroom teaching, as well as her tendency to refer to her practice as being largely governed by outside influences such as the curriculum and her school administration, led me to flag Meg as a potential candidate for this study.

After re-familiarizing myself with the teachers' blog posts, I copied and pasted representative excerpts from these online essays to the spreadsheet under a column titled, "Potentially Relevant Evidence/Examples from Blog Entries." Teachers for whom the excerpts reflected a relatively strong perspective, whether that perspective was interpreted as enthusiastic and supportive of STEM *or* disaffected and skeptical, were considered potential candidates.

I then reviewed the transdisciplinary lesson plans that each of the remaining candidates had completed. Again, I was seeking examples that indicated the teacher would potentially yield rich amounts of data. I highlighted lessons, for example, in which teachers gave detailed descriptions of the reasoning behind the pedagogical strategies that they included in the plan. For example, Gabrielle, created a lesson plan designed to support her students in developing a better understanding of Earth's systems, specifically focusing on how and why scientists collect and study information on weather patterns. Her students were tasked with using elements of the engineering design process to construct a technological tool that would allow them to measure wind speed. In her plan, Gabrielle explained, "Some students may choose to create other products that look different from anemometers but as long as they have a way of measuring the wind speed, it is completely acceptable!" I interpreted this as indicating that Gabrielle may be privileging the students' creative agency in designing a tool that would accomplish the goal over their abilities to follow a prescribed procedure. I was curious to learn if this is a philosophy she consistently applies in her teaching practice or if it is something she considers an element of integrated STEM. This lesson excerpt lent further indication that Gabrielle might be a productive subject for this study.

In reviewing these lesson plans, I was also attending to evidence for approaches that seemed to inconsistently support transdisciplinary pedagogies. Meg, for example, created a lesson that would allow her students to use principles of engineering to design a 'solar oven' that could be used to cook food in the absence of electricity or fire. Her plan included several dynamic essential questions that, according to the assignments, were intended to be student-friendly, open-ended questions that provoke inquiry about the core concepts for the lesson and/or unit. Her questions included:

- How is evidence used to determine a change in temperature?
- How is heat energy transferred?
- How can tools, materials, and skills be used to carry out a task, conduct an investigation, or address a problem?
- How can the engineering design process address a problem or improve an idea?
- What steps are used to carry out the engineering design process?

These questions, interpreted in a certain way, represent a natural and engaging interdisciplinary approach to understanding the core ideas behind a human-centric problem and are reflective of the elements of transdisciplinary STEM teaching and learning discussed in the program. The description of the individual portions of her lesson, however, indicated that Meg intended to use a more traditional approach that did not seem to clearly match these questions. Many of her descriptions appear limited or indicative of teacher and textbook-driven pedagogies. For example, in order to understand what natural resources are available in a particular region, Meg noted that they would watch a video and "Review the difference between renewable, nonrenewable, and inexhaustible resources." The extent to which the students would be given meaningfully opportunities to engage in scientific and engineering practices for the purpose of constructing and critiquing knowledge as it pertained to these terms was not made clear in her plan. This led me to wonder how Meg was conceptualizing the role of the students in transdisciplinary STEM and what factors might be contributing to her understandings and pedagogical choices.

The initial steps in my fieldwork allowed me to narrow my selection sample from the initial twenty to a field of nine teachers. Next, I consulted with two instructors of the program in order to gather their impressions of the sample and select a group of four or five candidates. As a team, we examined the initial data from the blog posts and lesson plans along with impressions of contributions in class and potential willingness to participate in the study as primary factors for selection. I asked the instructors to particularly consider diversity in program 'buy-in' as perceived through their interactions with the teachers in their courses. This led us to add an additional column to the spreadsheet titled "Predicted buy-in." We discussed each teacher and gave him or her a rating according to a simple, three-point Likert scale ("high," "medium," "low") to represent our collective perception of the level of engagement with and commitment to the principles of STEM endorsed by the program. We also noted the grade levels taught and years of experience each teacher currently held, however, due to a relative lack of variation in these factors across the group- particularly regarding the number of years of teaching experience that each held (most teachers had between 2 and 7 years' experience), these were secondary considerations.

The chart below represents the final sample of teachers selected for this research. The chart includes the demographic information as well as our preliminary determination of each teacher's "buy-in." Each teacher was approached on an individual basis to explain the purpose, scope, and procedure of the study and to sign additional consent forms.

Table 2: Participant Information

Teacher	Grade level	Years Teaching Experience	Predicted buy-in
Meg	3rd	8	low
Kevin	6th	4	low
Gabrielle	4th	3	medium
Kate	1st	3	medium
Carrie	3rd	5	high

Data Collection: Individualized Protocols

Following subject selection, I developed a protocol to serve as a guide for the interviews, which included open-ended questions that were intended to provide a variety of access points into teachers' perspectives and experiences. For example, in order to collect rich, 'multi-faceted' data on teachers' impressions of the meaning of STEM I asked: *How would you explain what transdisciplinary STEM means to you? How does transdisciplinary integration compare to other forms of integration? Has your perspective on STEM changed over the course of your participation in the program?* I also tailored that guide to each teacher subject by including questions that pertained specifically to sections of blog entries and/or lesson plans. For instance, when preparing to interview Gabrielle, the teacher who discussed real-world problems and critical thinking skills in one of her online essays, I decided to include this selection from her blog entry as part of her interview:

> In one of your blog posts, you write, '*It is our job as educators to inform and expose our students to these real-world problems so that they can apply their higher-level thinking skills to creating a solution*.' Could you tell me more about what you mean by this? What are higher-level thinking skills? How do you think that real-world problems encourage or support higher-level thinking skills? Could you give an example?

The choice to include interview questions that were responsive to the individual teacher was made for several reasons. First, I felt that some of the ideas that the teachers had initially expressed in course-related assignments had the potential to add depth to the responses they would give during the interviews. In other words, asking questions about certain points the teachers had brought up in the past could serve as yet another access point into understanding the meanings they make with regard to the nature of, the challenges to, and implications for STEM. Additionally, as noted earlier, I had conducted rather extensive preliminary fieldwork into resources in which the teachers were describing their impressions of STEM. The majority of these artifacts were created as part of their graduate course work and I wanted the opportunity to see whether, under stimulated recall, the teachers would have similar or divergent ideas in the context of an interview that is taking place several months after the initial assignments were completed.

This might, in turn, provide evidence to better make sense of how elements of the degree program might influence the teachers' beliefs in particular contexts. The teachers' written essays and classroom artifacts would additionally be utilized in this study as secondary data sources to confirm and/or disconfirm interpretations and themes that emerge in the interviews.

Thematic Analysis

Several methodological frameworks and analytical protocols informed my approach to data analysis including Braun and Clarke (2006), Maxwell (2013), Sandelowski (1986, 1993, 2000), and Yin (1994). The qualitative content analysis began with a low-inference application of codes using the software program, *Dedoose,* and built toward more focused and theoretical categorization (Maxwell, 2013). I found the need to regularly return to the literature in order to make better sense of the data and inform the theoretical categories that developed. My analysis was, as described by Sandelowski, "reflexive and interactive," particularly as my treatment of the data accommodated insights from the literature (2000, p. 338). The following details the systematic approach that I applied.

Phase 1: Familiarizing Myself with the Data, Identifying Items of Potential Interest

I had begun to familiarize myself with the secondary data sources (blog posts, essays, class assignments, lesson plans) as part of the intensity sampling process. Once the sample had been determined and interviews conducted, I reviewed and transcribed the interviews and took notes on my preliminary reactions. I then compared these notes to those taken during the interviews themselves, and cross-referenced with secondary data sources, looking for initial points of consistency and/or conflict.

Phase 2: Generating Initial Codes

As I began to systematically classify interesting or provocative features of the interview data, a series of broad, initial codes were established in response to compelling or provocative sections of text. I applied a line-by-line analysis to each individual interview transcript searching for ‘units or segments of data that seem important or meaningful in some way” (Maxwell, 2013, p. 107). At this phase, I did not attempt to search for thematic connections or patterns *across* the individual cases; rather, I approached each teacher’s transcript as a unique and bounded artifact**.**

Phase 3: Organizational Analysis

From my initial examination of the data, I refocused my analysis at a broader level by searching for patterns or topics both within and across the individual cases under which I could organize the initial codes. At this stage, I continued focusing on low-inference thematic patterns. In other words, I used language that was as objective as possible to describe the patterns I interpreted as emerging. Through this process, I created both new top-tier codes as well as sub-codes for each. For example, initial codes of *connections to career-preparations benefits to learning*, and *benefits to society* were categorized under a top-level thematic code of *Affordances of STEM education*.

I found that in addition to incorporating elements of advantages or opportunities that STEM education affords, each teacher demonstrated consistent patterns of identifying and describing barriers, obstacles, constraints, or challenges to implementation of transdisciplinary STEM education. My initial fieldwork had also indicated that, at least for Meg, barriers were a significant element in her considerations of STEM. Now, within the interview data, each teacher participant, regardless of whether attention to barriers was elicited by the question, made references to them. This suggested that identifying obstacles to the practical application was a critical consideration for conceptualizations of STEM. In other words, for these teachers, theoretical rationales alone might not adequately convey STEM education in school contexts. While the identification and description of barriers to implementation were found across all cases, variations in the ways they would describe the constraints and their responses seemed to offer rich points for exploration.

Thus, in addition to *Affordances of STEM education*, *Barriers to implementation* and *Responses to barrier* emerged as top-level codes for my analysis[4]. I subsequently returned to the interview data from each teacher and first applied an analysis that focused on coding for affordances--which included both opportunities and advantages to this approach—as well as for barriers. At this time, I also created and applied descriptive sub-codes under each. For example, when asked early in the interview to describe what

[4] Other top-level codes emerge at this point however Affordances, and Barriers most relevant to the research reported here.

integrated or transdisciplinary STEM means to her, Gabrielle’s response included both affordances and barriers:

> OK basically TD STEM is um, I guess it's more student-driven learning, and it's kind of centered around where they want to take their learning and, also, makes that real-world connection which is really important when it comes to STEM education.
>
> I think the reason why people don't actually want to actually do it or teachers don't invest in it is because of the fact that it is student-driven and it's hard to give up that responsibility to the students and really trust them to know basically where they want to take it or where they're going.
>
> But I guess that's the magic behind it is you're not really sure where it's going to end up...[pauses] but then again, you know, of course, in our county we have to follow the curriculum and it's hard to have time for stuff like that. So it is hard but essentially, I guess it's what everyone strives to be moving towards, is, moving away from multidisciplinary and interdisciplinary and more towards transdisciplinary.

I identified three segments of the response that I would categorize under *Affordances* and sub-coded them per the specific advantage or opportunity that they referenced. I also noted two segments that could be considered *Barriers* and sub-coded them according to the specific type of barrier indicated. Table 3 illustrates the organization and application of coding analysis for this phase based on Gabrielle’s response above.

Table 3: Sample Organization and Application of Coding Analysis

Datum	Thematic Code	Sub-Code
"more student-driven learning"	Affordances of STEM	connections to learning
"centered around where they want to take their learning"	Affordances of STEM	connections to learning
"makes that real-world connection"	Affordances of STEM	connection to the real-world
"it's hard to give up that responsibility to the students"	Barriers to STEM	requires the transfer of responsibility to students
"[it's hard to] really trust them to know basically where they want to take it or where they're going"	Barriers to STEM	requires trusting students with learning progressions
"But I guess that's the magic behind it is you're not really sure where it's going to end up...[pauses]"	Response to Barrier	Whether it's a barrier is a matter of perspective
"but then again, you know, of course, in our county we have to follow the curriculum"	Barriers to STEM	External requirements play out as restrictions
"and it's hard to have time for stuff like that."	Barriers to STEM	STEM requires more time/time in addition to time spent on required curriculum
"So it is hard but essentially, I guess it's what everyone strives to be moving towards, is, moving away from multidisciplinary and interdisciplinary and more towards transdisciplinary."	Response to Barrier	I understand the barrier but it is/should be reconcilable

Phase 4: Reviewing Potential Themes

The extensive attention that these teachers were giving to barriers led me to return, at this point, to the literature in order to review prior research and theory regarding barriers to education reform. I found Anderson's work (2002) on inquiry-driven science education reform to be particularly productive for making sense of my data. Anderson notes that attention to "barriers and obstacles that must be overcome for teachers to acquire an inquiry approach to teaching" is common, however he argues that these constructs imply factors that are *external* to the individual teacher and suggests the addition of the word, 'dilemma," to categorize *internal* factors which include "beliefs and values related to students, teaching, and the purposes of education" (2002, p. 7). Use of the word, dilemma, to refer to particular challenges has been used by scholars for decades to make sense of and predict successes and deficiencies regarding of education reform (Blumenfeld, Krajcik, Marx, & Soloway, 1994), however the distinction that some challenges are connected to personal values, beliefs, and perceptions, while others are factors of institutional norms and structures of schooling, was particularly productive in that it provides an additional lens through which I am able to view the nuanced differences in the ways that individual teachers in my study describe barriers.

Phase 5: Defining and Naming Themes, Categorizing Data

Whether a teacher described a challenge to implementation in terms of an internally-influenced dilemma or an externally-controlled barrier had become a prominent theme in support of understanding my research question, which sought to identify and understand factors that mediate these teachers' capacities and inclinations for embracing a shift toward transdisciplinary STEM education. To best make sense of the individual cases through this thematic lens, I created a series of comprehensive categorical coding matrices[5] to organize the data of all teachers that focused specifically on sections of text that were coded as "Barriers.[6]" This allowed me to more closely cross-analyze the ways that each teacher described a particular barrier/constraint and allowed me to further focus attention on the teachers' *responses* to the barriers. This, in turn, allowed me to identify points at which each teacher seemed to characterize the challenge as an externally controlled barrier, an internally influenced dilemma or, perhaps both. I then broke the cross-case matrices into individual data categorization charts for each teacher (see Table 4 below). Here, I found responses to an identified challenge that clearly implied a solution to be particularly informative for making the internal-external distinctions. For example, Kate explains that an advantage of a traditional approach to teaching is that it aligns with a common mindset held by most teachers that the approach to their work either must be or *is* inherently "organized" and follows established patterns and routines, and thus a shift to more blended learning approach might be 'intimidating' to these teachers. She also notes here that there is not much training available to teachers.

I had initially coded this section of text as representing three distinct barriers: *TD STEM is at odds with instructional/professional requirements/institutional norms, TD*

---

[5] See Appendix D: *Transdisciplinary STEM & Teacher Beliefs: Sample Categorical Coding Matrices: Barriers/Constraints I and II*

[6] Note: at this point in the analysis, I continued to use word barrier to include that which might later be categorized as an external barrier or internal dilemma. I would tag sections of text for these nuanced distinctions in the next phase of analysis

STEM requires more training, and *TD STEM is intimidating to teachers.* I also attached a top-level organizational code of Response to Barrier with sub-codes *I understand the barrier and I have a solution,* and *the barrier is a result of status quo.* A closer analysis through the internal dilemma/external barrier lens, however, led me to make more nuanced sense of the two parts of the statement (challenge/constraint/barrier and response). The conflict that she identifies may stem from her perspective of teachers' mindsets being relatively inflexible, however, being a 'mindset,' it is under the control or at least strongly influenced by the individual. Thus, this could be considered an internally influenced dilemma rather than an external barrier.

I also considered the solution that Kate offers in her discussion of the particular challenge of teachers' mindsets. In isolation, a statement noting the lack of adequate training opportunities might suggest that Kate views the challenge to be an external dilemma in that the solution of more training is circumstantial and out of the control of individual teachers (in this case the teachers that Kate is referring to as well as Kate, herself). That the solution of additional training is being offered in the context of what she describes as incongruous mindsets, *however,* suggests that she does view the core issue as an internal dilemma that could be overcome with external support.

Table 4: Sample Data Categorization Chart -Individual Teacher

Barrier/Constraint	Agency over /Response to Barrier	Kate	Notes/Themes
Barrier: TD STEM is at odds with instructional/professional requirements/institutional norms **Barrier**: -requires more training*** **Barrier** It's intimidating to teachers	I understand the barrier I understand the barrier and I have a solution Barrier-fault is in current situation-NOT in STEM	A: Do you see particular benefits for that approach versus the integrated approach? Or...maybe um... [00:06:35.26] C: It's definitely easier for the teacher to be able to figure out one science lesson, one technology lesson. [00:06:42.02] I think that a lot of things like that are already out there. I mean we do teach science as just science already and we do teach math as just math. [00:06:49.15] So a lot of the stuff already exists in those kind of lessons. Um. [00:06:55.16] organizational-wise, it's probably a little bit easier as well. Just thinking in a uh.. you know a very [air quotes] "organized...." like a , teacher's mindset you know, they're typically very "this is my lesson plan, [makes a chopping gesture with one hand against the other] I do this, I do this, I do this. I do this in the morning, and this in the afternoon" so it's probably like a bit easier to plan for and just teacher experience-wise, [00:07:20.25] **there's just not much training**-I don't know if any undergrad programs train for teaching the STEM integrated, transdisciplinary lesson and probably people are intimidated by the idea of attempting that or going for it because, I mean, besides maybe a literacy block that blends reading and writing, there's not really a time during	Carrie also said it's easier She's not so much saying that it REQUIRES more training as much as she's saying that there ISN'T that much training. **--This challenge is an internal dilemma-** teachers' mindsets **This challenge is an external barrier**: there isn't much training

		the day at school where it is using all the different content areas and blending it into one learning approach. **So so it's new**. So that would be, you know, kind of harder for teachers' mindset to get used to.	One solution: external availability of more training (more education about it should be made available to teachers) to support internal shifts

I employed this approach of analyzing the individual data sets for each teacher in terms of identified barriers and the responses (e.g. suggested solutions) to those barriers to determine the relative frequency with which the challenges that they identified were framed in terms of internal dilemmas or external barriers (or both). As a result, the following connected themes emerged: *Barrier (External)*, *Dilemma (Internal)*, *Solution is External*, *Solution is Internal.*

Phase 6: Identifying Epistemology Markers

The final stage of my analysis consisted of a review of the data points pertaining to ‘barrier’ and ‘solution’ statements for indications of epistemological stances that do and do not align with the constructivist perspectives underpinning the transdisciplinary approach. The models of Schommer (1990) and Hofer and Pinrich (1997) significantly informed the ’markers’ that I flagged as evidence of epistemology (for example, evidence that the teachers view knowledge as certain, fixed, or tentative and whether sources of authority for knowledge and validation are considered external or relatively independent). I also applied Elby and Hammer’s framework for epistemologies as contextual resources when determining the extent to which each data point aligns or does not align with constructivist perspectives as well as to its contribution to the relative constructivism of the teacher’s personal epistemology in the context of considering the implementation of transdisciplinary STEM education. This meant, for example, that a statement that was marked as reflective of an epistemology that is commonly viewed as reflective transmissionist epistemologies, might, in fact, be considered constructivist given its productivity in the context of the teacher’s claim or idea. For example, in Kate’s discussion of teachers’ “mindsets” as being a source of difficulty for STEM implementation described above, she notes that there was not much training available to teachers.

> …organizational-wise, [traditional approaches to teaching is] probably a little bit easier as well. Just thinking in a, you know, a very [air quotes] "organized...." like, a teacher's mindset you know, they're typically very "this is my lesson plan, [makes a chopping gesture with one hand against the other] I do this, I do this, I do this. I do this in the morning and this in the afternoon" so it's probably, like a bit easier to plan for, and just teacher experience-wise, there's just not much training-I don’t know if any undergrad programs train for teaching the STEM integrated transdisciplinary lesson.

In addition to coding this statement for *Dilemma-Internal* as described above, I coded it as reflecting a solution to the barrier that she proposed: the challenge of incongruous mindsets may be addressed through more training. Epistemologically, the deference to an external authoritative source of knowledge, such as undergraduate teacher preparation programs, for providing a solution to a challenge might be coded as more reflective of ‘transmissionism.’ These trainings are, after all, invariably designed and delivered by professors, instructors, and other individuals who are not current classroom teachers, are thus not considered peers to the teacher candidates receiving the training, and are, as such “outside authorities.” Kate’s statement, however, is being made within in the ‘real-life’ context of professional teaching practice in which it is *customary* for external authorities to be the source of knowledge pertaining to sharing professional information and strategies with teachers through ‘professional development’ activities. Kate, herself, is currently enrolled in a professional learning program designed to help her develop more sophisticated understandings of STEM and she notes several times throughout the discussion that the program has influenced her perspective—her “mindset.’ While her statement may superficially seem indicative of deference to authority, a closer consideration indicates that she is acknowledging an authority as a source of information and inspiration that can help teachers to construct a new mindset, rather than positioning the authority as a source of *knowledge*. In other words, she is using an ‘expert’ as a resource for building understanding, which reflects the application of constructivist epistemological resources. Thus, Kate’s own consideration and ‘uptake’ of professional development as an opportunity for potentially (re)constructing her ‘mindset’ rather than as an opportunity merely to absorb knowledge led me to code Kate’s call for more professional development as aligned with a constructivist view of teacher learning.

Summary & Statement of Limitations

This study was designed to better understand factors that mediate the inclinations and capacities for embracing a shift toward transdisciplinary education of a group of teachers enrolled in a STEM Education Leadership graduate degree program. As such, my primary goal was to understand the broader and more familiar phenomenon (Merriam

1995) of teacher ‘buy-in’ and take-up’ of education reform in the relatively unfamiliar context of a sample of teachers learning together in a program designed to help them transition to constructivist driven approaches to teaching through transdisciplinary STEM pedagogical models. In the processes of analysis, I identified a previously underexplored link between two factors that influence teachers’ uptake of reform in the context of transdisciplinary STEM: constraints and epistemological beliefs.

There are necessarily limitations in all designed studies (Anderson, 2010; Marshall & Rossman, 2013), and, as qualitative research, the trustworthiness of this study is dependent on how well my report communicates what I designed the research to do (Merriam, 1995) and in my transparency about processes by which I make claims. My involvement in the development of the STEM degree program and my relationship with the teacher participants (both as one of their instructors and as the program coordinator) inevitably has contributed to the bias and lenses that I brought to the study design, data collection, and analysis. While I am sure that there are elements of influence that I have missed or misunderstood, I have nevertheless sought to be highly conscious of and sensitive to this issue and to work to address it through rigorous methodology and throughout, transparent reporting.

Participants were purposely chosen for their potential to contribute rich data (Maxwell, 2013) and thus an understanding of the teachers that extended beyond demographics was critical, however, it was also important that I engage other faculty advisors to inform the selection process to reduce the influence of my own biases on the selection. While the interview protocol I designed was based on a standardized set of questions, I recognized the possibility of my relationship with the teachers influencing the way that I posed questions to the teachers as well as the ways in which they answered. I felt it therefore important for me to include raw samples of transcript in this report that include the exact language I used to ask the questions and intentionally included all speech disfluencies in the teachers' responses to be transparent about the role I played in the asking and to give a fuller illustration of the answering. It was further important that I triangulate the data collection (Maxwell, 2013; Shenton, 2004) to reduce the risk of associating pieces of interview data with codes biased by my history and relationship with the teachers as well as to reduce the risk that the associations were heavily skewed by the teachers' impressions of me and our relationship at the time of the interview. Written reflections that the teachers had submitted for the graduate program, which provided for additional samples of direct statements of beliefs, and the lesson plans that teachers designed and submitted, which communicated more indirect clues about their epistemologies, were very productive supporting my analysis, and I include several examples of this triangulation throughout this report.

My relationship to the participants and context undoubtedly influence aspects of this study, as such I provide detailed, thorough descriptions of my approach to data collection and analysis in order to be transparent about my "interpretations of reality" (Merriam, 1995).

Results & Discussion

My introductory fieldwork into blog entries and other assignments that the teachers had completed as part of their coursework led me to expect that the teachers' descriptions of the affordances of STEM education would be data-rich indicators of the personal values and beliefs that may be influencing their conceptions of transdisciplinary pedagogies and, subsequently, their propensities and practices. Over the course of our interviews, each teacher did indeed identify benefits, positive outcomes, and opportunities for STEM. A cross-case analysis of the data relevant to each teacher indicated that these affordances were described in terms of themes, which could be broadly classified as benefits to the learner, to the institution of schooling, and to society. Each teacher's individual view on the positive 'inputs and outputs' of STEM undoubtedly contribute to his or her likelihood of meaningful and sustained implementation. However, in nearly every instance of the identification of an affordance, the teacher also addressed a potential or existing barrier to implementation. This was prevalent to the extent that identifying and considering challenges to implementation was a significant element in each teacher's conceptions of the nature and purpose of transdisciplinary STEM education. The descriptions of barriers to reform as well as the teachers' subsequent responses to those barriers seem to both reveal and influence these teachers' personal epistemologies on the nature of knowledge and knowing within STEM disciplines, which, in turn, may be a strong indicator for how they approach teaching and learning in school-based science and STEM. Perhaps unsurprisingly, and to varying degrees, each teacher noted that transdisciplinary STEM is distinctly different from the institutional norms of professional teaching--in other words, the 'status quo'-- and this code emerged as the most frequent descriptor of barrier/dilemmas, often applied in conjunction with other, more specific barrier/dilemma codes. For example, in many instances, descriptions of this challenge were linked to issues of teacher comfort levels and confidence facilitating STEM as well as the time commitments for pre-planning and implementation that STEM requires.

As noted previously, my methodology consisted of selecting all sections of interview texts that were coded as broadly representing a 'barrier or dilemma,' and more closely analyzing the statements to determine whether the teacher was describing the constraint (and, if given, the response or solution to this challenge) in terms of internally-influenced dilemmas or externally-controlled barriers. I then sought to make claims regarding the proclivities toward embracing the shift toward transdisciplinary STEM that each datum indicated. Finally, I reviewed the data for evidence of the use of epistemological resources in order to make claims about the relative alignment of the teachers' personal epistemologies with regard to the constructivist learning principles that underpin the model of transdisciplinary STEM promoted by their degree program.

In the discussion of results that follow, I focus on the epistemological stances that were revealed in this barrier/dilemma category, "*TD STEM Is 'At Odds With' Institutional Norms of School and Schooling*," and the two coding categories which emerged most frequently either alongside or separately: "*Teacher Comfort Levels,"* and *"STEM Requires more Planning/Instructional Time."* My analysis indicates that Carrie and Kevin more frequently described challenges to STEM implementation in terms of internally influenced dilemmas and, furthermore, made more frequent use of constructivist epistemological resources in their considerations. Data for these teachers also indicated that they had already begun to make a shift toward transdisciplinary teaching practices themselves, suggesting that the relative extent to which the epistemological resources that they applied align with those underpinning transdisciplinary STEM is a strong indicator of inclination to implement. By contrast, analysis of data from Meg's interview indicated that she consistently applied epistemological resources that are more reflective of 'transmissionist' views in the description of barriers over which individuals-- herself included-- had little control. Her responses further imply reticence on her part to authentically embrace transdisciplinary STEM as well as skepticism for widespread successful implementation. There is strong indication that the misalignment between the personal epistemologies that mediate her conceptualizations and those that underpin transdisciplinary STEM are contributing to her implied disinclination. Gabrielle and Kate each applied both constructivist *and* transmissionist principles in their sense-making around STEM. Gabrielle frequently used constructivist resources to reconcile dilemmas that stemmed from transmissionist perspectives, indicating that she was productively working toward epistemological alignment and is likely to continue to embrace STEM. Kate consistently activates constructivist principles to understanding the nature, value, and purpose of STEM, however, tends to take a more epistemologically neutral, yet 'transmissionist-leaning' stance when discussing barriers to implementation. In other words, she has 'bought-in' in theory, perhaps, but not yet practice. Consistent with all cases, is that epistemological beliefs were tightly entangled with each teacher's conceptions of obstacles as dilemmas, barriers, and/or constraints as well as with the associated solutions.

Carrie

As detailed in the preceding Methodology section, Carrie was selected for participation due to a perception that she is representative of a teacher who has ‘bought-in’ to the transdisciplinary STEM approach. Data collected for this project strongly supports this perception. During her interviews, Carrie consistently indicated that she strongly values STEM for its potential to better support long-term school goals for citizenship and society. She explains that she believes the goal of school is “to prepare the children to be citizens that participate and give things back to society whether it's through their career or volunteering, or something. So, just equipping them with the real-world skills that they need, that maybe have nothing to do with academics, more of, like, the social-emotional. Like collaboration, um, the willingness to take risks.” But she also attends to the value of STEM for supporting constructivist principles for how children learn. For example, when asked to describe what she sees as some of the affordances of traditional, [objectivist, transmissionist] approaches to teaching and whether she sees productivity in those approaches, she responds with evidence that she attributes to ‘learning theory’ that was discussed in the graduate program. She says,

> No, it's not because you're learning it in isolation. So, in terms of the learning theory that we talked about, students learn best when they are making connections, because I think it helps them remember better when they are putting it within their own, like, network, in their mind, like the organization of learning in their mind. So, if they can't tie it to anything or connect it to anything, I don't feel like they will remember it. And if they can't see why it's relevant to what they'll be doing in the future, ‘Why do I need to learn it anyway?’ You know, ‘I'm just going to learn it to get this grade and then I'm going to move on.’

This statement suggests that Carrie is reflecting on information, theories, and ideas that were discussed during the program[7] and applying them to her considerations of STEM in this context. In this way, she is explicitly valuing constructivist epistemological principles, acknowledging them as learning theory, and authentically modeling their application.

Carrie also frequently leveraged these principles in her reasoning and responses to potential barriers to implementation. For example, when asked to describe the kinds of teaching styles (a phrase that she had used in an earlier response), beliefs, or practices that she thinks would make it easier for a teacher to embrace STEM, Carrie offers that being ‘teacher-centered’ might make it difficult for teachers to embrace STEM given that it requires active student learning, which contrasts with a teacher-centric approach. She says,

> Um, well the teacher has to be comfortable releasing some control. I know that some teachers are very teacher-centered, as we've talked about in your class, and I think that if you're a teacher-centered type of classroom, that you're going to have a harder time embracing the STEM, because to do it authentically, the students

[7] Likely selected readings from Donovan, M.S., and Bransford, J. (Eds.). (2005). *How students learn: Science in the classroom*. Washington DC: National Academies Press.

See citations for specific readings in Appendix ___the *Developing a Professional Portfolio* Syllabus. Note that these readings were assigned and discussed in class more than a year before these interviews took place.

> have to guide the instruction, they have to be involved, it can't be passive learning, it has to be active learning.
>
> So, I think that if you're really comfortable with, kind of...if you're the kind of person who likes it to go your way and you know exactly what's going to happen next, then I think it's harder for you to become comfortable with integrated STEM. And if you're comfortable, kind of letting go of the reins and letting the students, you know, be loud, be messy… but you know, learning is messy. I feel like if you have a hard time accepting that, that's going to be hindering you from really integrating STEM effectively.

Carrie recognizes that ‘teacher-centeredness’ is a potential barrier to STEM implementation; however, she uses reasoning based on principles for learning to respond to that barrier. Her frequent reference to a feeling of comfort suggests that she views this barrier as an internal dilemma over which the teacher has--and *should* have--agency to resolve.

Carrie also associated a dilemma with teachers’ individual feelings and perceptions when explaining her views on the role of teacher content knowledge, pedagogical knowledge, and ‘pedagogical content knowledge.’ She points out that STEM has the potential to be intimidating, and suggests that teachers’ own experiences as students may be contributing to their discomfort teaching STEM subjects. She then proceeds to offer a tangible solution to such a dilemma and describes it in a way that indicates she is continuing to apply constructivist principles to her considerations. She says,

> I feel like that's why a lot of teachers are intimidated by STEM. So like, when you say STEM, I think they're just kind of like, "Aaah!" Like, 'What's that?' Or they're not really sure how to approach it. And I think I wrote about that in one of my blog posts, too, how I think that teachers, a lot of the time, stay away from things they're not comfortable with. So I think, words like "STEM," or maybe the subjects of science and math in particular, and engineering are just intimidating for a lot of teachers because they don't, they're like, "Well I wasn't good at math in school" or "I wasn't good at, you know, science in school.'

Carrie goes on to explain that teacher comfort is "a barrier that we need to overcome" and admits that she's "not sure how to do it." She initially considers that "professional development for existing teachers or pre-service teachers, maybe more courses to get them more comfortable" with STEM could be a solution to the barrier. She then goes on to suggest that another solution may be found in "bringing more STEM professionals into the classroom and having kind of a partnership with the teacher so that teachers would feel that they had someone there to support them in terms of the content knowledge." When asked how that solution might fit in with the current 'status quo' of schooling she responded,

> Oh, [laughs] I don't think it fits in at all. I mean, I don't think schools really try to set up partnerships with STEM professionals. I mean, my school has annual events like career day, and so, you know people will come into the class and speak about their job, but they're not there to support a teacher's lesson. So, I think to be really effective it would have to be an on-going partnership throughout the year where the STEM professional would kind of know what was going on. It would kind of be like an ideal team because the teacher would have all the pedagogical knowledge and then the STEM professional would have the content

knowledge to support the teacher in case the teacher did feel kind of uncomfortable.

The way that Carrie describes the barrier of teacher comfort levels indicates that she views this as an internal dilemma that may be tied to teachers' perceptions of their own abilities in STEM when they, themselves, were students. The first solution that she considers, professional development, is largely an external one and, in isolation, it may suggest a displacement of responsibility for addressing the barrier to an external authority and implies a perspective of knowledge as 'propagated stuff.' In context, however, her explanation that professional learning could "get them more comfortable with it," suggests that Carrie views increased content knowledge as *a means to* the end of increased comfort for teachers. Likewise, her subsequent solution of bringing in an expert, a "STEM professional," suggests deference to authority; however, she states that the professional would have the content knowledge to *support the teacher if* s/he felt uncomfortable and thus suggests a proximal developmental perspective on collaborative learning and teaching. She's suggesting that teachers' intimidation with STEM might be relieved through a partnership with more knowledgeable professionals, rather than framing the solution in terms of the STEM professional being positioned as an available authority for transmitting knowledge. She further notes that this suggestion runs counter to the way that her school operates, but does not let the contradiction hinder her promotion of the solution. She reflects on ways that her school might come close and provides an extended explanation of how her suggestion could more productively meet the particular challenge of teacher confidence and comfort. Carrie's explicit claim here that “barriers” must be “overcome” and her thorough description of potential solutions (note that she spends significantly more time attempting to identify and make sense of solutions that she does to the challenges) again suggests flexible application of epistemological resources to productively make sense of both challenges and solutions. The epistemological resources that Carrie uses to make sense of STEM closely align with the complex constructivist epistemologies that underpin transdisciplinary STEM, which likely contributes to her readiness to authentically embrace transdisciplinary STEM as a model for her teaching practice.

Kevin

Kevin had been selected for participation in this study as a representative of the middle school perspective and because, while his participation in the program indicated that he enthusiastically values science, engineering, and mathematics, his instructors held the impression that his ‘buy-in’ for student-centered, integrated instruction at the beginning of the program was relatively low, as was his confidence in the ‘necessity’ for transdisciplinary reform. As the year progressed, however, assignments that he completed for the graduate program revealed that he values and applies constructivist principles for supporting meaningful, inquiry-driven learning. His interview data further supports the claim that Kevin applies constructivist epistemological resources in his consideration of and learning about STEM, its affordances, and challenges to implementation.

Like Carrie, Kevin spends considerably more time discussing and exemplifying solutions than challenges and one of the more prominent challenges that he frequently reiterates is that of generating widespread buy-in among teachers, particularly as a result of the current structural norms of schooling. In describing this challenge, Kevin tends to reflect on and use his own experiences to both understand the dilemma and to consider solutions. This suggests that he views this challenge in terms of a dilemma that is both internally-influenced--and influence*able*-- rather than an externally-controlled barrier, which may be explained by the congruence of the epistemology that mediates his beliefs with that which underpins transdisciplinary STEM.

Kevin noted that teachers might be intimidated by STEM, particularly due to how different it seems to the normative practices of traditional schooling and school culture. Kevin, who teaches in a middle school setting in which each subject is typically taught by a different teacher, notes that one of the advantages of that system is that teachers become “experts” in their respective subject area, but notes the accompanying drawback that this might result in teachers believing, perhaps mistakenly, that they are unable to recognize connections between subjects and take up an integrated approach. He says,

> Yeah, I mean I think in any way of teaching there's gonna be positive and drawbacks. Positives: you have people who kind of become experts in their subject area and teach that one subject and you know I know I hear English teachers all the time, say I’m glad I don’t teach math and math teachers say I'm glad I don't teach English. So they're comfortable with the subject area they are teaching but at the same time, they don’t even realize, probably how easy it would be to integrate other subjects into what they're already doing…

Kevin is suggesting that the structure of schooling in middle school settings--a factor that individual teachers have little control over--contributes to the internal dilemma of being intimidated by disciplinary integration. He understands the intimidation that teachers feel and suggests that reconciliation may be found in considering situations that students will likely face upon graduation and that siloed approaches to learning, particularly those in which disciplines are literally separated into separate rooms, might put students at a disadvantage. He continues,

> …which for the students is definitely a drawback, like I said earlier, most careers are going to require you to use most of the subjects that you get in school and um to, kind of downplay that, and have them go from room to room and talk about completely different things, I think is a mistake. I don't think any job is like that today and if there is, you know, it's few and far between.

Kevin goes on to validate the potential intimidation that teachers might feel when asked to adopt integrated pedagogies but uses his own experience as evidence that there are ways to resolve the dilemmas that might be problematic. He then offers an incentive for facing the dilemmas in the form of student benefit.

> Yeah, to pitch the idea to a teacher that, you're going to all of a sudden now teach every subject and be a master of every subject and integrate that all the time, it SOUNDS overwhelming. But you know, from my experience in doing it, it's you know, it's really not that bad. It's something that you, I think you find what you're most interested in about what you're teaching and I don't know, I kind of find what works for me and then find how I can wrap all the subjects around that. And I don't know, the kids seem to benefit from that and as long as I'm excited about it, they're always excited.

Kevin's solution of considering the effects on students and that each teacher should find "what works" for him/her and progress from there indicates that he is consistently applying constructivist epistemological resources to considerations of teacher learning. He's explaining that he recognizes that individual teachers have control over their perspectives and comfort levels and approaches to integrated STEM.

Artifacts from his participation in the graduate program such as the "Integrated STEM Lesson" plan that he designed further indicate that Kevin carries constructivist principles through to his approaches to student learning as well. For example, Kevin's lesson was designed to support the NGSS Middle School Life Science Standard, *Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem,* as well as the Common Core State Standard for Mathematics, *Summarize numerical data sets in relation to their context,* and the Common Core State Standards for English/Language Arts, *Cite specific textual evidence to support analysis of science and technical texts* and *Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually.* Kevin designed his lesson to situate learning associated with these standards in the context of factors that influence population dynamics of organisms in their local environment. The entirety of the lesson reflects the perspective that knowledge is constructed, requires student agency, and is communicated in a variety of learner-centered ways. In the overview of the lesson, Kevin explains that students "will need to start with a review of the following previous classroom topics: ecosystems, imbalances, cause-effect relationships, and chain reactions." Rather than relying on transmissive, text-to-student exercises, Kevin provides examples of activities to help students review that are collaborative, student-centered, and constructive. For instance, he suggests,

- Students can draw a picture of a habitat outside the school while taking a hike with the class. The teacher can encourage students to include biotic and abiotic factors in their drawings.
- After students develop an accurate representation of their observations, the teacher can ask students to draw the picture again with a limiting factor incorporated. These limiting factors can include natural disasters, various forms of pollution, human influences, overpopulation of a species, extinction, and any other "causes" the teacher would like students to consider.

In this 'review' activity that is intended to set students up for the STEM investigations, Kevin has described an opportunity in which students can apply previously constructed understandings to making sense of the more immediate context of school-yard habitats and communicate their understandings through drawings, shifting authority for the communication of understandings to the students. Kevin clearly indicates that the students will be accountable for accuracy, but that accuracy seems to be calibrated in relation to the "representation" of observations made by the students, rather than the teacher or curriculum. The second part of the review then asks the students to adjust their drawings to represent one of the 'limiting factors' he has suggested. Again, though the teacher controls the choice of 'factor,' the students retain authority for applying their own understandings of the effects of that factor on the ecosystem that they are using as the context for learning. The main lesson activity likewise provides opportunities for students to explore ecosystem dynamics from a variety of student-directed investigations into the question, *how can the elimination or addition of an organism to the food chain of a given ecosystem impact the organisms with an already established habitat?* He stipulates that through the investigation, students should work in groups to identify a population of organisms that faces habitat loss. He leaves it open to the group to choose the organism and habitat, but the suggestions he supplies (white-tailed deer and the eastern oyster) suggest that he intends for the investigations to be relevant to the local region, which increases the likelihood that the investigations will be relevant and meaningful to the students. His notes indicate that this choice is both thoughtful and intentional: “Providing resources will be up to teacher discretion to ensure students have enough freedom to have a personal engagement with the organism they ultimately identify.”

He indicates in his plan that after selecting an organism, students will research the organism and ecosystem, focusing on cause-and-effect relationships between the organism and factors threatening or impacting its survival. Even though the students will likely be turning to external authorities as sources of information in their research, the students are given agency over the questions they believe will be most productive to their investigation.

Kevin’s plan describes a lesson that integrates the core ideas and practices of multiple disciplines in the service of making sense of local, life-relevant phenomena. It demonstrates in a clear and convincing way how addressing more than one learning objective at one time through integrated, student-centered inquiry—a dilemma that he mentioned other teachers might reasonably identify-- is not only possible but productive. It is important to note here that, rather than serving as an exemplary, or “best” lesson, the plan discussed here is an example that typifies Kevin’s approach to building learning experiences for his students.

Meg

The data collected from interviews with Meg rather sharply contrast with those of both Carrie and Kevin, who consistently employ contextual epistemological resources that align closely with the constructivist principles underlying transdisciplinary STEM instruction to make sense of STEM and challenges to implementation and seemed to have embraced a shift in their own practice. As with the other participant interviews, the descriptions of challenges that Meg provides largely relate to the contrast between STEM and traditional approaches to schooling; however, whereas Carrie and Kevin tend to describe these contrasts in terms of dilemmas that must be resolved, Meg’s responses reflect a perspective that individuals have very little influence over existing school structures. She also frequently defers and deflects agency to unnamed authorities, indicating that her personal epistemological perspectives may diverge—in some contexts sharply—from the constructivist epistemologies of STEM.

For example, when responding to an opening interview question asking her to describe her experience in the degree program so far, Meg shared that she had hoped for more ‘hands-on’ experiences and seemed to disapprove of the attention that the program devoted to theory and scholarship. She says,

> Well, it's not exactly what I had expected I guess. I guess I had thought...we would get to experience what STEM is like more, rather than just, you know, like, the research behind it…and talking about how why it's beneficial because we KNOW it's beneficial and we know that, I mean, we know that it needs to be done because it's part of the curriculum.
>
> So, I thought that it would be more hands-on and we'd actually see it more in action and be able to experience it and, um. Yeah, so I thought it would be a lot more hands-on cause that seems to help me more, and cause then I'll be able to apply it in the classroom and at least have an idea of how to make my lesson more STEM-centric versus just knowing the theories and research behind why it's good. Because we already know it's important [laughs].

While dismissing potential value in theory and research for understanding and implanting STEM, she implies that she was hoping for more literal examples of activities that she could immediately use with her students. A preference for activities that are created by external, presumably 'expert' sources that she might directly transfer to her students suggests passive acceptance rather than critical construction. Furthermore, Meg speaks with certainty that STEM is important and "needs to be done," not because of intrinsic affordances, but because it is "part of the curriculum." In this moment, she is deferring the designation of importance to external authorities: the program and the curriculum. Deference to the authority of the curriculum and the assertion that the curriculum supports STEM perspectives is a consistent theme in her blog posts, as well. For example, when reflecting on the principles of learning described in a chapter of *How Students Learn: Science in the Classroom* (NRC, 2005), Meg writes:

> Exploration and inquiry is a lot more than simply presenting facts and spoon-feeding information to students. It allows students to question and discover answers and adjust their own thinking as they go along... Students are better able to apply their learning this way, rather than spitting back information learned through rote memorization. The new curriculum attests to this framework.

Here Meg seems to be reflecting on the relationship between factual information and conceptual understandings, presents memorization as an unfavorable approach to learning, and notes that students are better able to 'apply *their* learning' through inquiry. In many ways, these perspectives seem consistent with constructivist principles of the program, which were described in the assigned reading. However, while she is working to explain her interpretations of these learning principles in a context that is familiar and comfortable to her (math), she finds the need to credit *the curriculum* with being able to 'attest to' the approaches she describes. The reference to the curriculum may be an effort to give 'credit' to it for supporting principles that are clearly valued in *How Students Learn* (a resource that in itself may be viewed as an external authority), or might reflect a need to use the support of 'the curriculum' to add legitimacy to her views. Whatever her motivations, that Meg pulls in an external source as an implicit authority while discussing her views on constructivist principles is a noteworthy juxtaposition.

Meg consistently demonstrates deference to one or more authorities in explaining her perspectives and it is noteworthy that she has seemingly detached each source of authority that she names from human actors. For contrast, Carrie routinely connected external 'authorities' to people. For example, when asked to share her thoughts on the role of teacher content knowledge in integrated STEM, Carrie's first response was, "Yeah, this reminds me, didn't you have us read an article about this?" referring to an article by Lee Shulman[8] that we discussed in the Portfolio course. She continued, "Yeah I remember when we were discussing it in class people had, like, really different opinions. Yeah, so I think you have to have a balance of the content knowledge and the pedagogy, the pedagogical knowledge, because if you know what to teach but not how to teach it, then I feel like you're not effective if you don't have the teaching strategies." Carrie is indicating that external 'authorities', in this case, me as her former instructor and an academic paper, had provided information that she and her classmates then made sense of. The use of the word opinions particularly implies that she views the conclusions and personal and personalized understandings.

As illustrated in Kevin's lesson plan, deference to an authority may, indeed, be evidence of constructivist teaching perspectives if it is evident that one recognizes that external 'expert-authorities' may be productively used as sources of information with which learners can sense-make. In these cases, deference to an authority for information does not reduce the agency of the learner over his or her own knowledge construction. It is not clear whether Meg is applying this view instead of one in which external experts maintain authority over knowledge and knowledge-building.

---

[8] Found in Appendix ___EDCI 614 Syllabus Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *EducationalResearcher, 15* (2), 4-14.

Inconsistencies in the extent to which Meg authentically applies constructivist principles are also evident in her descriptions of her own instructional practice. For example, in the subsequent section of the blog post described above, Meg offers evidence for how the curriculum 'attests' to inquiry-based learning. She says,

> For example, in math, rather than teaching students how to go through the process of using the algorithm for addition, we spent more time teaching strategies involving place values so that students can truly understand what it means to add and compose (a.k.a. regroup) numbers. Students can go through the motions of using the algorithm, but without truly understanding WHY they have to compose (regroup), they don't truly develop the number sense behind addition.

While she notes that rationale for why regrouping as part of addition procedures is important, she implies that she views learning as a direct product of teaching. Rather than offering opportunities, for example, for students to explore number sense through their own investigations, Meg explains that the curriculum has teachers spending more time 'teaching strategies,' which may be strategies for approaching place value from a sensemaking perspective, but may just as likely involve strategies for application of alternate formulas.

Another example of seemingly contradictory applications of constructivism may be found in the lesson plan that Meg submitted. When asked to describe what transdisciplinary STEM means to her in the opening of our interview, she indicates that she has, at times, integrated multiple disciplines in order to "make learning more real-life applicable," however examples from her writing suggest that she does not consistently apply a view of 'real-life' applicability' in terms of authentic activity in contexts that are relevant to the lives of students such that they foster meaningful knowledge transfer and learning. The challenge that serves as the center for inquiry in the integrated STEM" lesson plan that Meg designed centers on a phenomenon that she describes as, "in areas of the world where wood is scarce (i.e.: Africa), alternative sources of fuel are needed to produce heat/light." For this to be a meaningful context for the students to explore the identified learning objective, *conservation of energy and energy transfer*, Meg's third graders should have experience interacting in situations relevant to the one she poses. For example, opportunities to make sense of the conversion of natural resources to energy in their own contexts and environments, experiences using wood as an exclusive source of heat or light, and so forth.

These inconsistencies further persist in Meg's descriptions of barriers to implementation, which makes up a significant portion of all her responses in the interviews. I asked her, for example, to elaborate on an analogy that she had given in one of her blog posts in which she compared transdisciplinary STEM to dragon boating, an activity in which she frequently engages. In that post, she wrote, "all skills and content should be integrated and applied together on a regular basis in order to effectively apply learning in real-life situations." In the interview, she responded by sharing that she tries to integrate "all subject matter" in order to solve "real-world problems" but also indicated that several external factors restricted her abilities to do so. She says,

> So, that it does tend to take a lot of time and time is our biggest constraint. Um I, I try not to push to have just a reading block or just a math block or just a science block during those days when I do try to have a more integrated day. It does tend

> to take the entire day and you do try to touch on all of those subjects but the problem with that is um we have a lot, I mean, we have to differentiate and leveled texts are very limited to certain subjects, at least the text that we have so been able to integrate all of those subjects is challenging.

Her response indicates that she is focusing on the organization and structure of integration, rather than the interdisciplinary substance of transdisciplinary STEM, restricting her sense of agency over implementation. It also seems as though she considers the need for differentiated instruction, something she describes in terms of a professional requirement rather than a pedagogical strategy to support learning to be an inhibition. Her description again implies that an external authority unassociated with any particular actor is imposing the barrier. Finally, she identifies the limited availability of curricular resources, in this case, leveled texts, as representing an additional challenge. She does not seem to employ agency over making sense of the challenge nor moving toward solution seeking.

Another barrier to implementation on which Meg concentrated is the significant amount of interest, ability, and knowledge that she believes STEM requires of teachers. When asked to describe advantages to STEM that Meg sees, particularly regarding student learning or teacher practice, Meg responded that adequate teacher preparation was critical. She notes that there are many opportunities in the existing curriculum for real-life connections, but that additional research into the subjects is required for teachers to have the content knowledge STEM requires. She shares that personal interest, as well as time, is necessary for success.

> Um. Well, I dunno if this is necessarily an advantage, but I think preparing the teachers in order to teach these types of topics is very important. The curriculum has a lot of real-life applicable-type activities and lessons but even with the science/technology lessons that we are trying to teach now, because I had a personal interest in those types of topics, I also put in the time to research more and look more deeply into the topics whereas my teammates, they never, they never learned about those types of things or maybe never had type of interest so I would end up teaching them but for teachers who might not have those types of interests, or time really, they wouldn’t necessarily be able to do those topics justice because they don't have the training. They don’t have the content background to be able to teach those subjects.

Other teacher participants in this study also referenced the need for professional development to support STEM implementation. Carrie, for example, cited teacher training as a solution to reduce or resolve some of the intimidation teachers might feel in the face of STEM. Liz, however, identifies the professional training as being necessary for teachers to receive the ‘content background’ that is required for STEM. Her response suggests a view of knowledge as certain, simple, and transferred from expert authorities.

It was not clear from interviews and field data whether Meg authentically understands or agrees with the constructivist principles supporting the approach to transdisciplinary STEM promoted by the degree program. She seemed critical of the program, which may be influencing her responses, yet much of the data seemed to be characterized by the contradictory application of contrasting epistemological principles. The apparent misalignment between Meg’s personal epistemologies and those of constructivist STEM seems to strongly influences her perception of barriers to implementation as being unresolvable.

Gabrielle

Gabrielle and Kate were both selected for participation as representatives of teachers who were supportive of STEM but had perhaps not yet fully ‘bought-in’ to transdisciplinary teaching. Much of their interviews were characterized by thoughtful reflection on their experiences in the program and in their own teaching. In their responses, both struggle with the reconciliation of the affordances that they value with the challenges they perceive. Analysis of their data through an epistemological lens indicates that this struggle may partly result from their ongoing attempts to bridge their personal epistemologies with those of STEM.

In describing what transdisciplinary STEM means to her, Gabrielle focuses first on the constructivist principles for learning that underpin and manifest in STEM. She explains, “it’s more student-driven learning, and it's kinda centered around where they want to take their learning I guess and also makes that real-world connection which is really important when it comes to STEM education.” Her reference to student-driven learning here and throughout the interview suggests that she may be applying constructivist-aligned epistemological resources, including the principle that understanding requires active participation by the learner, rather than transmission from an authority (such as the teacher) and a relativist view that knowledge is socially constructed. It also suggests that the pedagogical and epistemological structures of STEM are as salient for her as the integrated nature of STEM or connections to the real world.

As she’s considering this response, Gabrielle quickly identifies a challenge to implementation. She says,

> I think the reason why people don't actually want to actually do it or teachers don't invest in it is because of the fact that it is student-driven and it's hard to keep up that responsibility to the students and really trust them to know basically where they want to take it or where they're going.

The challenge that Gabrielle identifies represents an internal dilemma teachers may face of releasing trust and control to the students. Control in the form of ‘classroom management’ is a commonly valued and an understandably reasonable element in today’s classrooms. In many cases, however, maintaining control over student behavior becomes conflated with control over learning and, essentially, cognition, thus leading to teacher-centered, transmissionist pedagogies. Gabrielle, like many teachers, has likely become accustomed to the objectivist epistemological principles, which support and are reinforced by these practices and it seems that she is attempting to reconcile their influence over her personal epistemologies with those of transdisciplinary STEM. She follows up by musing that the uncertainty and flexibility of STEM may, in fact, be part of its value before once again considering a challenge, this time one that is more external: that curricular restrictions make this sort of flexibility more difficult, particularly given that, in her view, it takes more time.

> But I guess that's the magic behind it is you're not really sure where it's going to end up... but then again, you know, of course, in our county we have to follow the curriculum and it's hard to have time for stuff like that. So it is hard but

> essentially, I guess it's what everyone strives to be moving towards, is, moving away from multidisciplinary and interdisciplinary and more towards transdisciplinary.

To the challenge that curricular expectations restrict the amount of time that teachers have to “do” or “invest” in STEM, Gabrielle offers reconciliation through a defeasible appeal to a broad goal presumably shared by educators, generally: that doing and investing in STEM and moving toward transdisciplinarity is what “everyone strives to be moving towards.” Though the challenge identified defers to external, expectation-setting sources, and the reconciliation implies external, consensual influence, Gabrielle’s descriptions suggest that she does not view them to be completely unaffected--or *unable to be* affected-- by individual or personal factors.

This pattern of identifying challenges and seeking reconciliation was recurring throughout Gabrielle’s interviews. For example, when asked to describe whether and how her perspective on STEM has changed over the course of the program, she begins by sharing that, through the program, she came to realize that STEM is more than siloed disciplines and began to reference the level of effort that it requires. She immediately counters the notion that STEM requires more effort by making a point that integration is more ‘natural,’ and potentially requires less time than a siloed approach.

> I just thought, ‘Oh, it's science, technology, engineering, and math,’ but I didn’t really know, I guess, how much goes behind it when you ARE trying to integrate those things, but then again there are ways where you can integrate without even,

> I guess, putting that much effort into it, it just comes naturally, um, and I guess having to do that lesson that you had us plan, things like that, that really opened my eyes to really experiencing "Oh, like, this isn’t that much different than if I were to teach math one, you know in a certain hour or science in a certain hour, I can kind of combine them both.' So, I definitely, [laughs] I’ve learned a lot.

She goes on to emphasize the power of real-world connectivity for supporting learning. Particularly, for helping students to think critically and “to really think outside of their classroom and outside of themselves, essentially, and think bigger picture which, I guess, even allowing them to even have that exposure to saying, 'Oh, well you guys are the future you guys are going to be taking care of ME, you guys are going to have to solve all these problems that we're having right now.’” She explains that, to her, critical thinking means “synthesizing information that they have learned from before anything that they are currently learning and trying to apply that to, I guess, in this context, real-world situations or problems” and shares several examples of ways that she approaches such tasks in her classroom. In particular, she described her experiences implementing the lesson that she created as part of an assignment for the graduate program, which focused on students working in design teams to create a tool that could measure wind speed. She explained that her students had previously learned about natural disasters, weather conditions, and different weather tools so they “had to take that background knowledge” and apply it in making sense of a real-world problem and she described the set-up for her students as follows:

> Within the last six months, different locations in our world have experienced weather conditions that were detrimental. These weather conditions occurred because of changes in the seasonal weather patterns where storms poured in rain and winds tore apart buildings so dealing with natural disasters of typhoons, tornadoes, and floods. So, we know that meteorologist do their best to predict the weather patterns in areas from analyzing data but many believe that weather doesn’t follow a set pattern and it's hard to measure.

Gabrielle described her role as “essentially just monitoring and posing questions” as the students designed and built their prototypes using common, everyday materials such as straws, cups, clay, cardboard, tacks, pencils. The teams tested their designs, “reworked flaws,” and developed systems for collecting data from their tools in the ‘field,’ in this case, on their school playground. Gabrielle noted that a challenge was finding an appropriate day to take the students outside to test their designs but smiles as she describes the results, which were not ideal,

> It was just a mess. Everyone's stuff was flying everywhere…but I guess that's the beauty behind what we did but then after that, it was a learning experience. We came in and we reflected on it and said, you know, ‘What could we have done so that we got better results,’ or ‘What could we do next time if we were going to do this again?’

Once again, Gabrielle seems to reconcile the challenge through her own perspective: recognizing what she calls “the beauty” in the experience and using the problems that arose as productive opportunities to reflect on exercise. She concludes her description of this experience by discussing her students’ enthusiastic and positive reactions to the activity and sharing the impact that their experiences had on her.

> …they were actually creating a product that they wanted to see come to life and actually had the opportunity to test it, so that was great and, um, of course, it was a lot better than just the traditional book work, or just do this worksheet and turn it in because they were actually able to um, be accountable, and um, I guess, take pride in what they were making, … it was nice to be able to incorporate [collaborative team work] and having them just work together on something and seeing it come to life…it was really fun for the kids and they were able to answer a lot of the questions that I did pose to them which was nice. I think it was beneficial for them.

The personal reflections that manifest in her responses, particularly her responses to the challenges that she identifies, illustrate Gabrielle's willingness and progress toward integrating and assimilating the constructivist principles of transdisciplinary STEM into her own epistemological schema. Though many of the constraints that Gabrielle identifies are largely external, her responses to those constraints suggest that she views them as surmountable. As noted previously, the pattern of describing an affordance of STEM, then immediately identifying a potential implementation challenge, followed by attempts to find reconciliation does characterize many of the teachers' responses during these interviews. While Carrie and Kevin tended to identify drawbacks or challenges that they could foresee *other* teachers identifying, Gabrielle seems to be expressing the challenges with which she, too, struggles. Her identification of the benefits to learning through constructivist principles indicates that she at least *recognizes* and *values* that epistemology and her attempts at making sense of these challenges and trying to develop solutions suggest that she is also *applying* the epistemology in her considerations. That she seems to be wrestling with this dilemma herself suggests that she sees herself as having some degree of agency over how STEM is perceived, interpreted and/or enacted, which is strong evidence in support of constructivist epistemology.

Kate

As with the other teachers, Kate's discussions of transdisciplinary STEM reveal subtle interactions between epistemology and perception of constraints. Unlike Gabrielle, however, who used constructivist principles to help reconcile dilemmas that likely have been shaped by traditional, transmissionist views of schooling, Kate seems to employ constructivist epistemological resources more consistently when considering affordances of STEM, however frequently adopts a more epistemologically neutral stance when discussing the constraints.

When asked to describe what "integrated or transdisciplinary STEM means" to her, Kate provides an analogy that illustrates the blended nature of the approach. She says,

> Hmm. Um, So I would say it's kind of like, uh, [laughs] probably the best analogy, maybe it's like, like a murky water, and like, within…are kind of all the subject areas of STEM: science, technology, engineering, and math, but it's not, you know, the one pool science, and one pool engineering, one pool math, and so forth, it's all kind of blended together.

Her response indicates a fair amount of independent thinking: she has taken information and understandings that were constructed through the program and developed a personal model to help both make sense of and describe it. She then elaborates on her understandings by describing how her analogy plays out in school through subject integration in the service of life relevant problem-solving.

> Um, so in the classroom, it's not teaching a specific science lesson followed by a specific technology lesson, and so forth. It's the integration of using different objectives from all of those content areas and blending them into one lesson that would work toward some kind of real-world problem-solving task.

Connections to the real-world and post-school preparation are elements of STEM on which Kate often focuses. For example, she notes the value of STEM for helping students develop skills that allow them to apply disciplinary learning to real-world problems and emphasizes the importance of this for life after school.

> I think what I'd really learned over this past year is that the purpose [of transdisciplinary STEM] is preparing these children for [the] kinds of jobs and problem-solving skills of the future. Um, working in collaborative groups, figuring out you know, like, real, relatable problems, um...and giving them those, you know, problem-thinking skills that you usually only sometimes get in regular classrooms in, like, word problems and things like that but like giving them actual, like, analysis and um having to work together in a team …so kind of like practice for real-world applications that they would need growing up and going into the job force.

Here she is drawing parallels between approaches to problem-solving in STEM and “regular” classrooms in order to illustrate a contrast that she sees. Her statement indicates that she views “problem-thinking skills” as a desirable outcome and notes that STEM provides opportunities for “figuring out” problems that are “relatable” in ways that standard word problems might not. Her phrasing here suggests that she is considering the type of learning environment that STEM affords as more active, collaborative, and permissive of critical thinking.

As evidenced in her course writings and interviews, collaboration is an element of STEM that Kate finds particularly compelling. She frequently cites it as a favorable component of STEM, often linking the benefit more tightly to its value for post-secondary education and careers than for its role in the learning process. In other words, although collaboration is a feature that she references when activating constructivist stances (as in the statement above), she also frequently discusses collaboration in ways that seem epistemologically neutral. For example, during one of our interviews, I asked her to elaborate on the idea of collaboration, “What is it to you, why do you think it’s important? What does it do for kids in terms of learning?” The question prompted her to respond with a potential constraint: that collaboration might not be a productive strategy for all learners.

> I have an autistic child this year and he just, he hates it. Every time I ask him to collaborate he hates it and you can see, like, how it’s, like an actual pain for him and it’s hard for me to think that collaboration is always the best for children who really have that difficulty…

Rather than describe her thoughts on the reasons why collaboration might be problematic for this student, Kate seems to focus on the student's response to this aspect of transdisciplinary STEM as being a constraint. Research has shown that interactions between students and teachers influence the ways teachers approach their practice (Brickhouse and Bodner, 1992; Cooney, 1985; Hargreaves, 2000) and "students' reactions can be an important constraint on their teachers' behaviors" (Brickhouse and Bodner, 1992, p.477). Kate views the reaction of her student as a classroom constraint, one that she might view in terms of realism given that she, for example, does not seem to flexibly consider contexts and approaches to collaboration that might productively service this student's learning without provoking a negative reaction. She concludes this statement with a response to the constraint,

> ….but at the same time, every project we do in grad school, everything I do at my school, like, it's always collaborative planning, collaborative this, working in a small group…So it becomes so relevant for [students] down the line that it makes sense that they would have so much practice with it growing up.

The reconciliation that she seems to offer is that collaboration is something students will encounter later in life and thus they should practice it in school. Even though Kate initially took a constructivist epistemological stance in describing the nature of transdisciplinary STEM, there is little evidence of epistemology in her discussion of this constraint and the few inferences that may be drawn indicate limited application of constructivist resources. However, when subsequently asked to elaborate on her thoughts regarding the *purpose* of collaboration, Kate one again activates constructivist resources. She emphasizes the benefits for co-constructing ideas and supporting metacognitive awareness. She says,

> Well, I think it develops better ideas. That's the kind of outcome from collaboration and then I think it's the reflection of "Oh, you know, I have this idea but then Joey added on to it and he made it a little bit better and then Lindsay had this idea and she kind of made it different but I kind of like this better than my original one" So it's that- I don’t know the correct term for it-but it's that kind of like cognitive awareness of just what you have can be expanded on, can be worked on…

The description of the products of collaboration here indicates that Kate does hold constructivist views of knowledge as complex, relative, and constructed, however once again it is for an *affordance* that activates them.

Later in the interview, when asked to describe the relative benefits of STEM and the traditional approaches to teaching, she attends primarily to the effects of each approach on organization and instructional planning and indicates that traditional approaches are “easier” for teachers to plan and prepare for given that they align more closely with the normative organization and structure of schools as well as the typical ‘mindsets’ of teachers.

> It's definitely easier for the teacher to be able to figure out one science lesson, one technology lesson. I think that a lot of things like that are already out there. I mean we do teach science as just science already and we do teach math as just math. So, a lot of the stuff already exists in those kind of lessons.

> Organizational-wise, it's probably a little bit easier as well. Just thinking in a, you know, a very [air quotes] "organized, " like, a teacher's mindset, you know, they're typically very ‘this is my lesson plan, [makes a chopping gesture with one hand against the other] I do this, I do this, I do this. I do this in the morning, and this in the afternoon,’ so it's probably like a bit easier to plan for.

Her responses here are not unlike Gabrielle’s reference to a teacher’s desire for control and a teacher’s attitude, outlook, or ‘mindset’ is a potential obstacle. Given that mindsets are inherently internal, it seems that Kate is considering epistemological resources of independence and relativism to make sense of this challenge. However, she is also referencing the influence of seemingly immutable authorities, such as existing lessons and the ‘way that teachers already teach.’ She goes on to describe several other external factors that contribute to the challenge of teacher mindsets.

> And just teacher-experience-wise, there's just not much training-I don’t know if any undergrad programs train for teaching the STEM integrated, transdisciplinary lesson and probably people are intimidated by the idea of attempting that or going for it because, I mean, besides maybe a literacy block that blends reading and writing, there's not really a time during the day at school where it is using all the different content areas and blending it into one learning approach. So, it's new. So, that would be, you know, kind of harder for teachers' mindset to get used to.

Here she first identifies a lack of training, a barrier controlled by external authorities, as being problematically unavailable yet necessary for helping teachers to resolve intimidation they might feel attempting to integrate subject matter of multiple disciplines. She points out that the situation is further compounded by the existing structure of school day schedules, another externally controlled constraint. While the identification of 'mindsets' implies an application of constructivist resources to make sense of this challenge, there is little other evidence to suggest a strong epistemological stance-- particularly in the absence of a given response to this constraint.

Many of the constraints that Kate describes throughout the interviews are presented as ineluctable conditions of schooling, to which she maintains relatively neutral epistemological stances. For example, she explains that successful implementation "would depend heavily on how well administration and, you know, your county would back it up, your school district. If it's a principal that is all about literacy, you're guaranteed to have the longest block of your day be given to reading and writing." Her statement does not necessarily indicate that she sees STEM as incompatible with the principles and structures that govern modern schooling, but that there are certain aspects of 'the way things are' that should be considered.

Despite evidence that she activates constructivist resources to make sense of the affordances of STEM teaching and learning, Kate tends not to engage epistemology-constructivist or otherwise-when considering constraints to implementation. This suggests a subtle, yet potentially significant nuance of the relationship between epistemology and her considerations of barriers to implementation, particularly constraints stemming from the normative practices of schooling.

Conclusion/Implications

This study sought to better understand the factors that mediate teachers' inclinations and capacities for embracing a shift toward more transdisciplinary approaches to teaching and learning in the STEM disciplines. Methodologically, in addition to studying the ways in which teachers describe the nature and purpose of transdisciplinary STEM, which contrast with the existing norms of institutional schooling, I found that studying the ways in which teachers describe and respond to challenges to implementation to be a productive way to access the epistemological beliefs that teachers are accessing and applying in their considerations. Thus, empirically, this study indicates that teachers' personal epistemologies are deeply intertwined with the ways in which they perceive, describe, and respond to implementation of the reform.

While all teachers in this study consistently and frequently identified challenges to implementation, the extent to which they described the challenges in terms of internally influenced dilemmas or externally controlled barriers worked to make their individual epistemological stances more salient. Carrie, Kevin, and Gabrielle, for example, each seem to recognize the potential for and influence of external constraints, however the forms of reconciliation-seeking with which they engage when responding to those constraints indicate activation and application of constructivist epistemological resources. They each struggle with the reconciliation to certain degrees in their own ways, but the consistent application of constructivist-aligned epistemological resources--particularly those that align closely with the epistemological principles underpinning transdisciplinary STEM-- to understand the challenges and consider solutions seems to strongly influence their ‘buy-in’ and inclination to make the shift. While Kate seems to activate constructivist perspectives when considering STEM in the abstract, she does not readily apply them when considering the ‘realities’ of implementation and instead adopts a more epistemologically neutral stance. Her neutrality when considering how STEM might fit into the constraints of schooling could, in and of itself, suggest the influence of transmissionist epistemologies if she perceives the structure and organization of schooling to be immutable to the point that enacting agency does not occur to her. For Meg, transmissionist epistemological perspectives seem to be strongly and consistently influential. She regularly activates and applies them both when considering affordances of STEM as well as when discussing barriers to implementation. The apparent nature and extent of the misalignment between Meg’s personal epistemological stance and that of transdisciplinary STEM seem to make it particularly challenging for her to embrace the reform. Considered together, these individual cases indicate that teachers’ epistemologies, which are productively accessed through their descriptions of challenges to implementation, are an important mediating influence on their approaches to reform initiatives. The extent to which personal epistemologies align with those underpinning that of the reform—and in particular, the extent to which personal epistemological views are foregrounded during the consideration of constraints--seem to be strong indicators of successful ‘buy-in’ and implementation.

The results of this investigation support the conclusions of previous research that teacher training programs aimed at education reform might benefit from accessing teacher beliefs in order to work toward authentic and productive alignment between personal epistemologies and those of the reform. These findings add a new perspective, however, to the discussion: that rather than function as a discrete factor, epistemological beliefs might be intimately entangled with teachers' perceptions of barriers to implementation and thus examining the ways teachers describe and respond to constraints may be particularly productive for accessing beliefs. A further implication of this study may be that understanding elements of teacher professional learning programs that might lead to or reinforce epistemological misalignment as well as those that foster convergence could strengthen the likelihood that the reform is taken up with integrity and fidelity. Carrie, for example, was able to readily engage and apply epistemological points and perspectives in course readings that were perhaps not as evident to Meg; exploring the factors contributing to their relative positioning in this context could be highly productive. Understandably, however, teachers will enter professional learning programs with myriad ideas, identities, experiences, and other constructs that influence epistemology and addressing each on an individualized basis is not always feasible or reasonable. It might, therefore, prove more practical and, perhaps, more productive, to instead provide multiple opportunities for teachers to explore their *own* beliefs in the context of working to understand epistemology and the influence it holds over teacher practice. Furthermore, rather than treating constraints as 'technical' problems for which there are relatively simple solutions that require a change in just one or a few places, teacher educators should consider whether and when constraints are more of an epistemic challenge**.**

Chapter 5: Conclusions & Reflections

This dissertation contributes to the field of science education scholarship by providing new insights into the potential for the Next Generation Science Standards and a complementary instructional model, transdisciplinary STEM, to support and advance constructivist approaches to high-quality education. Together, NGSS and STEM provide a framework *and* a pedagogical model that authentically communicate these learning principles for practitioners. Through two separate, yet connected research projects, I explore key issues that proponents of education reform frequently face: whether the goals for student achievement are attainable and worthwhile and, if so, will teachers be able to adapt to the epistemological and pedagogical perspectives that underpin and drive the reform.

Conclusions & Implications

In Chapter three, “Exploring Relationships Between Discursive and Epistemic Agency and Authentic Enactments of School Science,” I use the discourse of a science classroom as a primary means of accessing and understanding the relationship between student agency and scientific authenticity. I explored the issue of whether students, in this case, elementary students, need to relinquish discursive agency for their participation in science to be considered authentic. Through a structural analysis of the discourse used in the context of both a whole-group ‘science talk,’ in which the teacher maintains control of the discourse, and a contrasting small-group sense-making discussion during which more discursive agency is shifted to the students, I provide empirical evidence for the theoretical claim that discursive agency directly contributes to authentic engagement in scientific practices as established by the NGSS and, furthermore, that this engagement leads to meaningful sense-making as students progress toward proficiency in science. Analysis of the talk of the students in this episode indicate that allowing them to take control of the discourse used in the service of science not only co-occurred with engagement of NGSS-authentic scientific practice but that the authenticity of the discussion was, at least in part, a result of that agency. I conclude that that engagement in authentic science practices (as defined by NGSS) permits, invites, and may even *require* children to take agency over the discourse and associated linguistic resources they apply in service of scientific sense-making.

The empirical evidence presented here is distinctly and admittedly limited in scope, and, while I argue that this does not diminish its value for illustrating my theoretical claim, it does invite further study. In addition to extending observations and analyses of the relationship between discursive agency and authenticity among elementary students in varying contexts, it would be valuable to explore the claim in the context of secondary education. Students in middle and high school have advanced further in the course of formal schooling, and likely have had more experience with traditional approaches to talking science in school, which may affect their interactions with each other and with the 'science.'

Additionally, it is reasonable to predict that some educators might misinterpret my claims as suggesting that teachers should abdicate agency in favor of increasing the ability of their students to have more control over discursive patterns. As noted throughout this dissertation, teachers have incredible influence over the ways that disciplinary learning plays out in school and it would be valuable to explore their perspectives on the relationships between agency and authenticity, particularly in the context of NGSS.

In Chapter four, "Transdisciplinary STEM and Teacher Beliefs: Exploring the Interplay of Epistemology and Constraints," I report on a case study analysis of the perspectives of a sample of five participants in a Teacher Leadership in STEM Education graduate degree program at a large Mid-Atlantic University. The program is designed to support teachers in making a shift toward more constructivist-driven, integrated and transdisciplinary approaches to teaching and learning. As NGSS lead Stephen Pruitt notes, "implementation is the more demanding, challenging, at times contentious, and professionally fulfilling part of any reform" (2015, p. xi). Given that teachers are the primary stakeholders responsible for the success of the reform, it is critical to understand both the affordances and challenges to implementation. In this study, I asked, *how do teachers' epistemological beliefs affect their perceptions of the locus of perceived barriers and the extent to which those barriers may be overcome?* My results support conclusions drawn by other research programs, which indicate that accessing teacher beliefs is productive for understanding the relative alignment between their personal epistemologies and those of the reform, a factor which contributes to teacher buy-in and implementation. The findings of my research further add a new perspective to the discussion: epistemological beliefs may be intimately entangled with teachers' perceptions of constraints to implementation of reform, rather than function as a distinct factor influencing buy-in and implementation. Thus, examining the ways teachers describe and respond to constraints may be particularly productive for accessing beliefs and rather than treating constraints as ‘technical’ problems for which there are relatively simple, straightforward solutions, teacher educators should consider whether and when constraints are more of an epistemic challenge.

Taken together, the conclusions of these two research projects indicate that epistemological perspectives pervade the discourse of science, the text of curricular resources, and the language teachers use to talk about the implementation of pedagogical models. Furthermore, authentic enactments of science and meaningful learning are at least partially dependent upon a consistent alignment between the epistemologies underpinning reform efforts, those reflected in the language of school, and the personal epistemologies of educators.

Reflections

The insights that I’ve gained as a result of this dissertation have significantly influenced the way I think about and approach designing and implementing professional learning experiences for school-based and field-based educators. My work as the Director of Teacher Professional Learning for the Chesapeake Bay Foundation (CBF), a large non-profit environmental organization, and my renewed position as an instructor for the M.Ed. Teacher Leadership, Special Studies in STEM Education degree program with the University of Maryland offer many opportunities for me to apply and continue to learn from my experiences conducting this research.

In my work at the Chesapeake Bay Foundation, it is my responsibility to develop, communicate, and provide professional learning around the ‘model’ for teaching and learning that our education staff use to lead field experiences and that the teacher participants in our programs use to design and implement environmental literacy learning experiences for their students. I share this model through ‘training’ and workshops with our education staff as well as a broader audience of field-based and school-based educators. The approach that we take to environmental literacy teaching and learning has been influenced by the NGSS 3-dimensional learning framework and is very much in line with the descriptions of transdisciplinary STEM featured in my research. Through our approach, academic learning objectives are supported through learning experiences that are situated in the context of an environmental issue, problem, phenomenon, or challenge. Learners construct understandings through interdisciplinary, field-based investigations and apply those understandings in authentic stewardship and civic action projects.

I am responsible for leading the pedagogical training for our field educators, most of whom come from science backgrounds with little (if any) experience teaching in formal academic contexts. I design, co-design, lead, and co-lead professional learning for these educators that is intended to help them shift from the transmissionist perspectives on teaching (that many of them have become accustomed to in their own experiences as learners) toward student-centered approaches grounded in constructivism. These educators go on to apply these perspectives to their approaches leading field experiences for students as well as teachers. Hearing how these educators take in and observing how they apply this constructivist learning model helps me, as a professional teacher educator, gain more perspective about ways to most productively access, understand, and influence the belief systems that they are engaging in thinking about these approaches. Like the teachers studied in Chapter four, these field-based educators frequently identify constraints with this approach to teaching and learning, particularly in the early stages of their professional learning. For example, a common response is that the educators have too much 'content' to go through in the limited amount of time that they have with students on a trip. Depending on how the educator describes the barrier, I often interpret this constraint as indicating that he (or she) is privileging a 'quantity' of informational knowledge over the 'quality' of conceptual understandings and that he is likely applying transmissionist perspectives in their conceptions of how learning 'happens.' I have found that working with these educators to epistemologically 'reframe' these constraints from externally-controlled barriers to internally-influenceable dilemmas has been extremely effective, at least in reducing the resistance to change that the constraints seem to cause. In the previous example, I may respond to the constraint by prompting the educator to think about the difference between what it means to "know" something and what it means to "understand." We might then discuss and model ways to approach his practice in terms of helping students to construct meaning around ideas using factual information *and* their experiences both prior to and during their trip, rather than simply conveying lists of facts.

My work with CBF also allows contributions to systemic education initiatives across the watershed. I have been a lead developer of the *Environmental Literacy Model* (ELM), a tool used to support educators as they design and implement student-centered, constructivist driven environmental literacy learning experiences. This model has subsequently been picked up by the Chesapeake Bay Program, the education division of the National Oceanic and Atmospheric Administration's (NOAA) Chesapeake Bay office, and the Chesapeake Bay Trust as the recommended method for designing and implementing Meaningful Watershed Educational Experiences (MWEEs). It has become a major component of An Educator's Guide to the Meaningful Watershed Educational Experience, a resource from the Chesapeake Bay Program, and for which I was a lead author, to support practitioners as they work to systemically integrate environmental literacy into curriculum. As a lead author of this document, I worked to ensure that both the explicit and implicit epistemological messages consistently reflect perspectives that learning is primarily a result of student-driven sense-making.

I am also currently designing and leading workshops for field-based providers and school-based educators (teachers, curriculum coordinators, administrators, science advisors to state departments of education, and more) both within and across the watershed and for state and national environmental education audiences on the value of this approach to learning. It is critical that in all sessions that I facilitate that I am able to describe and present education models from a consistently authentic constructivist perspective, which means designing and facilitating 'training' sessions from a participant-centered, rather than transmissionist approach.

This semester, I am looking forward to once again serve as the instructor for the *Designing a Professional Portfolio* course for the M.Ed. Teacher Leadership in STEM Education program, which is now in its third cohort. I intend to continue to focus the goals of this course on supporting teachers to develop their own personal, professional philosophies on teaching and learning—philosophies that are reflected in the artifacts of their portfolios. This dissertation, though, has led me to focus more directly on the elements of this course and the program that might lead to or reinforce epistemological misalignment for the teachers. These teachers will be coming to this program with a variety of experiences, ideas, and other resources that they will access and engage as they make sense of the approaches to learning that we will explore. Reflecting on my own experiences in making a shift toward constructivism, I believe that the two strongest influences were my experiences as a graduate student in courses that authentically and seamlessly approached learning in through learner-centered approaches and the opportunities to read and discuss research and scholarship on how people learn as part of the doctoral seminars I later joined. Like Meg, I saw significant barriers to implementation and frequent, explicit meta-cognitive reflections on my perspectives and those of my colleagues, of teachers like Carrie, Kevin, Meg, Gabrielle, and Kate, and of academic communities was immensely helpful in helping me to understand and advance my views. It might be productive to provide multiple opportunities for the teachers in this new cohort to explore their own beliefs in the context of working to understand epistemology and the influence it holds over teacher practice. As the instructor and facilitator of these processes, I will encourage the teachers to voice their perceptions of barriers and constraints and work with the teachers to epistemologically understand and reframe them. These efforts will likely be supported by a stronger course focus on epistemologies and epistemological perspectives that may be reflected in the 'talk' of science classes. I have found Lemke's work, particularly his book, *Talking Science:*

Language, Learning, and Values (1990), to be particularly compelling and useful as an accessible resource for understanding how epistemological perspectives are revealed through classroom discourse and I will likely include this as one of the readings for class discussion. I think it will be very productive to apply the work of Lemke and others in class analysis and discussion on the nature of science "talk" with these teachers who, compared to those of cohort one, have had more experience with learning models of NGSS.

I'm looking forward to continuing to explore issues of discursive agency, authentic enactments of science in learning contexts, and epistemological beliefs about teaching.

Operationalizing Terms and Constructs

STEM Education

I have found the operational definition of STEM education provided by Vasquez, Schneider, and Comer (2013) to be extremely productive for making sense of STEM education:

> STEM education is an interdisciplinary approach to learning that removes the traditional barriers separating the four disciplines of science, technology, engineering, and mathematics and integrates them into real-world, rigorous, and relevant learning experiences for students (p. 4).

To this definition, I would add that a considerable amount of the power and potential of STEM education comes from the ability to leverage the mutually supportive natures of the STEM disciplines toward deep, conceptual understandings of the disciplinary core ideas and the practices through which they are constructed. As one of the teachers in our M.Ed. STEM Leadership program has reflected, when solving problems in the real world, blended application of the knowledge of multiple disciplines is more "natural," and more "organic" than considering the individual contributions of each discipline.

Discipline

In order to make sense of various approaches to disciplinary learning in the classroom, it is helpful to consider what is meant by the word discipline. Per Nissani (1997), a discipline can be conveniently defined as "any comparatively self-contained and isolated domain of human experience which possesses its own community of experts" (p. 203). Klein (1990) further explains that the word, discipline, refers to the “tools, methods, procedures, exempla, concepts, and theories that account coherently for a set of objects or subjects” (p. 104). In the context of schools, the term often is used synonymously with the word, ‘subject’ to describe the self-contained canons of concepts, ideas, and skills that we teach. Traditional approaches to schooling typically feature an intradisciplinary model in which learning about disciplines occurs exclusively in isolated contexts.

Integrated Curriculum

As Mathison & Freeman note, once we have a semblance of consensus on the use of the word, discipline, particularly as it pertains to school contexts, the question now becomes, “What happens to the disciplines in interdisciplinarity? Are they linked, combined, restructured, transformed?” (1998, p. 7). Stakeholders in education have promoted integrated approaches to curricular learning from as early as the Progressive movement in the early twentieth century. Similarly to twentieth-century trends, the general perspective today holds that the classroom environment should be relevant to everyday life and that the subjects explored by students should be presented in a way that integrates knowledge and skills from multiple disciplines and encourage critical thinking and reasoning. In other words, the curriculum should be designed such that it would unite traditional academic subjects around significant and engaging topics (Norris, 2004, Zilversmit, 1993). How this plays out in the classroom, particularly with regard to levels of disciplinary integration, varies considerably between contexts.

Three approaches to integrated organizations of curriculum--multidisciplinary, interdisciplinary, and transdisciplinary--become relevant to analysis and discussion of my research, particularly in the context of the second stand-alone paper on understanding teacher perspectives on STEM. Many scholars and teacher educators characterize these approaches to integration as falling on a continuum (Vasquez, Schneider, and Comer, 2013) or progressing up a metaphorical "ladder" (Harden, 2000). As curriculum moves along the continuum, integration becomes more pivotal and emphasis on the individual disciplines declines. It is important to note that it is merely the level of integration that increases as one moves along the spectrum. Each approach is productive for particular purposes and none should be considered superior to the others.

Multidisciplinary Integration

Multidisciplinary integration is an approach in which learning in separate disciplines is organized around a central problem or theme such as "nutrition," "the water cycle," or "oceans." By exploring a topic in multiple disciplinary contexts, students are encouraged to make connections among disciplines and appreciate that there are many ways to come to understand phenomena. Learning typically occurs in separated disciplinary contexts, for example in mathematics, science, Physical Education (PE) class, language arts, and social studies. The ways in which exploration of the same topic or phenomena across disciplines may improve learning, in other words, to lead to what Spiro, Coulson, Feltovich, & Anderson (1988) refer to as advanced learning, in which students "attain a deeper understanding of content material, reason with it, [and] apply it flexibly in diverse contexts" (p.4) is often largely dependent on the local school contexts. Thus, the success of multidisciplinary approaches to learning hinge upon the commitment and effort of school personnel as well as the extent to which teachers are able to coordinate planning around curriculum redesign (Wicklein & Schell, 1995).

Interdisciplinary Integration

Much like multidisciplinary approaches to integration, interdisciplinary approaches seek to help deliver a sense of coherence to the learner. Whereas traditional learning focuses on instruction within distinct disciplines, interdisciplinary integration (like multidisciplinary integration) organizes instruction between disciplines. In this approach, ways of thinking and knowing, as well as distinctive concepts and/or skills of two or more disciplines are simultaneously used in a single line of inquiry (Harden 2000, Klein, 1990, Nissani, 1997, Vasquez, et. al, 2013).

Interdisciplinary integration may be particularly productive for enhancing understandings of concepts or skills that are common to more than one discipline. For example, students could explore the parallel importance of collecting and representing data to both mathematics and science. The skills would likely then be applied to making sense of a concept in science or mathematics, respectively, and, as such, the disciplines are still identifiable, however, the distinctions are minimized in favor of explorations of the connections between them.

Transdisciplinary Integration

Transdisciplinary integration is considered by many to be the most complex approach to organizing curriculum. It seeks to, in part, meet the need to situate or contextualize integrated learning (Wicklein & Schell, 1995) and design productive opportunities for learning transfer. Transdisciplinary pedagogies are seen as a way to connect K-12 education with post-secondary skills and practices and thus strive to go beyond disciplinary learning exclusively for academic purposes. The traditional boundaries between disciplines soften, and in some cases, dissolve completely. Goals for learning disciplinary concepts and skills are in service of understanding a human-centric problem, or life-relevant challenge. The application of these concepts and skills towards making sense of the nature of and potential solutions for a problem, in turn, help students develop more sophisticated understandings of those concepts and skills. As Rustum Roy observed, "the inexorable logic that the real problems of society do not come in discipline-shaped blocks" (1979, p. 165).

Pedagogies that situate learning within problem-solving or project-based contexts are not new and transdisciplinary approaches share many similarities to and have been shaped by models of project-based learning, project-based learning, experiential learning, hands-on learning, and active learning. Of these, transdisciplinary pedagogies share perhaps the most parallels with models of project-based learning (PBL). As with many promising teaching strategies, there are many instances and variations among approaches to PBL and scholarship on the topic has noted a distinct lack of a universally adopted model or theory for project-based learning (Thomas, 2000). When implemented into the classroom, some models assume the 'showing and telling' approach of traditional hands-on activities in which projects serve to verify what has been taught. Others may employ a 'drop-in' approach in which projects are undertaken as supplementary activities to traditional instruction. Though both of these instantiations conflict with transdisciplinary learning, many of the descriptive criteria for authentic PBL that are found in education literature, however, are largely applicable to transdisciplinary pedagogies. For example, according to Thomas (2000), PBL emphasizes the importance of framing projects as central rather than peripheral to curriculum, require constructive investigations, and ensure that projects are student-centered and realistic rather than "school-like" (pp. 3-4). Furthermore, rather than intending to serve purposes of student engagement and motivation alone, proponents of project-based learning claim that activities should be "orchestrated in the service of an important intellectual purpose" and that through investigation into solutions for realistic problems, students "acquire an understanding of key principles and concepts" (Blumenfeld, Soloway, Marx, Krajcik, Guzdial, & Palincsar, 1991, p. 4).

In certain contexts, commitments for transdisciplinary and project-based learning overlap to such a significant degree, that some may use them interchangeably, or situate transdisciplinary learning as being "framed" within PBL (Greenwich Public Schools, 2006). Capraro, Slough, and Morgan (2013), for example, specifically promote project-based STEM learning and note that it "provides the contextualized, authentic experiences necessary for students to scaffold learning and build meaningfully powerful science, technology, engineering, and mathematics concepts supported by language arts, social studies, and art" (p. 3).

I am particularly sensitive to semantics and the influence of word choice on interpreted meaning, however, and while I acknowledge the compliments and connections between transdisciplinary and project-based learning, I privilege use of the former in my analysis and discussions. While advocates note that PBL promotes links between disciplines and deep level understanding of content (Blumenfeld, et al., 1991), there are a variety of practices that fall under the banner of project-based learning (Thomas, 2000), and, as the name suggests, there is significant potential for many of them to privilege orientation to task over epistemology. In my research, I emphasize and attend to the interdisciplinarity of practice as well as ways of thinking and knowing that are applied and develop as a result. The lesson, unit, project, or task through which these habits of mind and practice are employed is secondary to the epistemic activities. Therefore, while I acknowledge and embrace the overlapping connections and intersections between the two approaches, I find transdisciplinary to be more productive for my purposes.

Appendix A: 'Progress Toward NGSS Proficiency:' 3-D Coding Scheme

A Practices	1.a. Asking questions (for science) 1.b. Defining problems (for engineering)
	2. Developing and using models
	3. a. Planning investigations 3.b. Carrying out investigations
	4. Analyzing and Interpreting Data
	5. Using mathematics and computational thinking
	6.a. Constructing explanations (for science) 6.b. Designing solutions (for engineering)
	7. Engaging in argument from evidence
	8. Obtaining, evaluating, and communicating information
B Crosscutting Concepts	1. Patterns. Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them
	2. Cause and effect: Mechanism and explanation. Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.
	3. Scale, proportion, and quantity. In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.
	4. Systems and system models. Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.
	5. Energy and matter: Flows, cycles, and conservation. Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.
	6. Structure and function. The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.
	7. Stability and change. For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.
CPS Disciplinary Core Ideas	PS1: Matter and Its Interactions PS1.A: Structure and Properties of Matter PS1.B: Chemical Reactions PS1.C: Nuclear Processes

Physical Sciences	Core Idea PS2: Motion and Stability: Forces and Interactions PS2.A: Forces and Motion PS2.B: Types of Interactions PS2.C: Stability and Instability in Physical Systems Core Idea PS3: Energy PS3.A: Definitions of Energy PS3.B: Conservation of Energy and Energy Transfer PS3.C: Relationship Between Energy and Forces PS3.D: Energy in Chemical Processes and Everyday Life Core Idea PS4: Waves and Their Applications in Technologies for Information Transfer PS4.A: Wave Properties PS4.B: Electromagnetic Radiation PS4.C: Information Technologies and Instrumentation
CLS Disciplinary Core Ideas Life Sciences	Core Idea LS1: From Molecules to Organisms: Structures and Processes LS1.A: Structure and Function LS1.B: Growth and Development of Organisms LS1.C: Organization for Matter and Energy Flow in Organisms LS1.D: Information Processing Core Idea LS2: Ecosystems: Interactions, Energy, and Dynamics LS2.A: Interdependent Relationships in Ecosystems LS2.B: Cycles of Matter and Energy Transfer in Ecosystems LS2.C: Ecosystem Dynamics, Functioning, and Resilience LS2.D: Social Interactions and Group Behavior Core Idea LS3: Heredity: Inheritance and Variation of Traits LS3.A: Inheritance of Traits LS3.B: Variation of Traits Core Idea LS4: Biological Evolution: Unity and Diversity LS4.A: Evidence of Common Ancestry and Diversity LS4.B: Natural Selection LS4.C: Adaptation LS4.D: Biodiversity and Humans

CESS Disciplinary Core Ideas Earth and Space Sciences	Core Idea ESS1: Earth's Place in the Universe ESS1.A: The Universe and Its Stars ESS1.B: Earth and the Solar System ESS1.C: The History of Planet Earth Core Idea ESS2: Earth's Systems ESS2.A: Earth Materials and Systems ESS2.B: Plate Tectonics and Large-Scale System Interactions ESS2.C: The Roles of Water in Earth's Surface Processes ESS2.D: Weather and Climate ESS2.E: Biogeology Core Idea ESS3: Earth and Human Activity ESS3.A: Natural Resources ESS3.B: Natural Hazards ESS3.C: Human Impacts on Earth Systems ESS3.D: Global Climate Change
CTEAS Disciplinary Core Ideas Technology, Engineering and Applications of Science	Technology is any modification of the natural world made to fulfill human needs or desires Engineering is a systematic and often iterative approach to designing objects, processes, and systems to meet human needs and wants An application of science is any use of scientific knowledge for a specific purpose, whether to do more science; to design a product, process, or medical treatment; to develop a new technology; or to predict the impacts of human actions.

Appendix B: Transdisciplinary STEM and Teacher Beliefs: Interview Protocol

Subject:
Date:
Time:

Themes

1. Background
2. General experience in program
3. Perspectives on STEM
4. Advantages & challenges of implementation (for subject, for average teacher, etc.)
5. Important elements of STEM (from subject's perspective) that other educations should know/understand

Prompt	**Notes**
Tell me a little about yourself. What do you teach? What experiences in STEM did you have before you came to this program? What led you to enroll in the program? • Are there experiences or activities that stand out to you as being particularly productive? Unproductive? (General)	
Please describe your experience in the program so far.	
Has your perspective of STEM changed over the course of the program? If so, how? *Ask specific questions to follow up on provocative points from blogs/course work*	
Are there particular experiences in the program that stand out to you as being particularly productive as far as developing your perspectives on STEM?	
How does (or could) transdisciplinary or integrated STEM fit into your academic program • Ask specific questions about the lesson plans the teachers' designed • Have they designed or implemented other TD STEM lesson? Why or why not? • What went well/did not go well?	
Explain the challenges to TD STEM implementation • What challenges/advantages does the average teacher face. • What challenges do you think other teachers in your program face? • What challenges/advantages do YOU face? • Describe ways the program has/has not influenced these challenges/advantages	
Explain the advantages of STEM implementation	
What do you think are the most important elements of STEM that teachers should know?	

Appendix C: EDCI 614 Developing a Professional Portfolio Syllabus

Course Description: This course has been designed for the **M.Ed. Teacher Leadership, Special Studies: STEM Education.** This course is presented in the form of three single-credit-hour strands running concurrently with program content courses. Each strand will focus on the interrelation between the following essential questions:

- *What is STEM education?*
- *What does it mean to teach for authenticity, equity, and achievement?*

Course Objectives: Teachers will

- Develop a comprehensive, dynamic, personal philosophy of teaching and learning in STEM education. Philosophies should be grounded in seminal theory and research on teaching and learning and developed through experiences in the program as well as in the classroom.
- Develop sophisticated understandings of the MSDE approach to STEM pedagogies (as illustrated in the STEM Standards of Practice).
- Establish and maintain an electronic portfolio that reflects the evolution of a philosophy of teaching and learning in STEM education.
- Develop and participate in a Professional Learning Network.

Course Format: This course has been structured as a seminar course that will run concurrently with each of three content courses in the program. During the fall semester, this course will meet alongside **EDCI 606, Teaching and Learning in the Biological Sciences**. During the spring semester, this course will meet alongside **EDCI 606: Learning and Teaching in the Biological Sciences**. Class sessions during the fall and spring semesters will meet one evening a week. During the summer semester, this course will meet alongside **688C Introduction to Engineering For Teachers**. A schedule of course sessions may be found on the Canvas organizational site (www.elms.umd.edu).

In Portfolio course sessions, we will focus on discussions of the weekly readings and how they are relevant to and intersect with your experiences in STEM education. We will read a variety of papers from diverse sources each week and you will be responsible for coming to class having carefully read and reflected on the assignments. Satisfactory participation will include thoughtful discussion on personal insights, questions, and careful attention and responses to those shared by classmates.

Course Portfolio: Teachers are expected to create an electronic portfolio in the form of a professional website/blog as part of the requirements of this course and maintain it throughout the **M.Ed. Teacher Leadership, Special Studies STEM Education** program. The portfolio will serve as a PLN tool to help shape each teacher's evolving knowledge, beliefs, and perspectives. It will be a collection of materials to highlight and illustrate your professional knowledge (content and pedagogical content), skills, and values and will be designed to represent a diverse and unique description of each of you as a leader in STEM education. Materials will be assembled and managed on the Web through the blog host of your choice (we will explore examples in class). Materials to include in your blog may include inputted text, electronic files, images, video, journal (blog) entries, hyperlinks, etc. You will be asked to present features of your portfolios at certain points throughout the course.

Course Assignments: Each week students will be expected to complete one or more assignments corresponding to the designated readings and/or class discussions. The assignments will include a group project, four reflective blog posts, an argumentation paper, and a formal lesson plan. Further details about each assignment will be provided in class sessions. The content of this course is intended to be dynamic and responsive to class discussion, thus readings and assignments are subject to change as appropriate.

Course Schedule: Below is the schedule of course topics and assignment due dates we will try to follow. Submission will correspond to the type of assignment.

Strand 1 – Fall 2013

Topic		Readings	Assignments
8/20/13	**Professional Learning Networks**	• Flanigan, R. L. (2011). Professional learning networks taking off. *Education Week, 31*. 10-12.	• Set up website/blog & post link to Canvas ***due: 8/26*** • Complete surveys ***due: 8/27*** • Group Project: Prezi-*What Are PLNs?* ***due 9/10***

8/27/13	**What is STEM?**	• Bybee, R.W. (2010). Advancing STEM education: A 2020 vision. *Technology & Engineering Teacher, 70* (1), 30-35. • Maryland State Department of Education. (2012). Maryland STEM: Innovation today to meet tomorrow's global challenges. Retrieved from: http://www.msde.state.md.us/w/STEM_20 13.pdf. • Maryland State Department of Education. (2012). STEM standards of practice. Retrieved from: http://www.marylandpublicschools.org/NR/rdonlyres/3ECF0379-2EE9-42AD-A5FCCA81E8F3FEEA/32260/MarylandStateSTEMStandardsofPractice_.pdf. • Next Generation Science Standards. (2013). Front matter. Retrieved from: http://www.nextgenscience.org/sites/ngss/files/Final%20Release%20NGSS%20Front%20Matter%20-%206.17.13%20Update_0.pdf.	• Blog Post: What/Why STEM? ***due 9/02*** • Group Project: Prezi-*What Are PLNs?* ***due 9/10***
9/10/13	**Academic Standards**	• Donovan, M.S., and Bransford, J. (2005). Introduction. In M.S. Donovan & J. Bransford (Eds.), *How students learn: Science in the classroom* (1-26). Washington DC: National Academies Press.	• Blog Post: *"The Science in Standards"* ***due 9/16*** • Final Project: NGSS-based lesson plan ***due 12/17***
10/29/13	**Inquiry & Science**	• Blog Post: Reading response question (TBA) ***due 11/4*** • Final Project: NGSS-based lesson plan ***due 12/17***	
11/19/13	**Facts, Misconceptions, & Myths!**	• Smith, J., diSessa, A., & Roschelle, J. (1993/1994). Misconceptions reconceived: A constructivist analysis of knowledge in transition. *Journal of the Learning Sciences, 3*(2), 115-163.	• Argumentation paper: Misconceptions ***due 11/25*** • Final Project: NGSS-based lesson plan ***due 12/17***
12/17/13	**What is STEM?**	• Vasquez, J.A., Schneider, M., and Comer, C. (2013). *STEM lesson essentials: Integrating science, technology, engineering, and*	• Check in on PLN over break (either one blog entry or one comment) • Upgrade NGSS-based lesson plan if needed

mathematics. Portsmouth, New Hampshire: Heinemann.

Strand 2 – Spring 2014

Date	Topic	Readings	Assignment(s)
1/07/14	**STEM-Centric Lesson Planning**	**Readings that we will discuss during this session:** • National Research Council (2012). Engineering, technology, and applications of science. In *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* **(pp.201-214).** Washington, DC: The National Academies Press.	**Assignments:** • Blog post: Engineering & STEM Education ***Due: 1/14/14 by 5pm***
1/14/14	**Pedagogy & Engineering**	**Readings that we will discuss during this session:** • MSDE STEM Standards of Practice. • Appendix F Science and Engineering Practices in the NGSS	**Assignments:** • Group Project: Evaluate and Revise a STEM-Centric Lesson/Unit plan ***Due 1/22/14 by 5pm*** STEM-Centric Unit plan • ***Due 1/28/13 by 5pm***
1/21/14 *Virtual session	**STEM-Centric Lesson Planning**	**There are no readings for this week.**	**Assignments:** • Switch STEM-Centric Lesson/Unit plans with a partner. Evaluate your partner's plan using the rubric. **Return to your partner by 8pm on Tuesday, 1/21/14** • Group Project: Evaluate and Revise a STEM-Centric Lesson/Unit plan ***Part 2: Due 1/22/14 by 5pm*** • STEM-Centric Unit plan ***Due 1/28/13 by 5pm***

2/18/14	**STEM Perspectives**	**Readings that we will discuss during this session:** • Bybee, R. (2013). The case for STEM education: Challenges and opportunities. Washington D.C.: NSTA Press.	**Assignment:** • Create a graphic/illustration to represent your current perspective on STEM.
3/11/14	**STEM-Centric Lesson Planning Assessing STEM**	**Readings that we will discuss during this session:** • Vasquez, J.A., Sneider, C., Comer, M. (2013). STEM lesson essentials. Pp. 123-137. Portsmouth, NH: Heinemann.	**Assignment:** • Spring blog post 2: STEM Perspectives
6/3/18	**STEM-Centric Lesson Planning Assessing STEM**	**Readings that we will discuss during this session:**	**Assignment:**

Strand 3 – Summer 2013

Date	Topic	Readings	Assignment(s)
6/30/14	**Knowledge & Teacher Effectiveness in STEM**	**Readings that we will discuss during this session:** • Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15* (2), 4-14.	**Assignments:** • Reflection Assignment: Impact of Instruction on Student Learning ***Due: 6/30/14 by 9:30am***
7/14/14	**STEM Professional Development**	**Readings that we will discuss during this session:** • TBD	**Assignments:** • Blog Post: Learning Objectives, PCK, and Assessing STEM ***Due 7/14/14 by 9:30am***
7/24/14	**STEM-Centric Lesson Planning**	**There are no readings for this week.**	**Assignments:** • Blog Post: Perspectives on STEM 2 ***Due 7/28/14 by 9:30am***
7/25/14	**STEM-Centric Lesson Planning**	**There are no readings for this week.**	**Assignments:** • Professional Development Project ***Due 7/28/14 by 9:30am***

Readings: All readings will be posted onto the Canvas organization page for our program.

Expectations and Grades: Each student will receive a letter grade on assignments. A final grade of "A" will require active participation in each class discussion and in the group projects, critical reading of assignments, the thoughtful and informed completion of each blog entry, and a well-developed lesson plan. Grading will follow the university's policy of awarding minuses (-) and pluses (+).

You will earn a grade at the end of each one-credit strand of EDCI 614 that reflects your work and effort for that semester. At the conclusion of the final strand in the summer of 2014, the three one-credit grades will be averaged for a final course grade.

Overall Percent	Grade
100%-95%	A+
95% - 93%	A
92% - 88%	A-
87% - 85%	B+
84% - 81%	B
80% - 78%	B-
77% - 75%	C+
74% - 70%	C
69% - 65%	C-
64% - 60%	D+
59% - 55%	D
54% - 50%	D-
≤49%	F

Major Assignments (Note: further explanations of assignments, including rubrics, may be found on canvas)

Blog Entries: You will each be responsible for posting a minimum of three blog entries on assigned topics throughout the semester. Each post should be a **minimum** of 500 words and should be informed by weekly readings and class discussions. **Blogs should adhere to APA rules for citation.** Additionally, you are encouraged to read and comment on classmates' blog posts. These comments will be considered part of the participation grade.

Group Project (fall semester): What is a PLN? During the first-class session, you will be organized into groups.

Each group will create a presentation on Professional Learning Networks using the web-based resource of your choice.
Each presentation should include (but is not limited to!) information on:

- the nature of PLNs
- examples of tools and resources available for use in educational PLNs
- The difference in a tool (like twitter or livebinder) and the PLN, itself
- advantages and drawbacks of participating in PLNs
- The potential impact of PLNs on Teacher PD

All group members are expected to actively contribute to their projects.

Group Project (spring semester): Evaluate and revise a STEM-Centric Lesson/Unit plan. You will work in teams to analyze and revise a STEM-Centric lesson/unit plan according to how well it reflects the principles of learning and productive learning environments described in *How Students Learn* (Donovan & Bransford, 2005), the MSDE STEM Standards of Practice, and the Framework for K-12 Science Education.

Group Project (summer semester): This assignment requires you to work in a small group to design a professional development (PD) activity that will support teachers in grades Pre K – 8 in enacting and understanding transdisciplinary STEM education. Specifically, the PD experience should support teachers in:

- Developing the pedagogical content knowledge[9] necessary to help learners in STEM
- Developing an integrated understanding of how the core ideas and practices of science, engineering, and mathematics may be used to explain phenomena and solve problems
- Understanding and implementing the MSDE STEM Standards of Practice The completed project should include (but is not limited to) the following components:
- A digital, shareable platform or medium for content delivery (Prezi, Powerpoint deck, Live Binder, video, document, etc.)
- One or more 'take away' resources, document, lesson plan template, etc.
- An interactive quality
- An opportunity for participant feedback (survey, poll, etc.)
- Explanation for how the feedback will be collected and utilized.

Essay: Misconceptions. The topic of "misconceptions" is often debated among members of the science education community. For this assignment you will first provide an explanation of what the word "misconception" means to you (If you use the definitions or descriptions of others in your explanation, be sure to use appropriate citations). Next, choose a common "misconception." Develop an argument that supports a situation in which the misconception is counterproductive to science learning. Then, provide a counterargument that supports a situation in which the misconception is productive to science learning. Finally, reconciles the two by stating which of the two arguments you believe, and why, including an explanation of why the *other* argument is flawed. Be sure to use evidence from your explanation of "misconceptions." Grading is based entirely on the clarity and quality of the arguments, not the particular argument you choose to support.

STEM-Centric Unit/ Lesson Plan based on the NGSS model for science education: Throughout the course of the semester we will continue to analyze the Next Generation Science Standards and compare them to current state science standards. Each teacher will be required to design an integrated STEM lesson plan on a topic of your choice that follows the 5E model (unless you request to use a different format; requests must be made before the assignment due date). The lesson plan should reflect the NGSS approach to teaching and learning in science and should be appropriate for the grade band that you teach.

Impact on Student Learning Reflection: STEM-Centric Unit/ Lesson Plan. This assignment requires you to reflect of the experience of implementing a STEM-Centric Unit or lesson plan

[9] Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57* (1), 1-22.

with respect to student learning. This assignment is intended to give you the opportunity to tie together many pieces of the process of teaching & learning in STEM to help you:

- Determine the effect of instruction on all students' learning
- Guide decisions about future instruction and plans to improve upon every Student's performance
- Communicate performance results to others
- Reflect on your performance as a teacher

University Honor Code: All students are expected to abide by the university's code of academic integrity. You may review the code at http://www.shc.umd.edu/code.html.

Accommodations: Please notify me as soon as possible if you would like to discuss accommodations for a documented disability.

Attendance: All students are expected to attend and participate in each class. If, for some reason, you will not be able to attend a class meeting, please notify me in advance.

Course Evaluation: As a member of our academic community, you as a student have a number of important responsibilities. One of these responsibilities is to submit your course evaluations each term though

CourseEvalUM in order to help faculty and administrators improve teaching and learning at Maryland. The final evaluation for EDCI 614 will be available at the conclusion of the third strand in the summer of 2014. We will, however, provide written evaluations at the conclusion of the fall and spring strands as well.

Appendix D: Transdisciplinary STEM & Teacher Beliefs: Sample Categorical Coding Matrices: Constraints I and II

I Constraint: *TD STEM is at odds with instructional/professional requirements and institutional norms*

Meg	Kate	Kevin	Gabrielle	Carrie
2.M. So that it does tend to take a lot of time and time is our biggest constraint. Um I, I try not to push	42.:AG Do you see particular benefits for that approach versus the integrated	61.AG So you're planning with these other teacher, or...	76. G: OK basically TD STEM is um, I guess it's more student-driven learning, and it's kinda centered around where they want to take their learning and	AG: So the curriculum, so one challenge already is that the curriculum

to have just a reading block or just a math block or just a science block during those days when I do try to have a more integrated day. [00:07:17.10] It does tend to take the entire day and you do try to touch on all of those subjects but the problem with that is um we have a lot, I mean, we have to differentiate and leveled texts are very limited to certain subjects, at least the text that we have so being able to integrate all of those subjects is challenging.	approach? Or...maybe um... [00:06:35.26] K: [cuts in] It's easier. AG: It's easier? K: It's definitely easier for the teacher to be able to figure out one science lesson, one technology lesson. [00:06:42.02] I think that a lot of things like that are already out there. I mean we do teach science as just science already and we do teach math as just math. [00:06:49.15] So a lot of the stuff already exists in those kind of lessons. Um. [00:06:55.16] organizational-wise, it's probably a little bit easier as well. Just thinking in a uh.. you know a very [air quotes] "organized...." like a , teacher's mindset you know, they're typically very "this is my lesson plan, [makes a chopping gesture with one hand against the other] I do this, I do this, I do this. I do this in the	K: As much as they'll let me, pretty much. As much as time allows. [00:10:11.20] K: And that's one of the big problems, is like cross-subject planning, you don't get collaboration planning with cross-subjects. You get collaboration planning with... like, I'll get it with other science teachers but if we meet... Like today I met during lunch with a couple of those teachers just to discuss things we're, you know, trying to do together to make the trout project, like a school-wide project rather than just a class project. [00:10:50.24] AG: So you're in a different situation than most of the other teachers are in in that you only teach science right? K: Right. Mm hmmm 62. I did my student teaching	also makes that real-world connection which is really important when it comes to STEM education. [00:01:27.20] I think the reason why people don't actually want to actually do it or teachers don't invest in it is because of the fact that it is student-driven and it's hard to keep up that responsibility to the students and really trust them to know basically where they want to take it or where they're going. [00:01:43.27] But I guess that's the magic behind it is you're not really sure where it's going to end up... [00:01:49.06] but then again, you know, of course, in our county we have to follow the curriclum and it's hard to have time for stuff like that. So it is hard but essentially, I guess it's what everyone strives to be moving towards, is , moving away from multidiscopliary and interdisciplary and more towards TD. 79. AG With what? Oh, Ebola. G: Yeah, So of course, kids are like, a lot of	already packs a lot into... C: Yes. AG: And gives you time frames? That you have to cover? C: Yeah, I mean, it says "week one" and the stuff I listed to you was week one. And so we are supposed to do all that in five days. AG: And, but it seems like [00:22:50.17] You felt like you were able to kind of branch away from some of these curricular expectations. Why is that, why do you feel.... C: I feel like it's so important that [00:23:02.08], Um, I'll take a risk to not maybe get through something in order to do something really meaningful and authentic. I mean, this project was so authentic. I mean, the earthquake had just happened,

	morning, and this in the afternoon" so it's probably like a bit easier to plan for and just teacher experience-wise, [00:07:20.25] there's just not much training-I don't know if any undergrad programs train for teaching the STEM integrated, transdisciplinary lesson and probably people are intimidated by the idea of attempting that or going for it because, I mean, besides maybe a literacy block that blends reading and writing, there's not really a time during the day at school where it is using all the different content areas and blending it into one learning approach. So, so it's new. So that would be, you know, kind of harder for teachers' mind set to get used to 52. Um, so yeah so curriculum, time, administration support, um, and then I guess, it'd be, the one thing I've thought	in elementary school [00:11:19.15] and you know, we, the the term that we used to use was like, cross-curricular and how were we meeting cross-curricular needs and, um, you know, a lot of it is, sometimes it seemed basic, sometimes it seemed a little more advanced but when I got to middle school, it was, it was much different in that it almost seemed like the subjects HAD to be separated and I wasn't really too crazy about that and I still try to integrate any, any kind of other subject area [00:11:57.01] into my science class and I'm lucky that I had experience with that in elementary school. I think it is probably was easier in elementary school depending on probably the school you work in. I know some of the people in class have said it's very strict when you do math when you do reading but in	kids a re like coughing and thinks like that and kids are like, "Oh you have Ebola!" And so we kinda, talk about that and how that situation is going in our nation right now, but [00:06:56.19] it's interesting to see, "oh, they really know, you know, SOMEthing about what's going on in our real world but if we were to take that information and actually given them the opportunyt it say, OK, like, "What do you think we could do to try to avoid, you know, the spread of it, or, you know, it's just really interesting to see what they come up with and just giving them that chance in the classroom would be awesome, but, [00:07:18.25] just like I said, it's hard because of the time and the curriculum that we do have to teach. So, um, [00:07:25.29] I don't know I just really think that, the critical questioning is vital when it comes to STEM education because that's basically, I feel, the BASIS of it, you know, the, the importance of it, really getting them to think about how, 'how can I take this situation and make it better?" [00:07:44.21]	you know it was all over the news and a lot of kids knew about it. They saw it on the TV and I just said, "You know that is a huge problem that we have to deal with. Engineers have to try to deal with earthquakes and other natural disasters whenever they are planning." So I guess to answer your questions, I kind of just was a rebel and, was thinking, you know, this is a really important, authentic...it's an opportunity: an opportunity to do a really meaningful, authentic project. [00:23:41.03] And I also felt like I was able to, kind of, [air quotes] 'get away with it' in the sense that I was still teaching objectives from a different subject. So, in reading this quarter we are doing informational reading skills. So, using text features to increase your comprehension, so while we were preparing for the activity we did

	about doing in my classroom that is kind of hard to figure out is the fact that there already ARE science objectives and there already ARE math objectives… [00:06:43.09] AG: So you were saying that there already ARE science standards...or science.. K: Objectives. AG: Objectives. [00:06:50.21] K: Right. And there already ARE math curricula. And a lot of it, like, I don't think STEM teaching would ever take away, like, math that is already there. Like, you still have to learn addition and subtraction, you have to spend the time doing that and so it's hard also to find the time, cause it's **not like replacing something, it's in additional to**.... so [00:07:17.12] 54. -55. Um, but yeah I think it	the elementary school I was in, we really had freedom to kind of cover anything we needed to at any point during the day and you could, [00:12:22.19] you could really integrate, you know a story into math class that kind of involved numbers that would, that would cover both math and reading 67. What about challenges for um, implementing this transdisciplinary STEM. I know you talked about teachers, especially at the middle school level are kind of comfortable with what they teach. k: mm hmm [00:19:58.02] I think a lot of, you know, a lot of curriculum resources are so, are so separated, um, that it almost would take, uh, you know, a team of people to be able to develop lesson plans and materials and resources to...[00:20:20.03]	and then, just like, giving them the opportunity to rework their scenarios and their designs, things like that, so it really gets them thinking. [00:07:53.05] 80. : Um, I feel like a lot of the times, what we teach them, obviously can be applied within the classroom but if they are able to take it and make a connection to something that maybe they do outside of school, or see something outside of school, I think that's taking it further and, um, really showing that they understand, maybe, what they have learned, and, I guess, analyze and apply their learning to things that occur outside of the classroom[00:08:47.11] So maybe something like, um, if they're in like a grocery store, they're watching the news, if they're able to apply and synthesize certain information that they're hearing and say, "hey!" you know, " I learned about, um, I dunno, something as simple as, I guess, ummm... I don't know, adding and subtracting decimals but then how that can be applied with, with say, um, measuring, [00:09:17.20]	with earthquakes, all the reading of articles that we did, I was practicing reading skills with them. [00:24:10.10] So, that's another reason I kind of felt OK with it, because I was covering informational reading objectives. Even though earthquakes are not a part of curriculum, we were still practicing those informational strategies. Which, I have found myself doing much more this year than last year. [00:24:28.29] I found myself more comfortable kind of going away from the curriculum and doing TD STEM lessons that might not be in our science curriculum or our social studies curriculum, but that I can find articles about that then I can tie in in terms of just the informational reading objectives.

	was...if it was something that we could put into our schedule and we had a [air quotes] "STEM block" and it was something as a team we planned for and did it would be great [00:10:15.10] but it was me not doing something else and, you know, kind of on my own having this lesson when so so much of our planning is collaborative planning and so much of our schedules look exactly the same because we talk about it we decide on everything together. [00:10:34.27] so it was like "Oh, I'm not doing that, I'm not doing that tomorrow because I'm doing this." But if it was something that WAS a designated time in our, like, day schedule or weekly schedule, once a week maybe at some point, it would be a lot easier because everyone would	you have to get teachers on board to be able to do that. You can come up with the best, um, kind of ideas for how a classroom would work but unless you're, [00:20:33.08] I think unless you're willing to put something out there, like, almost like a recipe and you could say, follow this recipe and, you know, it's going to work, cause you know, I know a lot of teachers, the first year they come in they kind of have to rely on lesson plans that are already there and I think that developing things like that for STEM is one of the first steps. [00:20:56.20] 68. I think we definitely have advantages in that we know what STEM is, we know what STEM can potentially do if used effectively, um, I think there's definitely challenges in **convincing people** that that's the best way to		24. AG: So, talk about, those are decisions that are made at the administrative level? C: yeah. [00:27:48.00] AG: For everybody? When you teach math when you teach reading? Why is that? C: Um I think it's just because it would be hard to honor what everyone would want. I mean, they take our feedback and ultimately they make the instructional schedule for the whole school. But it is an interactive process between us and them. So, it's not like they just kind of like tell us that this is the schedule. They kind of go through multiple drafts and show us and, "OK what does everyone think about this?" And ultimately someone isn't happy because, you know, some people complain

	be doing it. [00:10:49.14] It wouldn't be like I was feeling, "Oh, I need to do this other thing." Like, it was like, "Oh this is what I'm supposed to be doing because I have my STEM block time period so let me think of a STEM lesson to put it."	do things and, you know, I [00:21:45.25]... teachers are like any other group of people, they're you know, it's not easy for people to just up and change. Um, but I think we definitely do have the advantage of the wide variety of references [00:21:59.09] that we've been, um, you know, introduced to, to show that, you know, STEM is a worthwhile thing and it is worth looking into and I think that's why we are all still in this program that we believe that it is something that works 70. : I know I struggle with grading, especially inquiry-based stuff. I think it's very difficult to put a grade on something if the student is showing an effort and not getting to what someone might consider the right answer, to tell that student that they're wrong, I think is a really		about having the late lunch or recess, or having the early lunch or recess or having specials, like art and music, like first thing in the morning or last thing in the day. Um, So, yeah it does ultimately come down to what the administration wants. What they think will make the school run the most smoothly and have the kids [00:28:39.01], you know, learn the most. 26. AG: Can you think of other factors at sort of the school level, maybe not just your school but school in general that would support integrated practices? Or maybe hinder the implementation of STEM? [00:32:14.01] C: Um, well like I said, the way the subjects are in the day in terms of the schedule could matter. Um, so if you wanted to integrate reading

		tough thing to do. [00:29:49.14] And it, it really interesting to me, the new grading system that elementary school has, which, we don't have in middle school [00:29:57.02] about, you know that if they're making progress or if they're satisfactory, I don't remember what all the letters were. I think it's very interesting to me because it seems so subjective to me. And I think a lot of STEM grading might have to be subjective, too. [00:30:15.29] Because you have a teacher who is there just kind of monitoring how the students are doing, the progress that they're making, almost like the effort level they're putting in, but [00:30:26.02] to me, grading STEM based on right or wrong, I don't think it always works. And I think...you know.		with science, it would be difficult if they were on different ends of the day. It would be better if they were right, backed up with each other. So you had like a really long time block to do reading and science together not to do it so disjointed. 27. I think another thing, at least in my school, is the make up of the team, each grade level team. At my grade level team, you know it's me and two other people, and one of them is a veteran, she's been teaching, I think this is her 29th year or 28th year, and the other person on the team, I think this is her third or fourth year. So, um, obviously, the other one has way more experience than both of us. **And, I feel like the more experience you have, the less open you are to change.** [00:33:24.17] So,

		71. E: Uh, well, I know in the community that I've taught in, Bethesda and Potomac are really close to each other so I've got a lot of the same population of students at both schools and every year I have students who come in and will not write anything down unless they know it's right and they'll constantly check with me to see if it's right [00:30:54.15] and I say, "Listen, you know, I'm most concerned about what you're thinking and if you're wrong, we're going to learn from it, we're going to change it, and, we'll move on. And their question always is, "How's that gonna affect my grade?" [smiles] and [00:31:08.24] I think it's unfortunate grades sometimes get in the way of learning. Um, but, at the same time, you also need grades to kind of be, like, that carrot in		On our team the dynamic is interesting sometimes because the other, younger teacher who has less experience, she's more willing to try more things, or integrated projects, than sometimes, the veteran teacher is, just because she's not as familiar with new technology or, um, so I think that's another big factor. Who is on your team, how many team members are there, how long have they been teaching, **what's their teaching style like anyway**. [00:33:58.12] 28. AG: OK good so this is bringing it to the level of the individual teacher, so, what kind of teaching styles, as you mentioned, or beliefs or practices do you think would make it such that a teacher has an easier time embracing STEM versus a

		front of the horse, that's like, you're working towards something. It's almost like telling someone to do a job without a paycheck and how can you do that? you really can't. 73. A: So could a student or a team of students still get an "A" if their bridge failed? [00:33:35.22] E: Yeah I think so [smiles] and I think that would be extremely frustrating to a lot of teachers out there. But, I mean, if you're I think if you facilitate the classroom right and you are there with the students through the whole process and, you know, verbal communication and written communication and you're giving them feedback and they're taking that feedback, then I don’t think that they've done		more difficult time? C: Um, well the teacher has to be comfortable releasing some control. I know that some teachers are very teacher-centered, as we've talked about in your class, and I think that if you're a teacher-centered type of classroom, that you're going to have a harder time embracing the STEM, because to do it authentically, the students have to guide the instruction, they have to be involved, [00:34:51.04] it can't be passive learning, it has to be active learning. So I think that if you're really comfortable with, kind of...if you're the kind of person who likes it to go your way and you know exactly what's going to happen next, then I think it's harder for you to become comfortable with integrated STEM. And if you're comfortable,

		anything incorrect in that situation. [00:34:11.26] If anything they've probably learned more than the group that just sort of built it up and it was a success and they were done. [00:34:20.17]		kind of letting go of the reins and letting the students, you know, be loud, be mess, I feel that some teachers are so, you know, anal about their classrooms, you know, like, "Oh it's going to make a mess**," but you know, learning is messy.** I feel like if you have a hard time accepting that, that's going to be hindering you from really integrating STEM effectively. [00:35:31.12] C: Why do you think some teachers are teacher-centered? [00:35:36.13] AG: Do you think that you are teacher-centered? C: No. [laughs] AG: Why not? C: I'm definitely [laughs], it's actually funny, I think the longer I've been teaching, the less teacher-centered I've become.

				AG: OK, why? C: I think at first, when you first start teaching, you're kind of thrown into it and you're kind of like, "OK, you know, I have to cover this and I have to be doing this at this time." And you're kind of nervous cause you know people are going to be coming in and observing you and you're just kind of paranoid. You know, "Am I doing it right?" And I think the more experience I've had, I've just realized how much the students CAN handle, um, you know, just in terms of releasing different responsibilities to them [00:36:49.01] Like, around, even in terms of helping to keep the classroom clean, you know they can really handle a lot. So I think just the more that you teach, the longer you teach, the more comfortable you become with it, just because you, you're not, well,

				first you're not under a magnifying glass like you are in the beginning years of your teaching and... 37. So why do you think that approach to teaching has persisted for so long? [00:47:13.27] C: I have no idea! [Laughs] I think it's because it's easier on the teacher. Um, it is, it would be easier to just do that. It would just be easier, as a teacher, in terms of preparation and work and grading and everything, it would just be easier to do it that way. Um, I think. And, so, I think that might be the reason why. 38. A: How do you think these kinds of approaches, say a teacher takes the approach of estimating volume, from the approach of doing it just to do it, doing it for the sake of doing it versus doing it for the sake of being able to

				apply it to the real world, what do you think are the underlying goals for education between the two? [00:48:03.01] C: Um, I think the traditional would be just cover a list of things you have to do, kind of just check it off your list, "OK, yep, I covered estimating and liquid volume, OK, check." You know, "I went over it with them, check. They can do it, check." Um and then the other, the integrated approach would be more focused on, "Can they use this in their future lives, in their future careers to help them, you know, do what they are trying to do in that time." So, can they apply it, can they actually use it to do something. Can they use it to solve a problem, can they use it to help them do something in their daily lives.

II Constraint: *TD STEM requires more time*

Meg	Kate	Kevin	Gabrielle	Carrie
2. I'm trying to integrate all of our subject matter so reading, writing, literature, math, engineering, technology and science all together and use all of those content areas in order to to um solve some kind of real world problem [00:07:02.15]. So that it does tend to take a lot of time and time is our biggest constraint. Um I, I try not to push to have just a reading block or just a math block or just a science block during those days when I do try to have a more integrated day. [00:07:17.10] It does tend to take the entire day and you do try to touch on all of those subjects but the problem with that is um we have a lot, I mean, we have to differentiate and leveled texts are very limited to certain subjects, at least the text that we have so being able to integrate all of those	So I think like initially, like, I mean the kind of overall segway that kids get is that it can be really fun-STEM lessons....like, most of the time, children love science. That's kind of just what I've found in first grade. It's something different, it's something kind of active. It's something where they get to move around and they generally like it so I feel like the STEM, um, lesson that I did was enjoyable for them and they definitely liked it. [00:09:06.23] I had to take away time, from my math block and time from other things to do it because it was, I think, a two or three day lesson..I did it last year so I'm not remembering exactly....but I took two or three days out of my normal, you know, curriculum 2.0 time to do it. Um. [00:09:25.26] But I think it was		76. 00:01:49.06] but then again, you know, of course, in our county we have to follow the curriclum and it's hard to have time for stuff like that. So it is hard but essentially, I guess it's what everyone strives to be moving towards, is , moving away from multidiscopliary and interdisciplary and more towards TD. 79. you know, the spread of it, or, you know, it's just really interesting to see what they come up with and just giving them that chane in the classroom would be awesome, but, [00:07:18.25] just like I said, it's hard because of the time and the curriculum that we do have to teach. So, um, [00:07:25.29] I don't know I just really think that, the critical questioning is vital when it comes to STEM education because	AG: So, the curriculum, so one challenge already is that the curriculum already packs a lot into... C: Yes. A: And gives you time frames? That you have to cover? C: Yeah, I mean, it says "week one" and the stuff I listed to you was week one. And so we are supposed to do all that in five days. A: And, but it seems like [00:22:50.17] You felt like you were able to kind of branch away from some of these curricular expectations. Why is that, why do you feel.... C: I feel like it's so important that [00:23:02.08], Um, I'll take a risk to not maybe get through something in order to do something really

subjects is challenging. 10. AG: what's the biggest challenge that an average teacher would face in trying to implement aspects of transdisciplinary STEM into her classroom, what would you say that would be? [00:19:46.17] M: Time. AG: Time? For...time for training? Time for actually doing the lessons? M: [laughs] both AG: everything [laughs] time in general. [00:19:54.16] M: That's the biggest thing, yes. I mean to prepare the materials, and to prepare ourselves with the content knowledge that's one thing. But just having the time, the amount of time during the day time to be able to do it [00:20:05.22] because we still do need to differentiate the reading, we are expected to differentiate the	something interesting & different for them. My children were especially excited because they hear a lot, the word, [air quotes] "STEM," I don't know how much the STEM teacher goes into what that means and how it connects to jobs, career-wise. [00:09:42.03] Like she kind of, like is really into the science aspect of it so she kind of focuses on science but I think the engineering is something that they also really much enjoy cause it can be a lot of hands on activities and it can obviously be very engaging. [00:09:55.27] So I think that also drives engagement for it. Um, but yeah, I think it was...if it was something that we could put into our schedule and we had a [air quotes] "STEM block" and it was something as a team we planned for and did it would be great [00:10:15.10] but it was me not doing something else and, you know, kind of on my own having		that's basically, I feel, the BASIS of it, you know, the, the importance of it, really getting them to think about how, 'how can I take this situation and make it better?" a[00:07:44.21] and then, just like, giving them the opportunity to rework their scenarios and their designs, things like that, so it really gets them thinking. [00:07:53.05]	meaningful and authentic. I mean, this project was so authentic. I mean, the earthquake had just happened, you know it was all over the news and a lot of kids knew about it. They saw it on the TV and I just said, "You know that is a huge problem that we have to deal with. Engineers have to try to deal with earthquakes and other natural disasters whenever they are planning." So, I guess to answer your questions, I kind of just was a rebel and, was thinking, you know, this is a really important, authentic...it's an opportunity: an opportunity to do a really meaningful, authentic project. [00:23:41.03] And I also felt like I was able to, kind of, [air quotes] 'get away with it' in the sense that I was still teaching objectives from a different subject. So, in reading this quarter we are doing informational reading skills. So, using text features to increase your comprehension, so

math, you know, and the types of content that we're supposed to be teaching for those are very um, are very specific, especially with the way the new grading system is, too. So we won't necessarily [00:20:22.00] be able to integrate all of our subjects and still hit on all of the different grading [indicators?] that we need to hit.	this lesson when so 55. so much of our planning is collaborative planning and so much of our schedules look exactly the same because we talk about it we decide on everything together. [00:10:34.27] so it was like "Oh, I'm not doing that, I'm not doing that tomorrow because I'm doing this." But if it was something that WAS a designated time in our, like, day schedule or weekly schedule, once a week maybe at some point, it would be a lot easier because everyone would be doing it. [00:10:49.14] It wouldn't be like I was feeling, "Oh, I need to do this other thing." Like, it was like, "Oh this is what I'm supposed to be doing because I have my STEM block time period so let me think of a STEM lesson to put it."			while we were preparing for the activity we did with earthquakes, all the reading of articles that we did, I was practicing reading skills with them. [00:24:10.10] So, that's another reason I kind of felt OK with it, because I was covering informational reading objectives. Even though earthquakes are not a part of curriculum, we were still practicing those informational strategies. Which, I have found myself doing much more this year than last year. [00:24:28.29] I found myself more comfortable kind of going away from the curriculum and doing TD STEM lessons that might not be in our science curriculum or our social studies curriculum, but that I can find articles about that then I can tie in in terms of just the informational reading objectives.

References

American Association for the Advancement of Science (1989). *Project 2061: Science for all Americans*. Washington, DC. Retrieved from: http://www.project2061.org/publications/sfaa/

Anderson, C. (2010). Presenting and evaluating qualitative research. American journal of pharmaceutical education, 74(8), 141.

Anderson, R. D. (2002). Reforming science teaching: What research says about inquiry. *Journal of science teacher education*, *13*(1), 1-12.

Anderson, D. S., & Piazza, J. A. (1996). Teaching and learning mathematics in constructivist preservice classrooms. *Action in Teacher Education*, *18*(2), 51–62.

Andrew, L. (2007). Comparison of teacher educators' instructional methods with the constructivist ideal. The Teacher Educator, 42(3), 157–184

Bächtold, M. (2013). What do students "construct" according to constructivism in science education?. Research in science education, 43(6), 2477-2496.

Ballenger, C. (1997). Social identities, moral narratives, scientific argumentation: Science talk in a bilingual classroom. *Language and Education*, *11*, 1-14.

Ball, D. L. (1993). With an eye on the mathematical horizon: Dilemmas of teaching elementary school mathematics. *The elementary school journal*, *93*(4), 373-397.

Ballenger, C. (1997). Social identities, moral narratives, scientific argumentation: Science talk in a bilingual classroom. *Language and Education*, *11*(1), 1-14.

Battista, M. (1994). Teacher beliefs and the reform movement in mathematics education. *Phi Delta Kappan, 17*, (2), 462-470.

Bell, P., Lewenstein, B., Shouse, A. W., & Feder, M. A. (Eds.). (2009). *Learning science in informal environments*. Washington, DC: National Academy Press.

Bennett, S., Harper, B., & Hedberg, J. (2001). Designing real-life cases to support authentic design activities. In G. Kennedy, M. Keppell, C. McNaught, & T. Petrovic (Eds.), *Meeting at the Crossroads. Proceedings of the 18th Annual Conference of the Australian Society for Computers in Learning in Tertiary Education* (pp. 73-81). Melbourne: Biomedical Multimedia Unit, University of Melbourne.

Berkenkotter, C., & Huckin, T. N. (2016). *Genre knowledge in disciplinary communication: Cognition/culture/power*. Routledge.

Berland, L. K., Schwarz, C. V., Krist, C., Kenyon, L., Lo, A. S., & Reiser, B. J. (2016). Epistemologies in practice: Making scientific practices meaningful for students. *Journal of Research in Science Teaching, 53*(7), 1082-1112.

Blickenstaff, J. C. (2005). Women and science careers: Leaky pipeline or gender filter? *Gender and Education, 17* (4), 369 – 386.

Blumenfeld, P., Soloway, E., Marx, R., Krajcik, J., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist, 26* (3&4), 369-398.

Board on Science Education (BOSE), 2013. *Monitoring progress toward successful K-12 STEM education: A nation advancing?* Washington DC: National Academies Press.

Bonk, C. & Cunningham, D. (1998) Searching for learner-centered, constructivist, and sociocultural components of collaborative educational learning tools. In C. J. Bonk, & K. S. King (Eds.), *Electronic collaborators: Learner-centered technologies for literacy, apprenticeship, and discourse* (pp. 25-50). Mahwah, NJ: Erlbaum.

Bransford, J.D., Brown, A.L., & Cocking, R.R. (2000). *How people learn: Brain, mind, experience, and school*. Washington D.C.: National Academy Press.

Braun, V. & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology,* 3, 77-101.

Brenner, M. E. (2006). Interviewing in educational research. In J. L. Green, G. Camilli, & P. B. Elmore (Eds.), *Handbook of complementary methods in education research* (pp. 357-370). NJ, Mahwah: Lawrence Erlbaum Associates, Inc.

Brickhouse, N., & Bodner, G. M. (1992). The beginning science teacher: Classroom narratives of convictions and constraints. *Journal of Research in Science Teaching, 29*(5), 471-48

Brooks, J., & Brooks, M. (1993). *The case for the constructivist classrooms*. Alexandria, VA: ASCD. 5.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*(1), 32-42.

Burkhardt, H, Fraser, R., & Ridgway, J. (1990). The dynamics of curriculum change. In I. Wirszup & R. Streit (Eds.), *Development in school mathematics education around the world,* (Vol. 2, pp. 3-29). Reston, VA: NCTM.

Bybee, R. W. (1993). *Reforming science education: Social perspectives and personal reflections*. New York: Teachers College Press.

Bybee, R.W. (2010a). What is STEM education? *Science, 329* (5995), p. 996

Bybee, R. W. (2010b). Advancing STEM Education: A 2020 Vision. *Technology and Engineering Teacher*, *70* (6) 30-35.

Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities.* Arlington, VA: National Science Teachers Association.

Candela, A. (1999). Students' power in classroom discourse. *Linguistics and Education, 10*(2), 139–163.

Caplow, T., Hicks, L., & Wattenberg, B.J. (2000). *The First Measured Century: An Illustrated Guide to Trends in America, 1900-2000*. Washington: AEI Press.

Capraro, R.M., Capraro, M.M. & Morgan, J.R. (Eds.) (2013). *STEM project based learning: an integrated science, technology, engineering and mathematics approach*. Rotterdam, the Netherlands: Sense publishers.

Cazden, C. (1988). *Classroom discourse*. Portsmouth, NH: Heinemann.

Cazden, C. (2001). *Classroom discourse: The language of teaching and learning* (2nd ed.). Portsmouth, NH: Heinemann.

Cazden, C. B., & Beck, S. W. (2003). Classroom discourse. *Handbook of discourse processes*, 165-197.

Chan, K.W., & Elliott, R. G. (2004). Relational analysis of personal epistemology and conceptions about teaching and learning. *Teaching and Teacher Education, 20*, 817-831.

Christodoulou, A., & Osborne, J. (2014). The science classroom as a site of epistemic talk: A case study of a teacher's attempts to teach science based on argument. *Journal of Research in Science Teaching, 51*(10), 1275-1300.

Cobb, P. (1994). Where is the mind? Constructivist and sociocultural perspectives on mathematical development. *Educational Researcher, 23,* (7), 13-20.

Collins, A. (2002). How students learn and how teachers teach. In R. W. Bybee (ed.), *Science educators' essay collection: Learning science and the science of learning* (pp. 3-11). Arlington, VA: National Science Teachers Press.

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprenticeship: Teaching the craft of reading, writing, and mathematics. In L. B. Resnick(Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser* (pp. 453–493). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Collins, A., Brown, J.S., and Newman, S.E. (1989). Cognitive apprenticeship: teaching the crafts of reading, writing, and mathematics, in R.B. Resnick (ed.) *Knowing, learning and instruction: Essays in honour of Robert Glaser* (pp. 453-494). Mahwah, NJ: Lawrence Erlbaum.

Creswell, J.W. (2009). *Research design: Qualitative, quantitative and mixed methods approaches* (3rd ed.). Thousand Oaks, CA: Sage.

Creswell, J. W. & Miller, D. L. (2010). Determining validity in qualitative inquiry. *Theory into Practice, 39*, (3). 124-130.

Czerniak, C. M., & Johnson, C. C. (2007). Interdisciplinary science teaching. *Handbook of research on science education*, 537-559.

Czerniak, C. M., & Lumpe, A. T. (1996). Relationship between teacher beliefs and science education reform. *Journal of Science Teacher Education*, *7*(4), 247-266.

Darling-Hammond, L. (2010). Evaluating teacher effectiveness: How teacher performance assessments can measure and improve teaching. *Center for American progress.* http://www.americanprogress.org/pressroom/releases/2010/10/evaluating_teachers.html

DeBoer, G. E. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching, 37*(6), 582-601.

Dewey, J. (1902). *The child and the curriculum*. Chicago, IL: Chicago University Press. [etext from Project Guteberg. http://www.gutenberg.org].

Draper, R. J. (2002). School mathematics reform, constructivism, and literacy: A case for literacy instruction in the reform-oriented math classroom. *Journal of Adolescent & Adult Literacy, 45*(6), 520-529.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23*(7), 5-12.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education, 84*(3), 287–312.

Duit, R. (2016). The constructivist view in science education–what it has to offer and what should not be expected from it. Investigaçôes em ensino de ciências, 1(1), 40-75.

Duschl, R.A. & Gitomer, D.H. (1997). Strategies and challenges to changing the focus of assessment and instruction in science classrooms. *Educational Assessment, 4*(1), 37-73.

Duschl, R. (2008). Science education in three-part harmony: Balancing conceptual, epistemic, and social learning goals. *Review of research in education*, *32*(1), 268-291.

Eisenhart, M. (2006). Representing qualitative data. In J.L.Green, G. Camilli, & P. B. Elmore (Eds.), *Handbook of complementary methods in education research* (567-582). Mahwah, NJ: Lawrence Erlbaum Associates.

Elby, A. & Hammer, D. (2001). On the substance of a sophisticated epistemology. *Science Education*, *85*(5), 554-67.

Ertmer, P. A., & Ottenbreit-Leftwich, A. (2010). Teacher technology change: how knowledge, confidence, beliefs, and culture intersect. *Journal of Research on Technology in Education, 42*(3), 255-284.

Fenichel, M., & Schweingruber, H. (Eds.). (2010). *Surrounded by science: Learning science in informal environments*. Washington, D.C.: The National Academies Press.

Fenstermacher, G. D. (1986). Philosophy of research on teaching: Three aspects. *Handbook of Research on Teaching, 3*, 37-49.

Fenstermacher, G. D., & Richardson, V. (2005). On making determinations of quality in teaching. *Teachers College Record*, *107*(1), 186-213.

Fisk, D.M. (2001). American labor in the 20th century. *Compensation and work conditions.* Retrieved from https://www.bls.gov.

Ford, M. (2008). Disciplinary authority and accountability in scientific practice and learning. *Science Education*, *92*(3), 404-423.

Ford, M. J., & Forman, E. A. (2006). Redefining disciplinary learning in classroom contexts. *Review of research in education*, *30*(1), 1-32.

Forman, E. A., & Ford, M. J. (2014). Authority and accountability in light of disciplinary practices in science. *International Journal of Educational Research, 64*, 199–210.

Foss, D. H., & Kleinsasser, R. C. (1996). Preservice elementary teachers' views of pedagogical and mathematical content knowledge. *Teaching and Teacher Education, 12*(4), 429 442.

Gee, J. P. (1985). The narrativization of experience in the oral style. *The Journal of Education, 167* (1), 9-35.

Gee, J.P. (1989). What is literacy? *Journal of Education: Literacy, Discourse, and Linguistics: Essays by James Paul Gee, 171* (1), 18-25.

Gee, J.P. (1999). *An introduction to discourse analysis.* New York: Routlage.

Gee, J. P. (2012). *Sociolinguistics and literacies: Ideology in discourses*. Fourth Edition. London: Taylor & Francis.

Gitlin, A., & Margonis, F. (1995). The political aspect of reform: Teacher resistance as good sense. *American Journal of Education, 103*, 377-405.

Grabinger, R. S., & Dunlap, J. C. (1995). Rich environments for active learning: A definition. *ALT-J, 3*(2), 5-34.

Greeno, J. G. (1997). On claims that answer the wrong questions. *Educational Researcher, 26*(1), 5-17.

Greeno, J. G., Collins, A. M., & Resnick, L. B. (1996). Cognition and learning. In D. Berliner & R. Calfee (Eds.*), Handbook of educational psychology* (pp. 15-46). New York: Macmillan.

Greeno, J. G., & the Middle School Through Applications Project Group. (1998). The situativity of knowing, learning, and research. *American Psychologist*, *53*, 5-26.

Greenwich Public Schools. (2006). *Transdisciplinary learning.* Greenwich Public Schools Virtual Library. Retrieved from http://www.greenwichschools.org/page.cfm?p=6697.

Halliday, M. A. K., & Martin, J. R. (2003). *Writing science: Literacy and discursive power*. Taylor & Francis.

Hammer, D. (1994). Epistemological beliefs in introductory physics. *Cognition and Instruction, 12*(2), 151-183.

Hammer, D., & van Zee, E. (2006). Seeing the science in children's thinking: Case studies of student inquiry in physical science, a staff developer's guide. Portsmouth, NH: Heinemann.

Handal, B., & Herrington, A. (2003). Mathematics teachers' beliefs and curriculum reform. *Mathematics education research journal, 15*(1), 59-69.

Haney, J. J., Czerniak, C. M., & Lumpe, A. T. (1996). Teacher beliefs and intentions regarding the implementation of science education reform strands. *Journal of Research in Science Teaching, 33*(9), 971-993.

Hartas, D. (Ed.). (2010). *Educational Research and Inquiry: Qualitative and Quantitative Approaches*. New York, NY: Continuum International Publishing Group.

Henderson, J. B., MacPherson, A., Osborne, J., & Wild, A. (2015). Beyond construction: Five arguments for the role and value of critique in learning science. *International Journal of Science Education, 37*(10), 1668-1697.

Hofer, B. K. (2001). Personal epistemology research: Implications for learning and teaching. *Educational Psychology Review*, *13*(4), 353–383.

Hofer, B. K. (2004). Epistemological understanding as a metacognitive process: Thinking aloud during online searching. *Educational Psychologist*, *39,* 43–55.

Hofer, B. (2006). Domain specificity of personal epistemology: Resolved questions, persistent issues, new models. *International Journal of Educational Research, 45,* 85-95.

Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research, 67*(1), 88–140.

Hofer, B. K., and Pintrich, P. R. (1999). Knowing and believing: Personal epistemology and classroom context. Paper presented at the annual meeting of the American Educational Research Association, Montreal.

Horn, R. A. (2002). *Understanding education reform: A reference handbook*. Santa Barbara, CA: ABC CLIO.

Howard, B. C., McGee, S., Schwartz, N., & Purcell, S. (2000). The experience of constructivism: Transforming teacher epistemology. *Journal of Research on Computing in Education, 32*(4), 455-465.

Jenkins, E. W. (2000). Constructivism in school science education: Powerful model or the most dangerous intellectual tendency? *Science & Education, 9*, 599-610.

Jones, M. G., & Brader-Araje, L. (2002). The impact of constructivism on education: Language, discourse, and meaning. *American Communication Journal*, *5*(3), 1-10.

Kardash, C. M., & Scholes, R. J. (1996). Effects of preexisting beliefs, epistemological beliefs, and need for cognition on interpretation of controversial issues. *Journal of Educational Psychology, 88*(2), 260-271. doi:10.1037/0022-0663.88.2.260

Kelly, G. J. (2014). Discourse practices in science learning and teaching. *Handbook of research on science education*, *2*, 321-336.

Kelly, G. J., & Chen, C. (1999). The sound of music: Constructing science as sociocultural practices through oral and written discourse. *Journal of research in science teaching*, *36*(8), 883-915.

Keys, C.W., & Bryan, L. (2001). Co-constructing inquiry-based science with teachers: Essential research for lasting reform. *Journal of Research in Science Teaching, 38*, 631– 646.

Kim, C., Kim, M. K., Lee, C., Spector, J. M., & DeMeester, K. (2013). Teacher beliefs and technology integration. *Teaching and Teacher Education, 29*, 76-85.

Klein, J. T. (1990). *Interdisciplinarity: History, theory & practice*. Detroit: Wayne State University Press.

Kress, G., Jewitt, C., Ogborn, J., & Tsatsarelis, C. (2001). *Multimodal teaching and learning: The rhetorics of the science classroom.* London: Continuum.

Kuper A., Lingard L., & Levinson W. (2008). Critically appraising qualitative research. BMJ;337. a1035.

Lave, J. & Wenger, E. (1991) Situated Learning: Legitimate Peripheral Participation, Cambridge: Cambridge University Press.

Lederman, N. G. (1999). Teachers' understanding of the nature of science and classroom practice: Factors that facilitate or impede the relationship. *Journal of Research in Science Teaching, 36*(8), 916-929.

Lederman, N., Abd-el-Khalick, F., Bell, R.L., & Schwartz, R.S. (2002). Views of Nature of Science Questionnaire: Towards valid and meaningful assessment of learners' conceptions of the nature of science. *Journal of Research in Science Teaching, 39*, 497–521.

Lederman, N.G., Lederman, J.S., & Antink, A. (2013). Nature of science and scientific inquiry as contexts for the learning of science and achievement of scientific literacy. *International Journal of Education in Mathematics, Science and Technology, 1*(3), 138-147.

Lederman, N. G. & Zeidler, D. L. (1986). Science' teachers' conceptions of the nature of science: 'Do they really influence teaching behavior? Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Francisco, CA. ERIC No. ED 267 986.

Lee, O., & Fradd, S. (1998). Science for all, including students from non-English-language backgrounds. *Educational Researcher, 27*(4), 12 -21.

Lee, O. (2002). Promoting scientific inquiry with elementary students from diverse cultures and languages. *Review of Research in Education. 26*, 23–69.

Lemke, J. (1990). *Talking science: Language, learning, and values*. Norwood, NJ: Ablex.

Lemke, J. L. (2005). *Textual politics: Discourse and social dynamics*. Taylor & Francis.

Levin, D.M., Hammer, D, Elby A. & Coffey, J. E. (2012). *Becoming a Responsive Science Teacher: Focusing on Student Thinking in Secondary Science*. Arlington, VA: NSTA Press.

Lombardi M. (2007) Authentic learning for the 21st Century: an overview. Educause Learning Initiative, ELI Paper 1/:2007. Retrieved from: https://www.researchgate.net/profile/Marilyn_Lombardi/publication/220040581_Authentic_Learning_for_the_21st_Century_An_Overview/links/0f317531744eedf4d1000000.pdf

Lovat, T. J., & Smith, D. (1995). *Curriculum: Action on reflection revisited*. Australia: Social Science Press.

Maggioni, L., & Parkinson, M. M. (2008). The role of teacher epistemic cognition, epistemic beliefs, and calibration in instruction. *Educational Psychology Review, 20*(4), 445-461.

Marshall, C., & Rossman, G. B. (2014). *Designing qualitative research*. Sage publications.

Martell, C. C. (2014). Building a constructivist practice: A longitudinal study of beginning history teachers. The Teacher Educator, 49(2), 97-115.

Matthews, M. (2002). Foreword and introduction. In W.F. McComas (Ed.), *The nature of science in science education: Rationales and strategies* (xi-xxi). New York: Kluwer Academic Publishers.

Maxwell, J.A. (1992). Understanding and validity in qualitative research. *Harvard Educational Review 62*, (3). 279-300.

Maxwell, J. A. (2013). *Qualitative research design: An interactive approach*. Third Edition. Los Angeles: Sage publications.

Mayer, R. E. (1999). Designing instruction for constructivist learning. Instructional-design theories and models: *A new paradigm of instructional theory, 2*, 141-159.

Mayes, T. & de Freitas, S. (2007). Learning and e-Learning: The role of theory. In H. Beetham & R. Sharpe (eds.*) Rethinking pedagogy in the digital age*. London. Routledge.

Merriam, S.B. (1988). *Case study research in education: A qualitative approach*. San Francisco, CA: Jossey-Bass Publishers.

Merriam, S. (1995). What can you tell from an N of l?: Issues of validity and reliability in qualitative research. *PAACE Journal of lifelong learning, 4,* 50-60.

Merriam, S.B. (1998). *Qualitative Research and Case Study Applications in Education*. San Francisco, CA: Jossey-Bass Publishers.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook* (2nd ed.). Thousand Oaks CA: Sage Publications.

Milner, A. R., Sondergeld, T. A., Demir, A., Johnson, C. C., & Czerniak, C. M. (2012). Elementary teachers' beliefs about teaching science and classroom practice: An examination of pre/post NCLB testing in science. *Journal of Science Teacher Education*, *23*(2), 111-132.

Moje, E. B. (1995). Talking about science: An interpretation of the effects of teacher talk in a high school science classroom. *Journal of Research in Science Teaching*, *32*(4), 349-371.

Moje, E., Collazo, T., Carillo, R., and Marx, R. (2001). "Maestro, what is quality?": Language, literacy and discourse in project-based science. *Journal of Research in Science Teaching*, *38*(4), 469-498.

Mortimer, E., & Scott, P. (2003). *Meaning Making In Secondary Science Classrooms*. McGraw-Hill Education (UK).

Moulding, B.D., R.W. Bybee, and N. Paulson. 2015. *A vision and plan for science teaching and learning: An educator's guide to A Framework for K–12 Science Education, Next Generation Science Standards, and state science standards*. Salt Lake City: Essential Teaching and Learning Publications.

Murnane, R. & Levy, F. (2004). The New Division of Labor: How Computers Are Creating the Next Job Market. Princeton, N.J.: Princeton University Press.

National Research Council. (1992). *Research and education reform: Roles for the Office of Educational Research and Improvement*. Washington, DC: The National Academies Press. https://doi.org/10.17226/1973.

National Research Council. (1996). *National science education standards*. National Academies Press.

National Research Council. (2007). *Taking Science to School: Learning and Teaching Science in Grades K-8*. Washington, DC: The National Academies Press. doi: 10.17226/11625.

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: The National Academies Press.

Naylor, S. & Keogh, B. (1999). Constructivism in classroom: Theory into practice. *Journal of Science Teacher Education, 10,* 93-106.

Newby, P. (2010). *Research methods for education*. (2nd ed). London and New York: Routledge.

Nissani, M. (1997). Ten cheers for interdisciplinarity: the case for interdisciplinary knowledge and research. *The Social Science Journal, 34* (2), 201–216.

NGSS Lead States (2013a). Appendix G-Crosscutting concepts. *Next Generation Science Standards: For States, By States.* Retrieved from: http://www.nextgenscience.org/sites/ngss/files/Appendix%20G%20-%20Crosscutting%20Concepts%20FINAL%20edited%204.10.13.pdf

NGSS Lead States (2013b). Appendix H- Understanding the scientific enterprise: The nature of science in the Next Generation Science Standards. *Next Generation Science Standards: For States, By States.* Retrieved from: http://nextgenscience.org/sites/ngss/files/Appendix%20H%20-%20The%20Nature%20of%20Science%20in%20the%20Next%20Generation%20Science%20Standards%204.15.13.pdf20Crosscutting%20Concepts%20FINAL%20edited%204.10.13.pdf

NGSS Lead States (2013c). Development overview. *Next Generation Science Standards: For States, By States*. Retrieved from: http://www.nextgenscience.org/development-overview

NGSS Lead States (2013d). FAQs. *Next Generation Science Standards: For States, By States.* Retrieved from: http:// https://www.nextgenscience.org/faqs

NGSS Lead States (2013e). Three-dimensional learning. *Next Generation Science Standards*: For States, By States. Retrieved from: http://www.nextgenscience.org/three-dimensions

Noddings, N., Maher, C. A., & Davis, R. B. (Eds.). (1990). *Constructivist views on the teaching and learning of mathematics*. National Council of Teachers of Mathematics.

Organisation for Economic Co-operation and Development (2008). *21st Century learning: research, innovation and policy. Directions from recent OECD analyses.* Retrieved from: http://www.oecd.org/site/educeri21st/40554299.pdf

Packer, M. J., & Goicoechea, J. (2000). Sociocultural and constructivist theories of learning: Ontology, not just epistemology. *Educational Psychologist*, 35, 227-241.

Pajares, F. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research*, *62*, 307-332.

Patton, M.Q. (1999). Enhancing the quality and credibility of qualitative analysis. *Health Services Research*. *34*(5 Pt 2)*: 1189–1208.*

Patton, M.Q. (2002). *Qualitative research & evaluation methods*. (3rd ed.). Thousand Oaks, CA: Sage Publications.

Prawat, R. S. (1992). Teachers' beliefs about teaching and learning: A constructivist perspective. *American Journal of Education, 100*(3): 354-395.

Pruitt, S.L. (2015). Foreword. In B. D. Moulding, R. W. Bybee, & N. Paulson, *A vision and plan for science teaching and learning: An educator's guide to A Framework for K-12 Science Education, Next Generation Science Standards, and state science standards* (p. xi). Salt Lake City: Essential Teaching and Learning Publications.

Richardson, V. (1996). The role of attitudes and beliefs in learning to teach. In J. Sikula (Ed.), *The handbook of research in teacher education* (2nd edition, pp. 102–119). New York: Macmillan.

Reeves, T.C., Herrington, J., & Oliver, R. (2002). Authentic activities and online learning. In A. Goody, J. Herrington , & M. Northcote (Eds.), *Quality conversations: Research and development in higher education*, *25* (562-567). Jamison, ACT: HERDSA.

Riessman, C.K. (2005). Narrative analysis. *Narrative, memory & everyday life.* University of Huddersfield, Huddersfield, (1-7). Retrieved from: http://eprints.hud.ac.uk/4920/

Roehrig, G. H., Kruse, R. A. and Kern, A. (2007), Teacher and school characteristics and their influence on curriculum implementation. *Journal of Research on Science Teaching, 44*: 883–907.

Rogers, E. M. (1948). Science in general education. In E. J. McGrath (Ed.), *Science in general education*. Dubuque, IA: William C. Brown Co.

Rogers, R. (Ed.). (2004). *An introduction to critical discourse analysis in education.* Mahwah, NJ: Lawrence Erlbaum.

Rosebery A., Warren B. & Conant F. (1992). Appropriating scientific discourse: Findings from language minority classrooms. *Journal of the Learning Sciences 2* (1): 61–94.

Rowe, M. L. (2008). Child-directed speech: Relation to socioeconomic status, knowledge of child development, and child vocabulary skill. *Journal of Child Language*, *35*, 185-205.

Roy, R., (1979). Interdisciplinary science on campus: that elusive dream. In: Kocklemans, J.J. (Ed.), Interdisciplinarity and Higher Education. University Park, PA: Pennsylvania State University Press.

Rutherford, F.J., & Ahlgren, A. (1990). *Science for all Americans*. New York: Oxford University Press.

Sandelowski M. (1986). The problem of rigor in qualitative research. *Advances in Nursing Science, 8*(3), 27–37.

Sandelowski M. (1993). Rigor and rigor mortis: The problem of rigor in qualitative research revisited. *Advances in Nursing Science, 16*(2), 1–8.

Sandelowski M. (2000). Whatever happened to qualitative description? *Research in Nursing & Health, 23*(4), 334–340.

Sanders, M. (2008). STEM, STEM Education, STEMmania. *Technology Teacher, 68*, 4, 20-26.

Sanders, M. (2012) Integrative STEM Education as "Best Practice," 7th Biennial International Technology Education Research Conference Queensland, Australia, Paper presented 12/8/12.

Sandoval, W. A. (2005) Understanding students' practical epistemologies and their influence on learning through inquiry. *Science Education, 89*(4). 634-656.

Saunders, M. & Chrisman, C. (2011). Linking Learning to the 21st Century: Preparing All Students for College, Career, And Civic Participation. Boulder, CO: National Education Policy Center. Retrieved from http://nepc.colorado.edu/publication/ linking-learning.

Savery, J.R. & Duffy, T.M. (June, 2001). Problem Based Learning: An instructional model and its constructivist framework. *The Center for Research on Learning and Technology*, CRLT Technical Report No. 16-01. Retrieved from https://4f9d1bea-a-62cb3a1a-s-sites.googlegroups.com/site/bilingeduc/pages-and-groups/learning-and-teaching-theories/ProblembasedlearningAninstructionalmodelanditsconstructivistframework.pdf?attachauth=ANoY7cq7UjjQPtDr3uDXkfWcZVIrmaQnkaAPV4cLLaoXAkAJFRlMz79csoDYFcFWsNJbrdB-Z7n1EBmTPoFfifq0hM3rCEU6ORg4mUQKGf5rZ1BOUH0LtZSptKVuvj3LI-79BJ9sP0jnYgpmOK9oaz4BM6CfunXBLKJgoGazywLvRfFa91foj3yJme2k6p9P efTQwFe9co2mHuDiHiM91vKmHd5eyuI-RoE6dmadWzthNgwvIL4JoLylSl1v7xE-5RnUD9bvjcxFq5pXaB96qYhCWOJOsJdIya-t0jIDEI4M82bt8YO9yNkfJAvYF756j5TKAKDWbp8ao9pIiE4F8TYh3SXI479PRs9DT7q2hcid6TafNcOeCNE%3D&attredirects=0

Schommer, M. (1990). The effects of beliefs about the nature of knowledge on comprehension. *Journal of Educational Psychology, 82*, 498–504

Schommer, M., Crouse, A., and Rhodes, N. (1992). Epistemological beliefs and mathematical text comprehension: Believing it is simple does not make it so. *Journal of Educational Psychology*. *82*: 435–443.

Schommer-Aikins, M. (2002). An evolving theoretical framework for an epistemological belief system. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 103–118). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Scott, P. (1998). Teacher talk and meaning making in science classrooms: A Vygotskian analysis and review. *Studies in Science Education, 32*, 45 – 80.

Shenton, A. K. (2004). Strategies for ensuring trustworthiness in qualitative research projects. *Education for information*, *22*(2), 63-75.

Short, K., & Burke, C. (1990). *Creating curriculum. Portsmouth,* NH: Heinemann

Short, K., & Burke, C. (1996). Examining our beliefs and practices through inquiry.Language Arts, 73(2), 97–104.

Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1-23.

Shulman, L. S., & Quinlan, K. M. (1996). The comparative psychology of school subjects. *Handbook of educational psychology*, 399-422.

Schulz, R. M. (2014). *Rethinking science education: Philosophical perspectives*. IAP.

Silva, E. (2009). Measuring skills for 21st-century learning. *Phi Delta Kappan, 90,* 630–634.

Slezak, P. (1994). 'Sociology of science and science education: Part I', *Science & Education* (3), 265-294.

Smith, J. P. III, and M. Girod. 2003. John Dewey and psychologizing the subject-matter: Big ideas, ambitious teaching, and teacher education. *Teaching and Teacher Education* 19: 295–307.

Stake, R. E. (1978). The case study method in social inquiry. *Educational researcher*, *7*(2), 5-8.

Stevens, R., Wineburg, S., Herrenkohl, L. R., & Bell, P. (2005). Comparative understanding of school subjects: Past, present, and future. *Review of Educational Research*, *75*(2), 125-157.

Stipek, D. J., Givvin, K. B., Salmon, J. M., & MacGyvers, V. L. (2001). Teachers' beliefs and practices related to mathematics instruction. *Teaching and Teacher Education,17*, 213-226.

Stroupe, D. (2014). Examining classroom science practice communities: How teachers and students negotiate epistemic agency and learn science‐as‐practice. *Science Education*, *98*(3), 487-516.

Sullenger, K. & Turner, S. (2002). Nature of science: Implications for education-An undergraduate course for prospective teachers. In W.F. McComas (Ed.), *The nature of science in science education: Rationales and strategies* (xi-xxi). New York: Kluwer Academic Publishers.

Teo, T., Chai, C. S., Hung, D., & Lee, C. B. (2008). Beliefs about teaching and uses of technology among pre-service teachers. *Asia-Pacific Journal of Teacher Education*, *36*(2), 163-174.

Thomas, J. W. (2000). *A review of research on project-based learning.*

Tobin, K. G. (1993). *The practice of constructivism in science education*. Psychology Press.

Tobin, K., & McRobbie, C. J. (1996). Cultural myths as constraints to the enacted science curriculum. *Science Education, 80*, 223–241.

Tobin, K. & Tippins, D. (2009) Constructivism as a referent for teaching and learning. In K.G. Tobin (Ed.), *The Practice of Constructivism in Science Education*. (3-22). New York and London: Routledge.

Tobin, K., Tippins, D. J., & Gallard, A. J. (1994). Research on instructional strategies for teaching science. *Handbook of research on science teaching and learning*, *45*, 93.

Turnbull, B. (2002). Teacher participation and buy-in: Implications for school reform initiatives. *Learning Environments Research*, *5*(3), 235-252.

US Department of Education. (2009). *Guidance on standards, assessments, and accountability*. Retrieved from: http://www2.ed.gov/policy/elsec/guid/standardsassessment/guidance_pg5.html

Van Driel, J., Beijaard, D., Verloop, N. (2001). Professional development and reform in science education: The role of teachers' practical knowledge. *Journal of Research in Science Teaching*, *38* (2), pp. 137-158.

Vasquez, J. A. (2015). STEM--Beyond the Acronym. *Educational Leadership*, *72*(4), 10-15.

Vasquez, J.A., Schneider, M., & Comer, C. (2013). *STEM lesson essentials: Integrating science, technology, engineering, and mathematics*. Portsmouth, New Hampshire: Heinemann.

von Glasersfeld, E. (1992). *A constructivist approach to teaching*. Paper presented at the Alternative Epistemologies Conference at the University of Georgia, Athens, GA.

von Glasersfeld, E. (1995). *Radical constructivism: A way of knowing and learning.* Washington, DC: Falmer.

Walsh, S. (2006). *Investigating classroom discourse*. Routledge.

Warren, B. & Rosebery, A. (1995). Equity in the future tense: Redefining relationships among teachers, students, and science in linguistic minority classrooms. In W. Secada, E. Fennema, & L. Adajian (Eds.), *New directions for equity in mathematics education* (298–328). New York: Cambridge University Press.

Warren, B., Ballenger, C., Ogonowski, M., Rosebery, A. S., & Hudicourt-Barnes, J. (2001). Rethinking diversity in learning science: The logic of everyday sense-making. *Journal of research in science teaching, 38*(5), 529-552.

Wells, G., & Arauz, R. M. (2006). Dialogue in the classroom. *The Journal of the Learning Sciences, 15*(3), 379–428.

Wenger, E. (1998). Communities of Practice. Cambridge: Cambridge University Press.

Windschitl, M. (2002). Framing constructivism in practice as the negotiation of dilemmas: an analysis of the conceptual, pedagogical, cultural, and political challenges facing teachers. *Review of Educational Research, 72*(2), 131-175.

Wyatt, Ian D. and Daniel E. Hecker. 2006. “Occupational Changes during the 20th Century.” Monthly Labor Review (March): 35-57.

Yin, R.K. (1994). *Case study research: Design and methods*. (2nd ed). Thousand Oaks, California: Sage.

Zhang, Y., & Wildemuth, B. (2009). Qualitative analysis of content. In B. Wildemuth (Ed.), *Applications of social science research methods to questions in library and information science.* Englewood, CO: Libraries Unlimited.

Zeidler, D.L., & Lederman, N.G. (1987). The effects of teachers' language on students' conceptions of the nature of science. Paper presented at the 60th Association for Research.