NAVIGATING THE TERRAIN OF STEM EDUCATION REFORM:

TEACHERS' PERSPECTIVES

by

Sarah M. Chesney

Bachelor of Arts, University of Pennsylvania, 1999

Master of Science in Education, University of Pennsylvania, 2000

Submitted to the Graduate Faculty of

the School of Education in partial fulfillment

of the requirements for the degree of

Doctor of Education

University of Pittsburgh

2017

UNIVERSITY OF PITTSBURGH

SCHOOL OF EDUCATION

This dissertation was presented

by

Sarah M. Chesney

It was defended on

July 18, 2017

and approved by

Dr. Ellen Ansell, Associate Professor, Instruction and Learning

Dr. Jennifer Iriti, Research Associate, Learning Research and Development Center

Dissertation Advisor: Dr. Ellice Forman, Professor, Instruction and Learning

NAVIGATING THE TERRAIN OF STEM EDUCATION REFORM:

TEACHERS' PERSPECTIVES

Sarah M. Chesney, EdD

University of Pittsburgh, 2017

This study concerns the work of teachers as they implement ambitious educational reforms, which often requires teachers to shift toward significantly different approaches to pedagogy within their unique contexts (Metz, 2009). STEM (science, technology, engineering and mathematics) education represents the context of ambitious reform for this study, particularly with focuses on integration across STEM and other disciplines. Current studies tend not to address the practices of STEM teaching and learning, or their effectiveness with respect to design, implementation and resulting student outcomes. *How then do educators do this work? As a problem of practice, how do teacher educators support educators in this work?*

As a qualitative case study, one interdisciplinary grade-level team, representing middle school mathematics, science, history and English Language Arts (ELA), was observed and interviewed during the planning and implementation of an upcoming collaborative project. Focus groups were used to clarify and member-check collected data.

This purpose of this study was to better understand what the *collaborative space* contributes to the work of teachers in interdisciplinary collaboration. Findings suggest that teacher agency, in combination with intentional utilization of the collaborative space, provide opportunities for teachers to engage students through non-traditional instructional practices. In

addition, the collaborative space appeared to allow for exploration of individual and group teaching practices. The external context also emerged as an essential support and motivation to sustain the collaborative space.

In terms of interdisciplinary outcomes, this case appears to be driven by implicit frameworks for collaborative design, instruction and evaluation. It is unclear to what extent the outcomes were STEM-focused or integrated. In addition, the high leverage of the team's beliefs may not represent actual student experiences (i.e., some students who thrive within a testing-focused culture, appear to resist open, student-driven learning experiences as designed by the team).

Because of these findings, this study suggests several implications for teachers in defining the explicit frameworks used in their practice. Collaborative exploration of these frameworks may help teams better leverage teacher agency to be more disciplined in their approach to design, instruction and evaluation, and sustaining the work beyond the boundaries of their team.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to the following people whom have been instrumental in the navigation of my own professional and life-long learning.

To Dr. Ellice Forman, Dr. Ellen Ansell, and Dr. Jennifer Iriti: I thank you for your continued guidance, insights, and diverse perspectives. For me, you changed the meaning of “committee” to one that inspires deep thinking and collective creativity. Thank you for sharing in the excitement of this journey.

To my esteemed friends: As we continue to contemplate our purpose on this pale blue dot, you’ve challenged me thoroughly in discourse that demands critical thinking, evidence, passion, and action. Thank you for teaching me and learning with me. (You know who you are).

To my mother in law, Linda: Thank you, Mema, for being here for all of us. It takes a village to raise a child, even those that have grown long ago. Thank you for bringing some sanity to our daily, unpredictable adventures!

To my parents, my first educators: Dad, you taught me to question and explore the puzzles of math and science. Mom, you taught me to set my sights high, go for it, and persevere. Together, you provided me with a love for learning that I hope I am bestowing onto my own kids.

To my dear children, John and Lily: You have grown so much these last few years…! I thank you for trying to understand my different roles as mommy, teacher, and student. But mostly I thank you for the needed breaks, laughs, and silly moments. You both are my golden sunshine.

And finally to my husband and best friend, Glenn: You have been an unwavering support for me, our children, and our family on this trek we call life. I have never met someone so positive about what the future can hold and the various forms it can take. Thank you always for your patience and encouragement to *boldly go where we have not gone before.*

1.0 INTRODUCTION

The last three years of study within this program have not only provided me with the opportunity to study key issues in education, but also to research these issues as related to my professional practice. As a result, this culminating work is a dissertation *in* practice. Inspired by the professional development opportunities I had been immersed in as a middle school teacher, I left the classroom to provide similar opportunities to other teachers. A passion for thinking about tricky concepts in science and inquiry-based teaching and learning applications led to me to my current organization, where "teachers teach teachers." We utilize a blend of best theoretical practices and each other's professional practice to engage teachers in the field. Professional development design has evolved from simple workshops to higher level institutes and courses that foster the implementation of new approaches, reflection of practice, and opportunities to make substantive changes in teaching and learning practices. I have experienced professional development in its many forms as an important vehicle for educators as they engage in challenging reforms, including the ambiguities defining the effort at the outset. It is from this perspective that I begin this inquiry.

1.1 BROADER PROBLEM AREA

1.1.1 Ambitious reform

At the broadest level, this inquiry of study concerns the work of teachers as they implement ambitious educational reform. The last several decades of standards-based reform have engaged our nation’s educators and students in a collective movement for improved equity, excellence and accountability. Much of education reform has its roots in mathematics and the sciences, with a renewed focus on learning theory and authentic disciplinary practices. My organization, too, was founded out of a need for reform in science education, building upon shifting approaches to curriculum, professional development, materials, assessment and leadership (Smithsonian, 2017). A broad base of literature has been devoted to studying the effectiveness of science and mathematics reforms and the impacts on the teaching and learning environment. In most cases, however, these reforms have been found to be quite ambitious for schools as they require teachers to shift toward significantly different approaches to pedagogy within their unique contexts (Metz, 2009). The challenges facing teachers to reform their practices may be mediated by many factors, including personal beliefs about teaching, instructional practices, curriculum options, and opportunities for professional development. From the perspectives of teacher *and* professional developer, I have experienced varying outcomes of reform efforts, typically due to differences in commitment and the desire to improve between individuals and school contexts. Reform, therefore, is a challenging effort from both sides of the spectrum. Professional developers, too, need the strategies to adjust to the shifting climate and culture in their room of practitioners.

1.1.2 STEM education as a reform

STEM (science, technology, engineering and mathematics) education represents one such reform with efforts toward increasing equity and achievement in mathematics and science, as well as improving the US workforce pipeline in STEM-related fields. Many national organizations, such as the National Governor's Association and American Association for the Advancement of Science, encourage an integrated, multidisciplinary approach for the teaching and learning of STEM topics, concepts, and issues (Rutherford & Ahlgren, 1990; Thomasian, 2011).

In 2013, my organization saw an influx of inquiries around STEM education materials and professional development opportunities. Consequently, our research and development team determined several ambiguities regarding the literature around STEM, and compiled a framework of best practices that helped to distinguish quality STEM education learning experiences.

For this inquiry, I derived an operational definition of STEM education from the current literature around best practices and models, and as well as from the research in mathematics and science education (Arizona STEM Foundation, 2013; Change the Equation, 2016; Engle & Conant, 2002; Stein, 2000). Aspects from each of these resources have been utilized in professional development within my organization and others around the nation. Research on effectiveness of this combination of features, however, appears yet to be conducted (as will be explored further in Chapter 2). The definition of "effectiveness" is also vague in this sense: Does effectiveness imply interest, attainment, learning or all three? Because the definition of STEM is currently ambiguous, I have articulated the following statement in order to anchor my analysis and discussion around STEM:

> STEM education reform: 1) removes the traditional barriers between disciplines, demonstrated by integrated or interdisciplinary teaching and learning practices. Integration may include any of the STEM (science, technology, mathematics, and engineering) subjects and other non-core disciplines (such as language, arts, and social studies). Integration refers to an explicit connection and opportunities for application between concepts and skills across disciplines. These connections may be linked by some overarching, issue, or theme, to further provide a context and rationale for learning (Arizona STEM Foundation, 2013; Change the Equation, 2016); 2) provides learning experiences designed to foster productive disciplinary engagement (PDE) and tasks of high cognitive demand (HCD) (Engle & Conant, 2002; Stein, 2000); and 3) promotes access for all students (Arizona STEM Foundation, 2013; Change the Equation, 2016). STEM education reforms vary along a continuum to the extent to which a program or curriculum enacts each feature. For example, a program may offer high to low integration; high to low PDE and HCD; and engagement for some to all students.

This description contrasts with some common views about STEM, such as what my organization has termed “check-the-box STEM” and “shiny objects syndrome.” Checking-the-box methods of STEM suggest simply engaging students in any one of the STEM subjects with very little emphasis on the connection between them. The implementation of “shiny objects” refers to engaging students in the latest technological advances or STEM-labeled programs, also with very little connection to students’ core learning experiences. In these cases, STEM appears as a separate silo unto its own.

The vision outlined in the operational definition above implies the need for reforming many of today’s traditional instructional, curricular, and assessment practices. Unfortunately, national publications provide very little programmatic or instructional guidance for successful implementation of these goals (Committee on Prospering in the Global Economy of the 21st Century & Committee on Science, Engineering, and Public Policy, 2007; National Research Council, 2011; President's Council of Advisors on Science and Technology, 2010). Guidelines for which to implement these initiatives are particularly unclear to the practitioner. For example, when describing “integrated approaches,” does this concept refer to disciplines, practices, or both? Then, what kinds of programs and instructional practices accomplish this description, and how effective are these programs in achieving the desired outcomes? And subsequently, how are teacher educators able to support teachers in reaching and sustaining these goals?

There appear to be few studies on the effectiveness of implementations of STEM initiatives on conceptual learning, particularly with an integrated approach. In a review of current literature, studies on STEM education tend to examine common themes, including: student engagement in STEM-focused subjects in high school; motivation for students to continuing secondary education toward STEM degrees; and attainment of STEM careers (Becker and Park, 2011; Gutherie, Wigfield, & VonSecker, 2000; Honey, Pearson, & Schweingruber, 2014). These studies are fewer about the effectiveness of the teaching and learning of STEM, which may be of importance to educators who design STEM curriculum and instruction for learners. Many studies link achievement in science and mathematics to a student’s participation in STEM programs (Hansen & Gonzalez, 2014; McClain, 2015; Scott, 2012). However, in most cases, it is unclear what qualifies a particular program as inclusive of STEM. On a broader scale, practitioners may find it difficult to compare the spectrum of STEM programs given that most implementations of STEM are so diverse in characterization.

1.1.3 A problem facing educators

Many questions remain for educators: Beyond the acronym and visionary definitions of STEM, what characterizes STEM teaching and learning? Beyond science and mathematics knowledge, what skills and practices should students develop in school, needed as a foundation for later education and career? From an instruction and curriculum perspective, what skills and practices do teachers need to know, demonstrate, and incorporate into meaningful learning experiences for all students? With focuses on integrated approaches, what work can take place collaboratively? How can this collaborative space benefit the work that teachers aim to accomplish within their individual classrooms?

A lack of common vision around STEM education between national, political, and educational institutions may be problematic for supporting teachers in this challenging work, and ultimately, addressing access for all. As a professional developer, my overarching focus of this inquiry will be to understand how educators navigate this challenging terrain, and ultimately, to collaboratively share lessons learned to other educators and teacher educators engaging in this work.

1.2 A PROBLEM OF PRACTICE

My problem of practice stems from the larger challenges facing teachers who are implementing reforms: in this case, STEM education reforms. In my current practice in teacher professional development for STEM educators, I encounter many educators with common questions surrounding STEM education. Often teachers and administrators alike are unable to articulate with specificity what encompasses quality STEM education. Is STEM education a focus on programs, teaching, or both? Many schools are developing their STEM education programs by redesigning or realigning their district's existing curriculum, selecting and piloting new curriculum, or adopting outside projects or programs. Often schools focus on enhancing or restructuring science and mathematics core curriculum to include technology and engineering connections. Many of these initiatives arise from our nation's goals to be more competitive globally in the STEM fields, and many teachers and administrator stakeholders imagine very different initiatives surrounding STEM. Consequently, many teachers are left to individually implement these changes to their practice and curriculum with little understanding of STEM, and in large part, without the structures to support their professional learning and practice. Such support structures may include strong administrative support, access to resources and materials, scheduling that promotes common planning time, professional development for implementing new programs, and continuous evaluation and feedback systems, to name a few (Arizona STEM Foundation, 2013).

Knowing that the challenges of vision setting, implementation, and collaboration exist for educators, as a professional development teacher educator, my ultimate goal is to support educators in such work. The close examination of a single case provided me a space within which to study the challenges and structures that support teachers as they navigate the complex terrain of designing and enacting STEM-focused, collaborative outcomes. For this study, one group of teachers was selected to participate in a case study of their practices and interactions as a collaborative team in the design and implementation of their work. Specifically, I identified one team within one middle school. From my prior experience as a middle school teacher, many middle schools offer the opportunity for a team of teachers to work closely together to teach and assess the same group of students. The selected team for this study has a history of team collaboration (i.e., common team planning and enactment of projects) and focused on integrating their four subjects (i.e., science, mathematics, English Language Arts and history). Primarily through interviews, observations, and focus groups, I examined their processes more closely, and in this document, provide a discussion about design and teaching challenges that may be able to inform the broader practitioner audience. [Note: Even though the context of STEM education typically includes technology and engineering, I chose not to focus on the integration of science and mathematics with these other two disciplines specifically. The research suggests that these approaches are also varied which makes it difficult to interpret their effects on student learning (Sanders, 2012).]

1.2.1 Conceptual framework

For this study, I specifically examined and described how teachers designed and planned their interdisciplinary approach to a collaborative unit. According to Remillard (2005) and M. Brown (2002), teaching is a complex act that involves a process of curriculum design. Teaching is not merely enacting curriculum, but an ongoing interaction with the curriculum that may yield a variety of outcomes for teaching and learning.

Let us imagine a group of teachers who have recently been presented with new inquiry-based science materials in professional development. The science teacher of the team has some ideas for modifying the written materials to reflect a STEM-focus, one that her team is planning enact back in their classrooms. Upon returning to the classroom, she begins to individually design and reconstruct the unit, and at times, collaborate with her peers. From an external perspective we may have questions about the science teacher's work: How does the teacher understand the curriculum as written? What are its implied goals and outcomes? What are her specific goals? How does the teacher structure her planning such that she can implement the curriculum to meet her goals? Does the integrity of the original program degrade? Does it matter? What would be the issue in modifying or adapting aspects of the curriculum? Does the teacher consider these or other impacts on student learning as a result of her planning? What tools does she need to do this work? How does the collaboration with others impact her decisions?

There are many decisions to be made with respect to curriculum use and instruction. Remillard (2005) and M. Brown (2002) suggest that teachers engage in a *participatory relationship* with curriculum which is mediated by teacher-related factors such as pedagogical content knowledge, beliefs about teaching, pedagogical design capacity, and personal learning and teaching experiences, as illustrated in Figure 1, reference *a*. The teacher brings these embedded aspects of their identity as an educator and designer to the curriculum. The curriculum itself (Figure 1, reference *b*) presents a subjective array of constructs, concepts, and representations within its materials that may align to teachers' current practices or suggest other new and innovative practices. As an artifact, the materials convey information abstractly. The voice and look of curriculum can greatly influence how it may be perceived by teachers. Only through interpretation and enactment by a practitioner does the curriculum become an active tool (Brown, 2002).

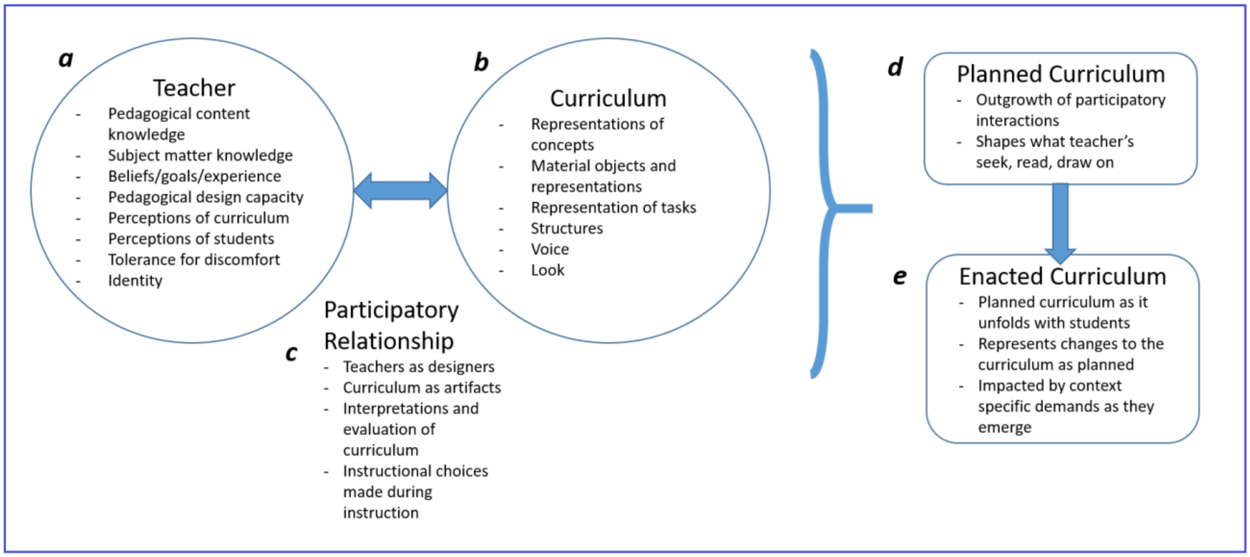


Figure 1. Teacher-curriculum relationship

As teachers read, interpret and evaluate curriculum, they begin to enter the *teacher-curriculum relationship* of which Remillard describes (Figure 1, reference *c*). The outcomes of these interactions impact the instructional choices made in *planning* (Figure 1, reference *d*) and *enactment* (Figure 1, reference *e*) of the curriculum. M. Brown (2002) defines this capacity to plan and design appropriate instructional experiences as *pedagogical design capacity* (PDC). This capacity includes an awareness of available and appropriate resources, the ability to mobilize and use resources, an understanding of how choices make affordances to learners, and the "degree to which teachers create deliberate, productive designs that help to accomplish their instructional goals" (p. 29). M. Brown suggests that understanding a teacher's degree of PDC may explain how teachers of similar knowledge and skills may enact similar curriculum in different ways.

Inspecting instruction and curriculum further, M. Brown (2002) characterizes in-the-moment decisions made during instruction, which occur during the *planned* (reference *d*) and *enacted* (reference *e*) phases. These three modes include offloading, improvising, and adapting curricular materials, and may suggest a particular level of teacher agency in curricular use and instruction. In our previous example, the science teacher who is incorporating inquiry-based materials to be more STEM-focused, may decide to rely primarily on aspects of the curriculum materials. In this sense, she offloads much of her teaching agency to the curriculum materials such that they guide her instruction. Her agency may be higher when she chooses to incorporate her own spontaneous connections and strategies by entering into improvisation, and thereby relying less on the curricular materials. Adapting curriculum suggests the highest agency in the use of both curricular materials and personal resources. M. Brown cautions that these three uses do not necessarily correspond to teacher expertise. The teacher may demonstrate lack of knowledge about a particular science concept and rely heavily on the curriculum (offloading), but then have great expertise in leading students through open-ended engineering challenges and support students easily with careful, unplanned questioning (improvisation). These three modes suggest the ability to mobilize materials at appropriate times that makes sense to them. A group of teachers may enact the same curriculum differently depending on their teaching and learning identity.

Remillard's (2009) notion of the teacher-curriculum relationship also speaks to the differences between the *curriculum as written* (reference *b*), the *curriculum as planned* (reference *d*), and the *curriculum as enacted* (reference *e*). In line with M. Brown's thinking, the curriculum as *written* does not represent actual teaching. It is an abstract and subjective form of designed curriculum. The *planned* curriculum is what is derived out of the participatory interaction. As teachers participate with the curriculum, both the teacher's identity and features of the curriculum influence what the teacher pays attention to, reads, interprets, and subsequently plans. The *enacted* curriculum represents the changes to what was planned; they are the plans as they play out during instruction, where the teacher, students, and context influence what happens during instruction. An examination of the changes in curriculum between what was intended, planned, and enacted may reveal teacher challenges and strengths, and potential opportunities for teaching learning.

Utilizing this framework in the context of STEM education raises some important questions. For example, in my practice, teachers often inquire about the silver bullet (the mythical one STEM program that “works”). It may not be enough to just steer a teacher in a particular direction. The curriculum represents only *one* possibility for what students may learn. What is actually enacted by teachers in the classroom is what is experienced and learned by students (Remillard, 2005; Stein, Remillard, & Smith, 2007). What, then, are the beliefs about teaching, pedagogical content knowledge, pedagogical design capacity, and experiences that are important and necessary for engaging teacher in the complexities suggested in the nation’s vision for STEM? When determining effectiveness of a STEM program, it may be important to understand the answers to such questions.

With respect to the *collaborative* nature of teachers’ work in designing and enacting STEM focuses, this study provides an opportunity for teachers to reflect about their collective practices as a team. Within a socio-cultural perspective, I examined the dynamics related to the co-construction of the goals, design and planning for a team’s collective work. In particular, what support structures are present or emerge to support their work? Do teachers utilize common planning as opportunities for self and team reflection? How do these interactions influence many of the factors described with the realm of the teacher’s domain, as suggested by Remillard (2005) and M. Brown (2002)? From my perspective as a professional developer, what implications can be gleaned from these teachers’ experiences for the kinds of professional learning experiences that teachers need to have to support their work in STEM once they return to their site?

Revisiting the teacher-curriculum relationship (Remillard, 2005) it may be important to understand how teachers negotiate and subsequently design current curriculum as a *collaborative* team, particularly when attempting integrated approaches. The teacher-curriculum relationship as depicted in Figure 1, represents one teacher teaching one discipline. In Figure 2, I modified the teacher-curriculum framework to show collaboration across four teachers. In the first phase of this conjecture, teachers collaboratively plan, which results in the articulation of collaborative goals. In some sense, these goals represent the "curriculum" of which the individual teachers must interact and enact. This diagram represents one possibility of co-design where teachers contribute his or her beliefs and experiences to a collaborative goal. In the last phase, it is conjectured that teachers may enact different outcomes once reaching their individual classroom spaces.

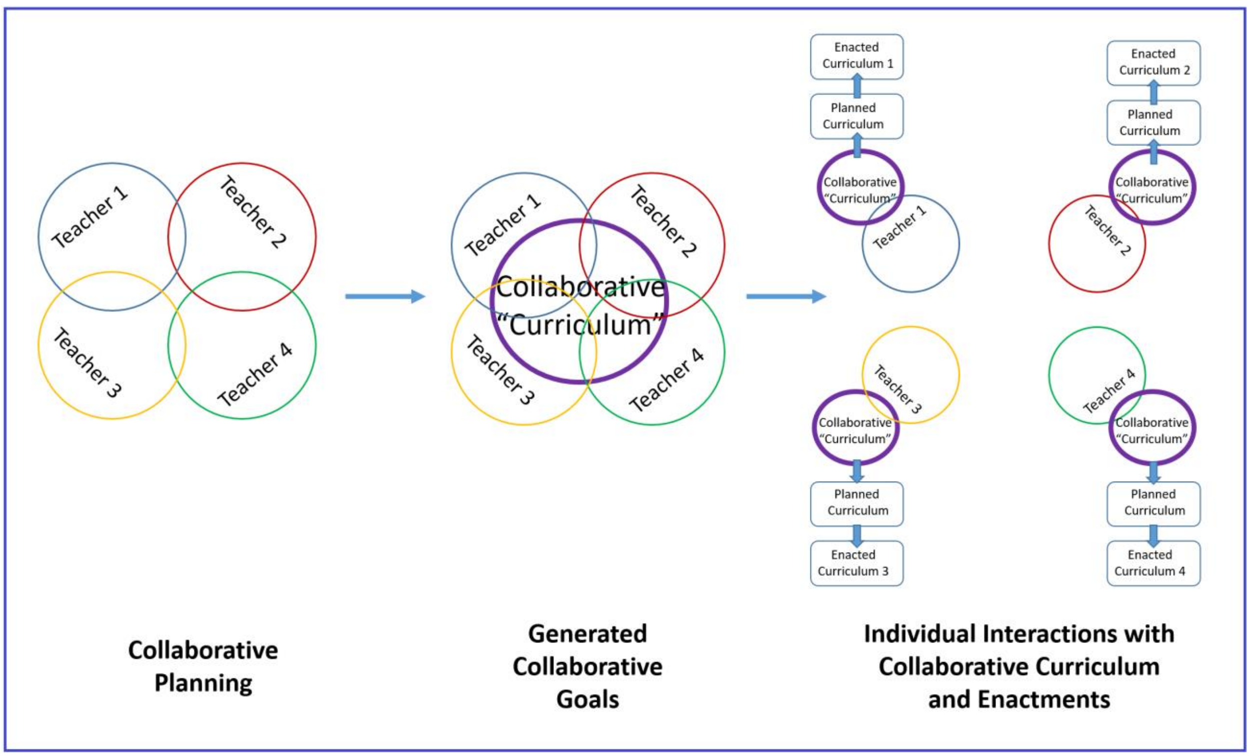


Figure 2. Conjecture map: T-C relationship within a group

As teachers determine how and what to plan, what outcomes result from their collaboration? What outcomes arise from individual enactments? Or does something else occur?

1.3 INQUIRY QUESTIONS

The overarching goal of this study is to describe the work of teachers designing and implementing a collaborative, integrated approach to STEM. *Integration* is one characteristic of STEM described in my operational definition presented above. Because this appears to be a largely undefined space in the STEM literature (i.e., how to systematically or successfully do this work), it may be informative to deeply examine the practices of teachers who are attempting these practices in order to share the emerging challenges and support structures in place, and raise important questions about individual and collaborative design and instruction.

In this case study, the selected teachers function as part of a middle school team. Each teacher is responsible for teaching and assessment of student learning within their specific content area (mathematics, science, history, and ELA). As a collective team, these four teachers share the same groups of students. These teachers have a history of collaboratively planning group projects, and determining integrated instructional and learning goals that work to connect their specific content areas. While the teachers work collaboratively to plan, the individual teachers are ultimately the enactors of these goals in their individual classrooms. After they leave the collaborative space, each teacher explicitly interacts with the decided upon curriculum to make choices about what to plan and enact within his or her classroom.

Given this unique context, *what does the collaborative space contribute to the work of teachers in interdisciplinary collaboration*? To help investigate this overarching question, two sub-questions guided this study:

1) *What does the collaborative space look like?*

Through various qualitative methods, my first goal was to describe *how* these teachers interact with one another together. Which processes does the team use to do collaborative design work? What lenses do the teachers focus upon in their collaborative approach (i.e., lenses of instruction and pedagogy, content, disciplinary practices, curriculum, and/or engagement)? As a result of asking these questions, I was able to document perceived challenges and the supports necessary to guide the teachers in the navigation of those challenges.

2) *What purposes does the collaborative space offer the team?*

The second goal of this study, in addition to uncovering how the team works together, was to understand *what* the team chooses to do collaboratively and *why* they choose to do this work. Specifically, examining underlying beliefs of the team revealed how a team collaboratively, and individually, makes sense of ambiguous constructs such as *integration* and *STEM*, and in which directions they choose to pursue and why.

By examining the group processes as a unit (Question 1), and then examining more deeply into the purposes of their collaborative work (Question 2), I was better able to examine the overarching question. Patterns of practice and elements of teacher agency emerged as drivers for collaborative work. Understanding the interactions and complexities between individuals and the collaborating team provides useful discussion for educators and those of us in teacher education with insights for better supporting teachers engaged in the complex work of integrated, collaborative STEM-focused design and implementation.

2.0 LITERATURE REVIEW

A review of the literature presented me with the opportunity to identify a more narrowed focus for my topic of study, which started quite broadly as an investigation into STEM education. In particular, I recognized three common concerns of teachers in my current practice. First, teachers struggled with defining STEM and the important components of quality STEM learning experiences. The notion of *integrating* subjects remains elusive to many. Specifically, teachers were concerned about their efficacy in teaching another subject that exceeded their comfort zone. Because integration often implies collaborating with other educators, teachers were unclear how to find the time and supports needed to cross disciplinary boundaries.

The following questions were derived from these organic concerns, and guided the present literature review:

(1) What is the current state of STEM education research? What defines quality STEM education efforts, and what has been the impetus for moving toward an interdisciplinary approach in STEM education? ***(2.1)***

(2) What can be learned from the space of science and mathematics educational reform? What are the challenges that educators face? ***(2.2)***

(3) What supports do teachers utilize to implement educational reforms and make shifts in their teaching and learning practices? How does professional development,

representative of my area of practice, emerge as a support structure for educators? ***(2.3)***

2.1 AN INTERDISCIPLINARY APPROACH

It appears that national and educational perspectives lean toward an interdisciplinary approach to STEM education (Morrison, 2006; President's Council of Advisors on Science and Technology, 2010; Rutherford & Ahlgren, 1990; Thomasian, 2011). The American Association for the Advancement of Science's (AAAS) *Science for All* set a vision for STEM education in 1989: By 2061, students will achieve scientific literacy necessary for productive citizenry in our nation's critical decision making. The authors articulated a need for making connections between concepts and practices within science, mathematics and technology. This suggests that teaching and learning should naturally reflect these relationships (AAAS, 1989). More recently, the Next Generation Science Standards called for an integration of engineering design and scientific inquiry, such that students can deepen their understandings of science within other connected contexts (NGSS Lead States, 2013).

Interdisciplinary approaches, often under other terminology, are not new to education and have been studied in the literature for almost forty years. In reviews of history and literature by Czerniak (2000) and Hurley (2001, 2003), consensus has not been reached on the preferred term or definition for these approaches. In much of the work of the past, the focus has been primarily on *interdisciplinary* or *integrated,* approaches, yet many other terms have been used interchangeably. Most educators and researchers agree that *disciplinary* usually refers to the specific core knowledge, practices, and ways of knowing that are distinct to that discipline. In its essence, *interdisciplinary* refers to the *integration* (e.g., connection) of two or more disciplines (Czerniak, 2000; Kurt & Becker, 2011; Stinson, Harkness, Meyer & Stallworth, 2009). The variations for how deeply disciplines are integrated, and through which focus, largely depend on who is defining the approach.

In practitioner journals as well, the descriptions of cross-disciplinary approaches are also used loosely to imply integrating disciplines (Drake & Burns, 2004). For example, *multidisciplinary* approaches are often thought of as teacher-centered, where the content and skills of specific disciplines are connected under a theme. In *interdisciplinary* approaches, teaching and learning of content and skills of one discipline occurs within another discipline. As a newly emerging term in STEM circles, *transdisciplinary* approaches tend to be more learner-centered, where learners work to solve central problems by applying the content and skills of many disciplines. The issues of focus are designed to bridge relevant connections and build new perspectives.

In general, the purposes for integrating science and mathematics have been aimed at improving student learning in these disciplines, increasing motivation and interest in learning, and shifting away from more traditional approaches to learning (Barakos, Lujan, & Strang, 2012; Becker & Park, 2011; Czerniak, 2000; Honey, Pearson, and Schweingruber, 2014; Sanders, 2012; Stinson et al., 2009). Research in the learning sciences seems to support the latter goal. Bransford, A. Brown and Cocking (2000) in their work on *How People Learn*, foundationally identified key principles of learning that highlight implications for teaching and learning in schools. First, learners require experiences that are designed to foster deep conceptual understanding. Learners enter the classroom with preconceptions, many of which are misconceptions developed from their everyday real-world experiences. School learning environments should provide students with the opportunities to challenge their initial thinking. It should not be assumed that students are to be filled with information via transmission of knowledge from teacher to the student. Learners begin to make sense of their individual processes of learning when they are engaged in metacognitive approaches (i.e., thinking about one's thinking during or after an experience). Teachers are charged with developing purposeful environments to support such learning, rather than relying on engagement in activity alone to be sufficient.

The prevalence of traditional approaches in classrooms today implies that a renewed focus is needed for teaching practices that are to result in effective learning. Bransford et al. developed a framework for the design of classroom environments that builds upon the foundational principles for learning. Schools, classrooms, and professional development programs all should be designed to be community-, learner-, knowledge- and assessment-centered. In this framework, a community-centered approach develops and sustains the values and norms of learning agreed to by all participants in the community. Centering on the learner focuses instruction and learning opportunities on the individual's thinking, knowledge, and development. The subject matter being taught and the overarching goals for instruction become intentional and follow specific criteria for success. Teachers that intentionally utilize information gathered from ongoing formative assessments are then able to shape instruction into meaningful learning experiences (Bransford et al., 2000). For interdisciplinary approaches in the case of STEM education, it would be important to evaluate the designed learning experiences to maximize learning outcomes.

Authors in STEM education claim that interdisciplinary approaches specifically help students learn more effectively (Barakos et al., 2012, Czerniak, 2007; Honey et al., 2014). On the surface, the desired outcomes seem to align with findings in learning sciences. Common claims in the literature suggest that integration builds relevance for students. For example, these experiences may make explicit connections between the sciences and mathematics that provide a meaningful purpose for engaging in these subjects in school. These learning experiences may foster deeper conceptual understandings, and as a result, may increase student achievement in these disciplines. In addition, interdisciplinary approaches are thought to enhance future motivation in these disciplines, as students find relevancy and different entry points into mastering their understandings. Finally, one goal for interdisciplinary approaches is to mirror the social complexity of problem solving in the real world. For example, investigating solving climate change issues, environmental scientists do not work in isolation. They work collaboratively on this problem with physicists, chemists, and engineers, to name a few. Such practices take into consideration interests and prior conceptions, and promote shared thinking and argumentation. It is assumed that individual and collective experiences drive learning, and present situations that allow for transfer of knowledge into new and complex situations. While these claims are motivating to the educational community and STEM reformers, the research findings are not yet conclusive on actual effects on students learning (Czerniak, 2006; Hurley 2001).

Below, I present the literature pertaining to interdisciplinary approaches in education. I classified several themes within this literature: 1) a more hypothetical, non-empirical base of articles, essays, and reports, 2) research literature focused specifically on science and mathematics integration, prior to the STEM movement, and 3) research literature in specific interdisciplinary approaches to STEM.

2.1.1 Literature that presents the hypothetical

A significant portion of the literature around interdisciplinary approaches to STEM is hypothetical or conjectural in nature. These articles are often written by government entities and educator practitioners who do not empirically support their claims with research findings. The move to an interdisciplinary focus in STEM education was fueled primarily by political agendas and the consensus therein that our nation's approach to teaching and learning would need to change in order to improve our future workforce. Much of this literature (e.g., Committee on Prospering in the Global Economy of the 21st Century & Committee on Science, Engineering, and Public Policy, 2007; Morrison, 2006; President's Council of Advisors on Science and Technology, 2010; Thomasian, J., 2011) presents a rhetoric whose purpose is to incite motivation for implementation. Several reports offer frameworks that move beyond the rhetoric, however, these have not been researched and supported by evidence to date. For example, Honey et al. (2014) crafted a framework to support educators in identifying their goals, outcomes, and explicitly defining the nature of integration and implementation. The consensus appears to be that instructional and curricular approaches in primary through college levels would need to shift to reflect the realistic disciplinary and interdisciplinary nature of our nation's academic and productive workforce. A move away from more traditional, disciplinary silos suggests innovation in teaching and learning, yet the reality is that very little research has been conducted to study the effectiveness of these approaches with respect to STEM education (Czerniak, 2007; Hurley 2001).

2.1.2 Research in science and mathematical integration

Educators in support of and opposition to interdisciplinary reform draw on earlier studies in science and mathematics integration. Hurley (2001) conducted a meta-analysis of 31 studies that integrated science and mathematics. These studies were conducted between the 1940s to 1990s, in a variety of settings and grade levels, and reported data on outcomes in student achievement in response to science and mathematics integration. She quantitatively classified five types of integration in this sample: *sequenced* (the intentional teaching of subjects in sequence such that connections can be made), *parallel* (the planning and teaching of subjects together), *partial* (a combination of separating and integrating subjects), *enhanced* (integrated teaching with an emphasis on one subject as enhancing the other), and *total* (two subjects integrated with equal emphasis). Her analysis compared these studies to non-integrated controls, and revealed a general trend for positive effects on achievement in science and mathematics when these disciplines were integrated. She noted, however, that effects in science learning were much higher than those in mathematics, depending on which approach was utilized. For example, for all integrated approaches except *sequenced*, mathematics achievement was found to be much lower than science. This finding is difficult to explain, as the descriptions of these studies do not reveal to what extent topics and/or processes were explored or which instructional methods supported learning in these cases.

In a smaller subset of qualitative studies, findings showed that instructional decisions made by teachers during integrated teaching had detrimental effects on student learning (Mason, 1996; Roth, 1994). Aspects of the content were found to be trivialized and oversimplified when teachers demonstrated a lack of understanding in one of the disciplines. When integration was forced to fit an overarching theme, certain logical learning progressions for mathematics or scientific concepts were found to be disrupted. In this case, students failed to develop foundational understandings and developed superficial notions of concepts.

In summary, there appear to be positive outcomes for both achievement and motivation with interdisciplinary approaches for learning. However, the varied approaches (which were largely undocumented) suggest that interdisciplinary design and implementation may be more complex than simply connecting two disciplines.

2.1.3 Research in interdisciplinary STEM

It would be important for the research literature to provide evidence to support effects on student achievement about an implementation or intervention. School leaders who are investigating STEM-focused programs will need to understand impacts on student achievement as relevant to their student population. A next logical step would be to understand the conditions necessary to generate these effects on achievement. Leaders would be better able to articulate a strategic plan for teacher and curriculum development to initiate the needed changes.

Most of the empirical research on interdisciplinary STEM efforts, however, is focused primarily on student interest, motivation, and attainment within the distinct STEM disciplinary fields. Such findings show increased interest, attitudes, and motivation to learn within the STEM disciplines (Gutherie, Wigfield, & VonSecker, 2000). It must be noted again that interdisciplinary approaches in these studies were quite varied.

Becker and Park (2011) in their meta-analysis of STEM integration studies suggest that even within a classification of the type of integration, it is still unclear as to whether teachers integrated the content, processes, or some combination of the two disciplines. It is difficult to determine what aspect of the integration had the most effect on any of these aspects.

As a collective, these findings have great limitations for generalizability and causality. Of the examples in the literature, these studies represent many diverse interdisciplinary approaches and institutional contexts, focused on small sample sizes and reliance on pre- and post- survey data (Czerniak, 2007; Honey et al., 2014; Hurley 2001, 2003). Very few comparisons can be made across the studies as a result. In addition, little research has been conducted on which approaches to use for integration and which conditions are most effective for achievement and motivation (Honey, et al., 2014). It appears that the foundational research in mathematics and science integration and those within the learning sciences have given STEM education reformers the inspiration to move in this direction.

Several implications for future implementation are offered from the research in interdisciplinary approaches. Through the meta-analyses of Czerniak (2007) and Hurley (2001), educators are cautioned to address the current state of instruction and curriculum within an institution, consider time constraints for such an implementation, and clarify and challenge basic assumptions, which may include teacher knowledge gaps and disposition.

A select few studies on integration implementation revealed that critical supports were needed to make interdisciplinary connections clear. Stinson (2009) conducted a study on middle school teachers' characterizations of integrated lessons. He found that teachers were less able to identify lessons as integrated when the connections were more abstract and the content less familiar to teachers. Teachers comparatively were inconsistent in their ratings, and offered varying explanations as to how they characterized lessons. Stinson concluded that teachers apply a set of internal criteria related to personal content understandings and preferences when deciding how to integrate concepts and processes. Stinson went as far to suggest that having a deeper disciplinary knowledge in one area seemed to interfere with conceptualization of interdisciplinary approaches. In other words, a teacher’s extreme focus on science concepts may hinder the power of mathematics to support or connect to science in an interdisciplinary attempt. Stinson suggests that highly effective teachers are recommended for this kind of work. These teachers would have been trained specifically in interdisciplinary teaching and learning practices, and possibly holding multiple disciplinary degrees in the areas they will teach. There are very few interdisciplinary approaches provided in teacher preparation courses (Sanders, 2012), which suggests that many teachers may not be fully prepared to teach in this fashion. This work can be supported, however, by intentional partnerships with experts in the community, disciplinary fields, and university scholars to increase achievability of these goals (Sanders, 2012).

In summary, there are several challenges presented to educators in this movement toward interdisciplinary approaches to STEM, including ambiguous models and definitions. There has been little emphasis on which approaches are most effective, and a lack of guidance for how to measure such effectiveness. Very little empirical research can be compared, and findings in foundational approaches to interdisciplinary approaches also vary on effectiveness in achievement. Interestingly, in Honey et al. (2014) in their *Agenda for Research for STEM Integration* argue, “the level of evidence gathered by this committee [may not be] not sufficient to suggest that integrated STEM education could or should replace high-quality education focused on individual STEM subjects. [As] parts of the STEM education community are already moving toward integration,…adding new tools to the STEM education toolbox is exciting and should be coupled with rigorous research and assessment of implementation efforts” (pp. 10-11). From my perspective in professional development, I believe that these words of caution remind the educational community that it is important to engage in practitioner research in this relatively new terrain. Their contributions to the field will help the broader community continue to learn and grow. Practitioners should continue to engage in the current research to understand what is lacking and what steps need to be taken to inform the broader community.

2.2 CHALLENGES IN EDUCATION REFORM

Broadly, this study is utilizing STEM education as a lens for examining education reform. For this section of the literature review, I consider reforms more generally, which may provide insight into the challenges facing teachers, and the mechanisms by which teachers make sense of the ambiguities and complexities within reforms. How do teachers navigate this terrain such that their existing (and potentially more traditional) practices shift to align to newer frames of instruction and curricular thinking? What would be a necessary and logical first step?

Honey et al. (2011) suggest that understanding STEM disciplines in their individual disciplinary contexts as well as in an interdisciplinary situation, requires a thorough understanding of the research-based and highly effective instructional practices known to the sciences and mathematics. In addition, the synthesis of the previous literature suggests that educators need a solid foundation in teaching mathematics and science well in order to integrate those practices. As such, it makes sense to review common challenges and issues pertaining to curriculum and instructions for *science* and *mathematics* education more specifically.

2.2.1 Standards-based reform

With the evolution of improving *America's School Act in 1994, No Child Left Behind* in 2001, and currently the *Every Student Succeed Act,* the primary goal in education reform is to create and implement “world class standards” (Resnick, Stein & Coon, 2008, p. 115). Unfortunately, as evidenced in the current educational climate, standards-based approaches that emphasizes high quality instructional practices but contradict the low cognitive demand associated with many standardized tests suggests an ineffective system for teaching and learning. Resnick and her colleagues (2008) envision a standards development process that is aligned to assessments from the start to create a “thinking curriculum” (p. 132). Assessments serve as tools to guide and shape instruction along a meaningful learning progression. Today’s standards-based reforms include the development and implementation of the Common Core State Standards and the Next Generation Science Standards as a promising, cohesive framework for standards. The assumption is that the success of these reforms will necessitate improved teaching and learning, and higher expectations for learner cognitive demand and assessment.

2.2.2 Effective curriculum

Over a decade ago, leading researchers in science and mathematics also suggested that traditional modes of instruction and curriculum were not necessarily effective for all learners (Engle & Conant, 2002; Remillard, 2005; Stein, Grover, & Henningsen, 1996). From a curriculum perspective, Remillard (2005)’s teacher-curriculum relationship suggests that teachers *participate* with the design and implementation of curriculum via several factors that impact their understanding of the purpose of curriculum. By also drawing on Brown’s work (2002), teachers draw on their own conceptions, resources for evaluation by adopting, adapting and replacing aspects of the intended curriculum. This is an important consideration for administrators and curriculum developers who face the adoption of STEM-focused curricula. What research supports the chosen curriculum? How well do teachers understand the intent of the curriculum? Does actual enactment of the curriculum reach intended outcomes? Remillard's (2005) and Brown's (2002) work collectively suggest that in-the-moment teaching decisions impact the effectiveness of learning. Individual pedagogical content knowledge, pedagogical design capacity, and beliefs about teaching and learning shape teaching decisions that impact instruction and ultimately student learning.

2.2.3 Effective instruction

With respect to instruction, Stein et al. (1996) explicated a framework based on the construct of mathematical instructional tasks, which describes ways in which students do authentic mathematics. They found that maintaining high cognitive demand for students in a task is critical for student learning of content and disciplinary practices. Teachers employed various mathematics tasks that intended to have a high level of cognitive demand, yet for a variety of factors (classroom norms, task conditions, instructional decisions and teaching dispositions) teachers and students did not maintain the high cognitive demand throughout the task implementation. This suggests a great complexity in providing effective instruction. Teachers are bombarded with situations that require quick decisions, where students often look to the authority in the room for assistance in lowering the demand for challenging tasks. In the average classroom, without due attention to these and other conditions, the probability would be high for degrading or lower-level cognitive tasks.

Engle and Conant (2002) also describe the importance of productive disciplinary engagement of tasks within learning environments. In both the sciences and mathematics, students are given the authorization and resources to engage in shared disciplinary practices and solve authentic problems. The practice of inquiry, argumentation, and discourse becomes a productive vehicle; it supports student engagement and learning of a discipline's content and practices based in authentic tasks. The authors claim that there are intentional instructional and curricular moves that can foster productive disciplinary engagement, including the development of a learning community within the classroom. Emphasis is placed on disciplinary practices and encourages the connections between them. For interdisciplinary STEM experiences, a similar goal may be achieved by attending to students' opportunities for productive disciplinary engagement. This would be no simple task, and suggests greater shifts away from more traditional approaches of teaching. For example, to simply connect two disciplines with a theme may be superficial. Students will need to grapple productively with the content, processes and thinking associated with both disciplines. In their engagement with the task and their peers, students can begin to make sense of these associations and delve into application of learning between the two disciplines. This is in stark contrast to more traditional approaches where connections are implied or passively determined by the teacher, not the students. Such productive *inter*disciplinary engagement may require that teachers have the expertise with and between both content areas and flexibility within instruction and assessment.

These studies taken together suggest that in a time of education reform, for mathematics and science instruction, and potentially interdisciplinary approaches, these are all ambitious efforts in reforming teaching and learning. When the espoused goals for teaching and learning do not align with current practices, these efforts become even more challenging. The immense amount of research in classrooms on effective practices and the enactment of curriculum suggests that it is imperative to be critical in selecting, understanding and enacting curriculum. The multitude of factors pertaining to each stakeholder's role may impact success, sustainability and continuous improvement of the effort.

2.3 MECHANISMS THAT SUPPORT REFORM

The final focus for this review focuses on the support structures that guide the work of teachers in ambitious reforms. There are a variety of support structures available to educators in their practice. The more formal mechanisms that exist can include professional learning communities, teacher leader development programs, cognitive coaching, and an array of professional development opportunities. There are also evaluative mechanisms and mandated policies that guide daily practice. Beyond these more formal structures, what takes place within the informal spaces when teachers begin to navigate the complex terrain of reform? In other words, how do teachers make sense of the plethora of information to make informed and effective decisions in their daily practice? As a community of practice, how do interactions with peers work to shift practice toward these more ambitious reforms in teaching and learning?

2.3.1 Collaborative supporting structures

At the heart of implementing ambitious reform is the opportunity for educators to engage in and benefit from supportive collaborative structures. Metz (2008) suggests that teachers experience the most difficulties when previous beliefs about teaching and learning are strikingly different from the proposed reforms. In her case study, Metz studied how four elementary science teachers of varying backgrounds conceptualized their teaching problems over several points in time. Her research team analyzed two years of videotapes of monthly teacher meetings and interviews with teachers to examine how teachers tended to negotiate their experiences as “problematic” or “unproblematic.” Metz’s team found that when problems were seen as learning experiences and shared collaboratively, they can become catalysts for conceptual shifts. When teachers found these problems within their “locus of control,” (p. 951) they were able to engage in purposeful problem solving. On the other hand, several factors seemed to impede productivity, including teacher beliefs about teaching and learning (i.e., deficit thinking about student learning), lack of understanding about the nature of the discipline, and a hesitation for trying new approaches as a result of the team meeting. The collaborative meeting structure provided unique opportunities for teachers to articulate problematic issues and set the stage for examining and changing their practice. Metz suggests that depending on what actions are taken, teachers can be seen as “agents of change” or as the “targets” of the reform themselves (p. 952).

2.3.2 Professional development

Research suggests that engaging in such collaborative practices supports teachers in developing new understandings about teaching and learning. For example, in ongoing professional development models that promote principles of learning (Bransford et al. 2000) may support teachers *as learners.* Collaborative engagement in reflective processes may better prepare teachers to adjust their preconceptions with new learning. Professional development in this forum provides opportunities for reflection on newly tried practices when supported by the collaborative environment of experienced staff and peers (Bransford, Brown, & Cocking, 1999; Loucks-Horsely, Love, Stiles, Mundry, & Hewson, 1998).

Ball and Cohen (1999) caution the empty rhetoric that often appears as quick-fixes to instruction and curriculum. In the development of practitioners, Ball and Cohen argue that professional development should offer a space where educators can reframe their current practices within a disposition of inquiry. By examining others’ practice, educators can contrast varying approaches to determine which afford or constrain specific outcomes. Professional development becomes less about how-to's and a menu of strategies, but valued as a structure for shifting practice and informing education as a whole (Ball & Cohen, 1999). In addition, Little (1993) suggests that professional development should provide the "capacity to equip teachers individually and collectively to act as shapers, promoters and well-informed critics of reform" (p. 130). In this way, professional development can facilitate teacher's underlying assumptions of their institutional context, educational policy, and the degrees to which existing practices align with the outcomes of the reform (Little, 1993).

2.3.3 Professional learning communities

Similarly, other formal structures, such as professional learning communities (PLCs), are found to be effective in supporting teacher practice. PLCs are usually established formally within a school to develop shared leadership and a vision to improve student achievement. Teachers who examined student work collaboratively in PLCs uncovered student thinking and generated more effective teaching practices (DuFour & Eaker, 1998).

Several studies examined by the *National Commission on Teaching and America's Future* also suggest that collaborative learning professional development models and PLCs support teachers in their understanding of pedagogy and student learning, particularly when science and mathematics were addressed individually. Fulton and Britton (2010) found that PLCs improved teacher instruction and attention to student thinking when specific goals, protocols, and structures were in place. For example, within discipline-specific PLCs, teachers were able to evaluate student work samples collaboratively to address issues in student thinking and generate decision for future instruction. Fulton and Britton cautioned, however, when PLCs emphasized integrated approaches (i.e., focusing on science and mathematics together), PLCs were found to be unproductive or unfocused for transferring learning to practice. The teachers focused on the aspects of the discussion that were relevant to their specific disciplines but found that the PLC did not deepen their understanding of the other disciplines. While these more formal structures have the potential to support teachers in improving practice, more research may be needed to determine which specific tasks designed for the work of an interdisciplinary STEM PLC would be beneficial for teacher learning.

2.3.4 Communities of practice

Researchers have examined other support structures that are defined by the informal and organic interactions between teachers, such as *communities of practice.* Lave and Wenger (1991) pioneered a distinct conceptual framework that describes the composition, interactions, and outcomes of learning within communities of practice. The conceptual framework of *communities of practice* falls within sociocultural learning theory. Stein and Coburn (2008) applied this thinking by studying the communities of practice of mathematics teachers, and found that teachers were engaged in deeper conversations around learning and pedagogy with each other and other communities of practice (2008).

Teacher communities of practice are the organic, informal spaces for discussion and exploration of practice with a shared purpose of learning together. In this framework, an individual's learning is a sociocultural experience that is shaped by the contributions of the community. The collective identity and learning of the community is additionally shaped by the contributions of each individual. In an educational setting, teachers discuss with one another everyday lesson planning, classroom experiences, and teaching decisions. They analyze challenges and gain another's perspective (Stein & Coburn, 2008). These are examples of *participation.* Participatory experiences build a foundation for learning that is influenced by the social and cultural factors that define a particular community. Teachers also engage in and make sense of various artifacts as mandated by a district, such as the set curriculum, or for the example of my problem of practice, a newly adopted STEM outcomes, principles or program. This engagement is a process of *reification* where ideas, processes and understanding become embodied in some physical object. The negotiation of meaning that arises from combined *participation* and *reification* results in collaborative learning. For example, new teaching experiences cause teachers to reify new meaning toward the curriculum or the standards, helping teachers to utilize these physical forms as frameworks more effectively (Wenger, 2000; Stein & Coburn, 2008).

Stein and Coburn (2008) articulate that learning at this level is only partial. Being part of a larger organization, teachers have the potential to overlap with other communities of practice and extend their individual and collective learning. Within a sociocultural perspective this makes sense. Initiatives driven by administrators, such as with STEM, have specific meaning and expectations relevant to their administrative community of practice. These understanding may not be unified throughout the educational institution. Even various communities of teachers may have different perspectives about practice or the meaning of the intended initiative. It takes the *crossing of boundaries* of various communities of practice to reach shared meaning, or *alignment*. Alignment refers to the understandings developed through participation and reification across many communities of practice. Alignment works between and among communities to connect shared investments to reach a unified goal (Wenger, 2000; Stein & Coburn, 2008). In the context of my problem of practice, the goal is the proposed ambitious STEM reform. Stein and Coburn (2008) determined that *bidirectional* approaches to communities of practice created an expectation for cross-boundary interactions between administrative leaders and teachers. Learning was found to increase with meaningful engagement (participation) in the reification of curriculum and frameworks, and evidenced in teacher practice.

A study by Voogt, Westbroek, Handelzalts, Walraven, McKenney and et al. (2011) potentially adds another layer to the *community of practice* construct, particularly as teachers collaboratively design curriculum on a variety of disciplines. Voogt et al. (2011) examined the resultant effect on their learning of pedagogical and content knowledge. As teachers worked with one another to re-design curriculum, it became a professional experiment based on their personal understanding of teaching, content and students. Similar to the conceptual framework of communities of practice, interactions can be seen as *participation* with other colleagues, experts, and exemplary curricular materials affirmed or challenged ideas. These interactions often result in shifts in thinking, which most aligns with the idea of *reification*. This study specifically distinguishes between *teacher change* and *professional growth* by examining change in practice over time. Voogt et al. (2011) additionally examined the relationship between evidence of change in various teacher-related domains (such as personal beliefs, expectations for outcomes, capacity for experimentation), when mediated by the external domain (external sources of information and stimulus) (Voogt et al.).

Horn and Little (2010) investigated the interactions between teachers within their teacher work groups, particularly in how they solved problems and pursued opportunities to learn about their individual and colleagues' practice. Utilizing a longitudinal case-study, Horn and Little analyzed audio and video taped sessions and observations of two teacher workgroups within the same high school. The study revealed that different conversational routines emerged to support or hinder the groups' interactions in diverse ways.

For example, when teachers articulated issues to the group as problematized, colleagues demonstrated a pattern of response in one of two ways. In the first case, responses to a problem promoted learning for the individual and community. Colleagues asked pertinent questions to help the teacher specify and reformulate the problem, and conjecture about the root causes of the issue. The goal of discussion linked practice and general principles of teaching and learning to support the teacher in visualizing actionable next steps. On the other hand, the second type of response functioned to constrain learning opportunities around the articulated problem. Teachers offered responses that "normalized" the issue. These attempts removed responsibility away from the teacher. Conversations in general tended to move away from teaching principles and focused on reassurance or superficial advice. Horn and Little suggest that the extent to which teachers shared frames of references may impact opportunities to learn. Shared leadership within the group may additionally establish norms that foster a collective vision of teacher learning. Horn and Little's approach sheds light on the importance of careful study of interactions within collaborative work. While there may be commonalities and differences that emerge, analysis can indicate which emergent processes lend themselves to affordances and constraints for effective progress in learning and shifting practice.

Also with respect to interactions between communities of practice and the learning that evolves in this space, Coburn (2005) investigated the importance of leaders' roles in teacher sense-making when enacting reform policy. By also utilizing a case-study approach of two urban elementary schools enacting literacy reform, Coburn found that principals of very different epistemologies offered different resources to their teachers. In some cases, preferred knowledge and strategies of the leading principal limited approaches teachers chose in their implementations. These conceptions may also limit the principal's understanding of the intended reform. For example, one principal's framework for teaching and learning was embedded within behaviorist theories. Professional development for her teachers generally focused on the giving of information from outside experts. Teachers were not given opportunities to actively engage in meaning of the policies or collaboratively reflect upon subsequent implementation of the reform. As such, the principal matched her understandings of the reform with her own personal beliefs in teaching, and filtered this message to teachers. Teachers ultimately delivered the new reform in literacy through this frame of instructional practices.

Coburn (2005) suggests that principals are often the forgotten stakeholder in attending and actively participating in professional development. As a result, leaders who have the most access to policy often decide what information to disseminate. These messages impact what is perceived as necessary for effective implementation. Coburn concludes that cross-interaction between communities of practice is imperative for building a shared vision and collective learning in an effort that involves all stakeholders.

2.3.5 Fostering communities of learners

The above conceptual framework and studies around communities of practice illustrate the importance of active participation within a community of practice to arrive at productive, professional learning about practice. It makes sense that a community of practice that is less effective in communication or less focused in promoting learning may result in different learning outcomes than those communities that are more effective. In my review, it seems imperative to understand not only what mechanisms drive communities of practice, but what conditions might best foster learning within a community of practice.

A. Brown and Campione (1996) have pioneered the thinking behind *fostering communities of learners* in their work of the learning sciences. I am taking the stance that *learners* can refer to adult professionals and young students. Learners are thought of as active constructors of their knowledge, where learning takes place within a deep disciplinary context that supports critical thinking. In their work, A. Brown and Campione (1996) describe key learning principles that must be established and practiced by a community of learners such that a mindset for learning becomes internalized for flexible and creative adaptation. A process of researching, sharing, and engaging in consequential tasks drives the work. In a sense, this process becomes a system of tools rather than modified activities that move toward proceduralized, non-intended goals. The environment that results is one of awareness and active, reflective learning. The goal for learning encourages diversity of thought, discourse, and solutions; learners are expected to delve deeply into intentionally crafted experiences so that the levels of complexity arise and stimulate learning.

In summary, the synthesis of the important work on *communities of practice* and *fostering communities of learning* suggests an emphasis on the importance of collaboration and diversity between learners focused by intentional purpose of action and critical thinking. In the communities of practice that center around ambitious reform, these moments of interaction become important spaces for sense making of an excess of ambiguous information. More importantly, as espoused vision becomes reality, this space is crucial for learning about one’s practice and about learning itself.

2.4 CONCLUSION

From the perspective of STEM education reform, this synthesis reveals several complexities in designing and implementing educational reform. First, it is important to consider the relationship between the teacher and curriculum when modifying or creating curriculum for a new purpose. Specifically, teachers' decisions about tasks experienced by learners have an impact for the student learners in this puzzle. The decision to enact more interdisciplinary connections within a STEM curriculum could take many appearances, and may vary in complexity of content foci and disciplinary practices. With respect to the challenges presented to teachers in implementing ambitious reforms, it is imperative that stakeholders engage in and understand how current practices may or may not align with current research-based practices. It will be important for educators to enact a framework for learning that includes both disciplinary and interdisciplinary experiences, and the pedagogical design capacity to inform these decisions.

The research base available to teachers also becomes a valuable resource for educators as they begin to answer important questions about the effectiveness of approaches and generalizability of research findings from their specific contexts. From a curriculum design perspective, understanding this interplay between learning principles and best practices may result in better program coherence and outcomes for meaningful and productive learning. I agree with the literature base that steady progress in research in this area will continue to raise additional issues and hopefully help to solidify the ambiguities surrounding expectations and outcomes in STEM education.

The case study for this dissertation in practice provides an opportunity for a select group of teachers who have history of team collaboration to engage thoughtfully about their practices. Careful analysis of interviews, focus groups and artifacts will enable a deeper inspection of processes that reflect years of collaboration. These reflections and analyses may enable the broader educational community to better understand the challenges in establishing STEM-focused goals, designing creatively to meet teaching and learning goals, and functioning together as a collective to do this kind of work.

3.0 STUDY APPROACH AND METHODS

In this chapter, the study approach will be outlined, including descriptions of how study participants were selected, and the history of the site and its stakeholders. The methods for data collection and analysis will also be described, including a statement on standards for rigor guiding this qualitative study.

3.1 INQUIRY APPROACH

The design of this inquiry follows models of qualitative case study research. Yin (2014) describes a case study as “an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-world context” (p. 17). There may be multiple variables at play within the context, which requires the researcher to attend to multiple sources of data. In addition, analysis depends on considering relevant theoretical frameworks, and recognizing where data tend to converge and where patterns emerge (Yin, 2014). In this case study, I am attempting to understand a context of practice, in which the selected teachers represent one perspective of many current STEM education reform efforts. These teachers have a unique perspective to share that may inform others engaged in similar work. A closer examination of these teachers’ practice and beliefs, may shed light on key support structures needed to do such challenging work.

This inquiry stems primarily from a socio-cultural perspective. This perspective describes learning as transformations of knowledge because of participation in social interactions and cultural practices (Engeström, 1999; Vygotsky, 1978). Hakkarainen and colleagues (2013) describe that collaborative learning results not only through dialogic structures of participation, but by externalizing knowledge such that authentic, problematic inquiries themselves become shareable artifacts for the joint purpose of learning. Working from this perspective, provided me, as an outsider, with a lens for which to investigate the complexities within the study's site. For example, in a typical school system there are ample opportunities for teachers to interact with one another for the purposes of individual and collaborative learning. The interplay of dynamics can also be associated with the larger scope of the school's district and administration, suggesting an array of information available (or not available) to teachers in a movement of education reform. As such, an understanding of these complex systems guides my perspective as a researcher in this context.

In addition, it is necessary to note I committed to maintain a quality of rigor associated with qualitative research, utilizing Toma's (2011) concepts for rigor. According to Toma, qualitative research is holistic, empirical, interpretive, and empathetic and requires the researcher to demonstrate *trustworthiness* from the perspective of study participants and the reader. While there are many traditions in qualitative research, Toma cautions the qualitative researcher to establish credibility (internal validity), transferability (external validity), dependability (reliability), and confirmability (objectivity). To meet these standards, I made concerted efforts to minimize misrepresentation of the information gathered and presented in my analyses, noted where conclusions have converged from triangulation, and identified areas of uncertainty. I also considered evidence that challenged my conclusions, by acquiring data from multiple sources, having those sources member-checked, and consistently reflecting upon my interpretations, potential biases, and assumptions. To aid in maintaining rigor, I utilized a *top-down* approach that recognized theoretical constructs to frame my lenses for data collection and analysis. Likewise, I employed a *bottom-up* approach to allow for other patterns and themes to emerge, particularly those as connected to my own perspectives in practice.

3.1.1 Participant selection

Many schools across the nation are implementing STEM-focused initiatives, driven by grants and funding to support such work (PCAST, 2010). In my professional practice as a teacher educator, I interact with many local schools and districts engaging in their vision of STEM, and have been in a unique position to be able to externally examine educator practice in such initiatives.

For this study, I established several criteria for participation, including: 1) the teachers selected would be part of an interdisciplinary team of teachers at the middle school level, 2) the team indicated working together collaboratively in teaching STEM-related lessons, units or projects, and 3) the team would implement what they determined to be an integrated unit or project during the time of the study. Given the short time frame of this study, I selected only one team, within one school and district for a detailed investigation.

The context of middle school was carefully selected for this inquiry into the larger problem area. The middle school learning environment typically places an emphasis on departmentalized teaching (i.e., teachers specialize in one core content area, and students rotate through a team of teachers throughout the day). Some models for middle level teaching and learning advocate for an integrated approach in a departmentalized structure, suggesting positive benefits to students' learning and development (Dowden, 2007; McBride, 1991). Given that my operational definition of STEM is centered on an integrated approach, a middle school learning environment could provide a lens for which to examine teacher practice within the challenges of STEM education reform. In addition, my perspectives as a former middle school science teacher and current teacher educator lent a layer of understanding into this specific context.

3.1.2 *Steel Squadron*: An exception

Over the past year as part of the EdD program, I have had the opportunity to reflect with a middle school mathematics teacher from the AGW District about the STEM-related programs occurring in her school. Tina is the Algebra teacher on her 8th grade middle school team, which she calls the *Steel Squadron*. In these informal reflections, she described her team as interdisciplinary, where together, she and her other teammates, determine how to make connections between their four core disciplines (math, science, history, and English-language arts) and often to other areas of technology, engineering, and the arts. The *Steel Squadron* is currently in its third year of implementing collaboratively planned projects, the core of which take a STEM-focused approach. However, the team has been together for much longer: Tina was partnered with David, the history teacher, fourteen years ago, where they began informally collaborating. David also has a strong technology education background, which spurred many of Tina and David's early smaller-scale STEM collaborative efforts. The science teacher, Sam, who specializes in inquiry-based conceptual physics, joined the team three years later, followed the next year by Joseph, the English-language Arts teacher. As a team, they have worked exclusively together for the last ten years.

Currently each teacher has a schedule of five classes of students, where the same sets of students cycle through all four teachers in a day. Their schedule allots for two official planning periods each day: personal planning preparation and grade-level team planning. The team indicated early on in conversations that all middle school teams in their building have access to grade-level planning, but in their view, their team appears to be an exception. Teams utilize this time differently, primarily for discussing and resolving student concerns in conjunction with support staff (i.e., special education specialists work with the teachers to support individualized evaluation plans). The *Steel Squadron* mentioned that for them this time has been utilized for these purposes as well, but more intentionally to plan for upcoming collaborative projects.

In the past, two-to-three larger scale collaborative projects occurred during the year, typically incorporating all four subjects in some way. The team informally described these projects as opportunities for students to experience teaming, develop 21st century skills, and explore connections between the four disciplines. Table 1 provides an overview of the types of collaborative projects designed and implemented by the *Steel Squadron*. Several of these projects were STEM-focused, as described by the team. Now in its third year, the *Space Kit* project was initially developed through a grant opportunity. Students launch a weather balloon affixed with a GoPro into the stratosphere, just below the space/atmosphere boundary. The *Space Kit* project occurs in the spring over several months, where components of the project are completed at different times over the four classes. At times, regular class instruction is connected to the project's goals. For example, in Algebra, students connected equations to the launch parameters of the weather balloon. However, this was not always the case, as each year's launch was implemented differently than the iteration preceding it. The first year's implementation was purely focused upon launching the device. Last spring, students designed scientific experiments to conducted in the atmosphere and space after the launch of the weather balloon. In these iterations, students focused on launch plans and experimentation in all classes, including history and English-language arts. In addition, teachers enacted smaller-scale collaborations across two disciplines more frequently throughout the year. In each of the types of collaborative projects described in Table 1, notice the variation in how disciplines are connected, how these connections relate to the current disciplinary curricula, and when these projects are implemented.

Table 1. Types of team collaborative projects

Type of collaboration	Large-scale collaborative projects	Individual classroom collaborations
Discipline connections	▪ Implicit connections made to specific disciplines (not specifically to the disciplines' written curricula) ○ Example: *Space Kit*: science, mathematics, ELA and history ▪ Few connections to specific disciplines (not specifically to the disciplines' written curricula ○ Example: *Geography of Self:* ELA, history, technology	▪ Explicit connections made between disciplines (specifically to the written curricula) ○ Example: science & mathematics – Ohm's Law and solving equations ○ Example: History & mathematics – history of and mathematics involved in electoral college ○ Example: Science & ELA – variations in constructing explanations for PSSA)
When implemented	▪ Implemented throughout the year, in conjunction with normal class periods ○ Example: *Space Kit* ▪ Implemented as a team-focused week-long project; completed instead of normally scheduled curricula ○ Example: *Geography of Self*	▪ Throughout the year; implicit and explicit connections made weekly

For this study, the team worked collaboratively on a project new to them, *Geography of Self*. Students were challenged with designing and publishing their own personal, live webpages, and expected to grapple with creating their digital identities while examining how their online presence is portrayed to a public audience. Each teacher facilitated one of four components which would comprise the completed student website. The entirety of the project took place in one week prior to the school's upcoming winter break, in place of regularly scheduled instruction. The team indicated they would be utilizing their grade-level team planning time to collaboratively plan and reflect upon the enactment of the project. This course of events presented an opportunity for exploration of their collaborative space, however, within a relatively short time period.

I anticipated several advantages and disadvantages for examining this context under these parameters. With reference to the larger problem area, I could examine practices that were already in place (i.e., systems for collaborative planning and reflection) and uncover a history of team development and collaborative practice that has evolved over time. Given the nature of self-reporting of past experiences, I anticipated that there may be limitations to the accuracy and completeness of recalled information. Recall about events in the past (i.e., how the team formed, and what processes were in place at that time) may be less accurate than those of current events. While these points of information may be more useful to teacher teams who are just beginning collaborative endeavors, it was unlikely that I would uncover a full history. It was my purpose to describe a collaborative space in action and discuss possible implications for a variety of perspectives.

3.1.3 School and district setting

Taking a broad view of the context, the *Steel Squadron* represents one interdisciplinary team, within one middle school in the AGW School District. AGW Middle School is comprised of grades six through eight, with two grade-level teams per grade. The *Steel Squadron* is one of two eighth-grade teams. As a district, AGW is recognized as one of the top public-school systems regionally and nationally, serving a high socio-economic community. This population represents a median household income of over $80,000, where 61% of adults have attained above a professional degree (AGW Community, 2016). Ten percent of students represent minority groups, and about 10% of students receive free and/or reduced lunch (National Center of Education Statistics, 2016). Its schools operate on a large budget, providing more than $16,000 per student in a range of resources to its students (AGW School District, 2016). A snapshot of resources includes: a comprehensive arts rotation, guidance counseling, writing support, tutoring, gifted education, and emotional support services. The district prides itself on its "national reputation for excellence [and the] a combination of highly trained staff with educated and committed families" (AGW, 2016). On the 2013 Pennsylvania System of School Assessment (PSSA), middle school students achieved 85-95% proficiency in mathematics, science, reading and writing (Pennsylvania Department of Education, 2016).

From the perspective of STEM-education efforts, members of the AGW school district have recently formed a STEM committee, including elementary through high school staff. The purpose of the committee is to develop their district wide STEM-related goals and determine what additional resources may be needed to support their work. They are currently participating in professional development with a local educational organization to facilitate these efforts. Two of the members of the *Steel Squadron* team have volunteered to represent the middle school on this committee.

There are a variety of perspectives for which to study the challenges in STEM education, such as schools that are just beginning STEM-related efforts or those that lack resources. A common preconception about STEM education is that successful implementation is determined by funds, technology, and external resources. Attention is placed on attaining resources, and less on how the materials are used effectively (Henderson & Dancy, 2011). My purpose for choosing a particular district was focused less on what materials were being used, or how they attained those materials. As a design, it may be more informative to understand beyond face value, *how* the teachers as a team to enact such work, particularly when they believe it is a productive approach.

However, given AGW's culture of high-performance and attainment of resources, it may be equally important to understand the extent to which *all* students have access, even in a high-resource school. A broad range of districts, schools and educators implement STEM-related programs, with various levels of access to resources and organizational supports. The operational definition of STEM education reform guiding this study places an emphasis on access to quality teaching and learning practices. As stated earlier, the *Steel Squadron* believes they utilize their common planning time differently than the other teams in their building, particularly to plan and enact collaborative, STEM-focused projects. Do all students in this context, then, receive the same learning opportunities? In this context, a culture of high test scores and resources may not necessarily signify access for all.

3.1.4 Broader scope of stakeholders

To describe the larger context, it is important to consider the broader scope of stakeholders who are affected by the problem area of ambitious reform implementation. While this study does not claim to investigate these perspectives, this system appears to be two-fold: 1) all those within the study site, and 2) those within the broader community who may benefit from considering lessons learned from a case such as the study site. The following figure provides a high-level view of the various stakeholder groups in the AGW School District. Each of the following subsections will examine each stakeholder group to illustrate the system's complexity of inputs, boundaries and configurations.

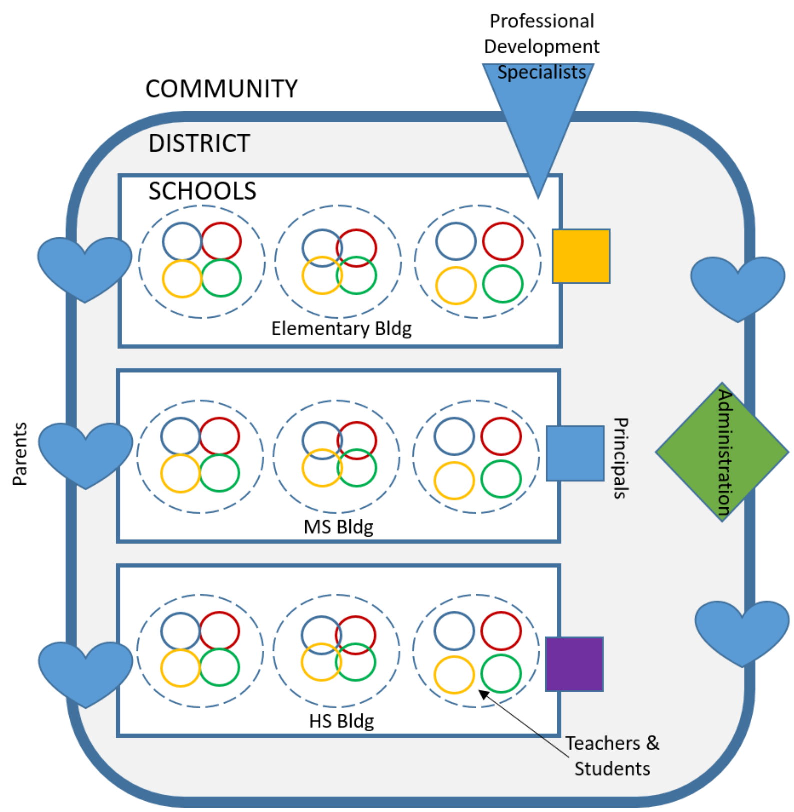


Figure 3. System diagram of AGW School District

3.1.4.1 Teachers

Within the context of AGW Middle School, the immediate stakeholders for this study are the teachers collaborating to enact some change. In the graphic above, the *Steel Squadron* teachers represent a group of teachers who collaborate, represented by *overlapping circles* within the middle school space. These teachers are users of their curriculum, decision makers of instruction and assessment, and could potentially be participants in one another's learning as part of a team. Drawing from research in the teaching of mathematics reform, implementation of curriculum is greatly impacted by many teacher-related factors, including teacher effectiveness, instructional decisions, and professional development (Stein, 2000). As an integrated entity, it may be important to examine teachers' interactions with their resources, curriculum materials, and one another as a collaborative community in their work. One purpose of this study is to determine the extent to which teachers utilize the collaborative space to make use of these educational practices.

3.1.4.2 Other educators

It may also be informative to keep in mind the broader culture in how teachers interact with other stakeholders outside of the immediate boundaries of their team: other teachers, professional development providers, and school administrators. Represented above, these boundaries are depicted by *closed and dotted shapes,* and suggests potential for movement or interaction between boundaries. Teacher work groups are represented by various configurations of *touching* or *overlapping circles*, which suggests that teachers collaborate differently within their groups.

Administrators (i.e., principals and curriculum leaders) potentially represent the espoused vision set by the school, and can influence the impact of the direction of implementation (Coburn, 2005). Administrators often reflect the district ideals but also the larger community outside of the district, representing parents and state officials. Other teachers (i.e., the other middle school teams) may represent a variety of opinions, beliefs, and values as related to teaching, learning, and STEM. In the graphic above, other teachers are represented in groups by various configurations of circles to suggest different approaches to teaming. *Touching circles* may represent limited collaboration; *circles in proximity* suggests unity by location. Each of these groups may represent self-identified teams (i.e., grade level teams and content specific teams).

In addition, professional development providers, stemming from the educational community outside of the district domain, may present alternate ways to frame decision making with instruction and curriculum. Opposing viewpoints and cognitively dissonant ideas may work to challenge the vision and progress of the team initiating the reform. This larger community of educators has an opportunity to collaborate and learn from one another in support of the broader vision of excellence in teaching and learning, amidst the ambiguity and challenges of implementation.

3.1.4.3 Students and parents

Additionally, students and their parents represent the ultimate stakeholders who receive the benefits (and possible limitations) of any educational effort. The national literature promoting STEM education efforts, for example, proposes that STEM learning experiences provide students, as future citizens, with the power to be effective and productive in their decision making when engaging in their world (NRC, 2011; PCAST, 2011; Thomasian, 2011). In this context, educators, alongside of the community they serve, work together to shape a collective vision for what is important for teaching and learning. These combined interactions impact the evolving perspective as to what is readily do-able and what is challenging.

3.1.4.4 Practitioners in the field

From a more widespread perspective not depicted in the graphic above, practitioners in the field of education (local and national) also have a stake in this issue. As practitioners, educators have the benefit of engaging with and learning from others. One such avenue is through the research literature and practitioner journals. Also, opportunities to interact with one another in professional development and conferences can become an informal space for sharing practices. In both cases, educators may be able to consider many factors that contribute to the challenge, and begin to evaluate a wide range of solutions. As a professional development teacher educator, I, too, have a stake in understanding the close work of others, such that I can share lessons learned with other educators, teacher educators, and the broader field of education.

3.2 INQUIRY METHODS

A qualitative approach has been utilized to answer the guiding questions of this case study, relying on multiple sources of data. The selected teachers engaged in focus groups and interviews, and participated in observations of already scheduled team planning sessions. The following subsections provide an overview of study activities, the rationale for the use of these methods to answer the stated inquiry study questions, and the specific procedures and protocols designed for conducting each method. The appendices include protocols for each method (Appendix A: Observations, Focus Groups, and Interviews).

The decision to operate within a purely qualitative approach was intentional as these methods seemed to complement my own practice as a professional developer and teacher educator. As a practitioner, my roles have included facilitation, questioning, and active listening to encourage teachers to think deeply about their practice. I have often engaged in interviewing and observing teachers in their settings which provided a context for cognitive coaching and improving professional development as part of our research and development process. The methods utilized in this study therefore seemed an appropriate and natural way to immerse myself within an authentic context and gather important evidence about teachers' practices.

3.2.1 Overview

As an overview, the following figure outlines the flow of inquiry activities that took place at the study site and a timeline for which these events occurred.

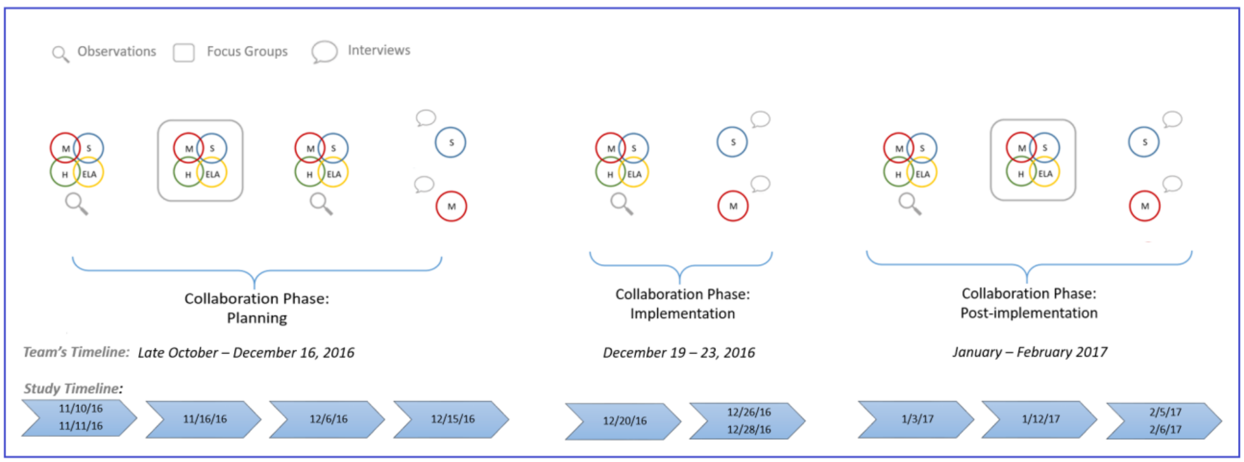


Figure 4. Flow of inquiry activities

The study followed the *Steel Squadron* through three phases of implementation of their collaborative project, *Geography of Self*. First, during their *planning* phase, the team participated in initial observations of their common planning time, and then engaged in a researcher-facilitated focus group that I recorded for further analysis. The primary goal of the initial observations and follow-up focus group was to provide a view into the dynamics and planning processes of the team. The focus group provided me with the opportunity to further investigate into team processes by gathering clarifications, insights and additional information about the events that took place in the observed planning meetings. Having gained rapport with the team, I was invited to join the team for several additional observations of team planning meetings than were originally unplanned.

After preliminary review of the data from the first two observations and focus group session, two teachers were selected to continue with more in-depth study. Given that science and mathematics are central to STEM education, I selected Tina who represented mathematics, and Sam for science. Tina and Sam participated in individual interviews along the remaining phases of their project: *implementation* and *reflection*.

Prior to their *implementation* phase, Tina and Sam were asked to participate in pre-implementation interviews to provide insight into their individual planning, thinking, and enactment of the collaborative effort. Tina and Sam identified goals, plans and expectations for their specific parts of the implementation, and after their implementation, completed one written reflection to be shared prior to a post-lesson interview. In addition, they each had the option to share artifacts from their implementations to support conversations during post-interviews. During their *implementation* phase, I observed an additional planning session held by the team and conducted post-interviews with Tina and Sam who shared reflections from their individual perspectives.

In the final *reflection* phase, the team participated in an observation of their team planning. This team planning meeting served as a debrief session of the completion of the implementation. To conclude the study, the team also participated in one final focus group session collectively. The final focus group provided me with the opportunity to share intentionally chosen examples gleaned from the observed planning sessions and interviews.

Specific questions around these examples allowed for discussion around my current interpretations and to the extent that these interpretations represent teachers' actual practice. In addition, Tina and Sam were asked to individually participate in one final interview as a form of member checking of researcher interpretation.

In the following subsections, I describe the three primary methods of data collection. It is worth noting that from a perspective of practice, I, too, became a methodological tool for the design of questions, areas of foci, and the approaches toward analysis. I utilized my experience as a classroom teacher and professional developer to develop key identifiers, which have been useful for facilitating sessions and coaching teachers in sessions. The follow table outlines these key identifiers, including rationales from my practice:

Table 2. Identifiers for inquiry methods

Broad identifiers	***Rationale from practice***	
	In facilitating sessions pertaining to:	*I have experienced that:*
Group processes	Teacher leadership, professional learning communities, and coaching	Understanding the processes by teachers to problem solve issues may provide insights in how they view their agency, curriculum, instruction, the role of learning, their peers, and their context.
Group dynamics	Professional development sessions in general	Teachers that work collaboratively often demonstrate particular modes of rapport; these dynamics are useful for understanding how a process may have been initialized, and highlight inherent successes or problems in their approach.
Expressed beliefs (teaching, learning, curriculum)	STEM strategic planning; science reform strategic planning	As educators work to formulate their educational philosophies for STEM, educators reveal, reference, and build their underlying belief systems.
Collaborative projects (foci, design)	STEM strategic planning	An ambiguity for what teachers focus upon exists as related to STEM, integration, and project based learning.
Collaborative projects (implementation, outcomes)	STEM strategic planning	Educators tend to have very global and common outcomes for collaborative projects, but are not stated with explicit methods for evaluation; in addition, implementation across the spectrum vary widely.

3.2.2 Observations

Observation is a useful method for exploring people's behavior and their perceptions about their unique context, particularly when these interactions would not be detectable by other methods (Menter, Elliot, Hulme, Lewin & Lowden, 2011). The observer's role is to observe and record detailed information about what happens in a natural context such that analysis of such data may reveal participants' issues and practice. Mertens (2010) outlines key features that would be important to observe and document, including the physical setting and the human and social environment. These may entail an attention toward informal interactions between participants, participants' native language and nonverbal communication, and what does *not* happen.

The nature of observation presents several limitations connected specifically to the researcher's role. First, observation requires many instances of interpretation about participant behavior, during the observation event and in analysis. Menter et al. (2011) caution researchers that observations only provide partial insights; researcher inferences may not truly represent actual participant intentions. Additional methods of data collection may be needed to strengthen and corroborate findings (i.e., interviewing). In addition, it may be important to capture multiple points of observation such that interpretations reflect typical behaviors rather than non-representative snapshots that cannot be replicated by other observations and methods.

Second, the physical presence of the researcher may influence the events as they unfold, even in the case of non-participant observation, where the observer does not actively participate in events being observed. The events that are normally natural to participants may inadvertently shift due to the knowledge of being observed. For example, participants may behave unnaturally on-task or interact with one another in ways that are overly polite. Menter et al. suggest building a rapport with participants to the extent that the researcher maintains objectivity.

For this study, I assumed a non-participating observer role during teachers' normally scheduled planning times. All observations followed a semi-structured format that included a general framework of look-fors and a process for recording. I kept a running narrative of field notes, summaries of discussions and pertinent quotes, in addition to audio-recording each session. Following each observation, I documented initial interpretations of the observations in memos, and utilizes session transcripts to clarify data collection. All observations were intentionally paired with focus groups or interviews, which aided me in generating questions from my emerging interpretations for use in the subsequent sessions.

The first two observations taking place at the outset of the study served as a baseline of typical team planning activity. I utilized the following identifiers, drawn from my practice, to focus observations:

- Group processes for planning (setting goals, presenting ideas, evaluation of progress, etc.,) and other emerging parts of their process
- Expressed beliefs and use of shared language around teaching, learning, collaboration, integration, and STEM
- Planning challenges (current or previous) and how the team resolved these challenges
- Impressions of group dynamics (as related to roles, leadership, and/or expertise)

The observations were paired with the focus groups (detailed in the next subsection) to provide the opportunity for further investigation into team processes. Purposeful questioning provided a space for clarifications, insights and additional information about the events that took place specifically in the observed planning meetings.

3.2.3 Focus groups

Focus groups provide an opportunity for researchers to explore phenomena, challenges, and dynamics in depth with a small subset of people who represent a larger population (Menter et al., 2011). In this case, the teachers in the selected middle school represent just one perspective in the broader spectrum of STEM education. The purpose of a focus group is to elicit the views, attitudes and dynamics of the collective group, while also revealing individual perspectives. The role of the facilitator of the focus group is to allow for an open discussion guided by carefully designed questions.

While the focus group offers a unique context in which responses and interactions between members can be documented, there are several limitations. One limitation is that the findings may not be generalizable to other situations as the sample size is small and potentially not representative of all contexts. The power of the focus group as a method is in the articulation of these perspectives such that outside entities can assess the relevancy to their own contexts. Other limiting factors may influence the dynamics of the actual session as well, including rapport between facilitator and members and interpersonal conflicts between the members. These constraints may limit the effectiveness of gathering important data (Menter et al., 2011). These challenges may be avoided by upholding a proper protocol and building rapport with the participating members.

For this study, all focus groups followed a semi-structured question-and-answer format. Questions were designed in advance with several follow up questions and prompts to facilitate movement of the discussion. All sessions were audio-recorded and transcribed for later analysis. I reflected upon the session immediately thereafter with written memos, which were added as annotations to the transcripts. Interpretations of transcripts were provided to participants, as needed, as a form of member checking (Yin, 2013).

The first focus group occurred early in the study, with the intent to uncover the team's and individuals' perspectives of the following items:

- The goals and outcomes of collaboration, integration and STEM education
- Past and current efforts to connect their separate subjects into an integrated approach
- The team's collaborative process and internal dynamics

The second focus group occurred toward the conclusion of the study, incorporating the same protocols for conduct, recording, and analysis. The intent of this culminating session was to reveal additional insights pertaining to the initial focus group questions and emerging interpretations of observations and individual interviews. In addition, this session provided opportunities for the team to collectively reflect about their work and member-check the validity of researcher interpretations.

3.2.4 Interviews

Like focus groups, interviews provide the opportunity to uncover personal perceptions, beliefs, attitudes and understandings about phenomena or challenges (Menter et al., 2011). Interviews are often informative for complementing other methods such as surveys or observations such that information can be expanded upon or clarified. In this study, interviews will be utilized in conjunction with both focus groups and observations to serve the same purpose. Interviews may provide an opportunity for individuals to explain events in their own language, and be reflective of their personal motivations and rationale.

Limitations for using interviews are consistent with focus groups. Sample size in this study is quite small which limits generalization to a broader context. To a greater extent, the power of the interviewing and questioning relies on the skill of the interviewer or facilitator. Data gathering could be limited by the influence of the interviewer's indirect biases and interpretations. In addition, this study only allows for analysis by one researcher. Because analyses have been limited to the interpretations of one researcher, it is also important to rely on member checks, where the participants affirm accuracy and completeness of what was stated (Menter et al., 2011).

In this study, all interviews followed a semi-structured format and were audio-recorded and transcribed for analysis. As with the focus groups, questions, along with follow-up questions and prompts, guided each interview. I continued to reflect upon each interview with written memos, which were added as annotations to the transcripts. Interpretations of transcripts were also provided to participants, as needed, as a form of member-checking (Yin, 2013).

The first set of interviews were paired with the implementation phase of the collaborative project. The pre-implementation interviews served to reveal individual perceptions about:

- Planning, concerns, and outcomes for upcoming implementation
- Efforts to collaborative or integrate aspects of the upcoming implementation
- STEM education, integration, and teaching more generally
- Team collaboration more generally

After their individual contributions to the implementation, teachers wrote a short reflection on the events that took place (See Appendix A). Teachers identified limited artifacts to be shared during interviews, which aided in conveying a point, illustrating an example, or justifying a specific position. Teachers were able to choose any of the following artifacts to share:

- Planning documents – lessons plans, curriculum documents, collaborative planning notes
- Implementation documents – prompts, worksheets, changes to lesson plan documents, student work samples

It was intended that the act of writing reflections and selecting artifacts could provide a space for teachers to engage in intentional and personal reflection of practice.

Lastly, as part of the interview portion of the study's design, the two identified teachers engaged in post-implementation interviews to reveal individual perceptions pertaining to:

- The lesson implementation and outcomes
- Any shifts (modifications or adaptations) of anticipated plans, and specific rationales for such shifts
- Reflections on impacts on outcomes due to shifts, if any
- Integrated elements within their lesson
- Their written reflections

3.3 METHOD OF ANALYSIS

In this section, I detail my method for analysis with respect to the study's inquiry questions. I utilized an inductive approach in the analysis of the multiple sources of qualitative data gathered in this study. According to Thomas (2006), inductive analysis refers to the "detailed reading of raw data to derive concepts, themes or a model through interpretations made from the raw data by [a] researcher" (p. 238). While inductive approaches often result in emergent theory, my analysis remained focused on the overarching conceptual framework (M. Brown, 2002; Remillard, 2005) outlined in Chapter 1 and foci drawn from my practice explained earlier in this chapter. However, my purpose was primarily to describe the work of teachers engaged in collaborative work. In this way, I utilized an inductive approach to allow for patterns and themes to emerge that fit within my outlined conceptual framework and also for others to emerge that may challenge or raise questions about the conceptual framework.

This study's overarching question asks: *What does the collaborative space contribute to the work of teachers in interdisciplinary collaboration?* I analyzed the data gathered from three primary methods to answer this question, and its two sub-questions: *What does the collaborative space look like?* (Question 1), and *What purposes does the collaborative space offer the team?* (Question 2). My raw data exists as transcripts, field notes, and analytic memos. Utilizing an approach outlined by Saldaña (2009), I engaged in a three-step process of primary coding, secondary coding and the writing of analytic memos. The careful reading and analysis of my documentation entailed identifying codes that "symbolically assign a summative, salient, essence-capturing and/or evocative attribute for a portion of language-based or visual data" (p. 2). The initial phase of coding helped me to codify, sort, and organize discrete points of data within transcripts and field notes relevant to terms associated with my inquiry of interest. The second phase of coding included reconfiguring and aligning these codes into categories and themes. Along both phases, analytic memos were written to document and reflect upon the processes I used for coding. In this way, my codes became connected to my thinking processes, rather than additional isolated bits of information (Saldaña, 2009).

The following table outlines the key categories that were anticipated to be collected, as described earlier in Table 2, and those that emerged as a result of data collection and analysis.

Table 3. Triangulation matrix

	Alignment to Inquiry Questions by Method Q1 – Question 1; Q2 – Question 3; OQ – Overarching Question		
Emergent categories	**Observations**	**Focus groups**	**Interviews**
Group processes	Q1	Q1	Q1
Group dynamics	Q1	Q1	Q1
Expressed beliefs (teaching, learning, curriculum)		Q2	Q2
Collaborative projects (foci, design)	Q1, 2	Q1, 2	Q1, 2
Collaborative projects (implementation, outcomes)	Q1, 2	Q2	Q1, 2
Impacts of collaboration on individuals		OQ	OQ
Impacts on collaboration on the collaborative		OQ	OQ
Interactions between individuals & group, group and individuals		OQ	OQ

As a matrix, this table helps to illustrate how these broad categories align with the overarching question and its two sub-questions, and indicates where opportunities for triangulation exist along the three methods of data collection. I specifically utilized triangulation during coding and analysis to find multiple instances of convergence along these different lines of evidence. As such, the data represent multiple points of the same phenomena, and allowed me to attain better accuracy and validity of my drawn conclusions (Yin, 2014). Appendix C presents sample selections of coding, triangulation, and analytic memos written during the analysis phase of this study.

In the following chapter, I will present the major findings of this analysis, utilizing descriptions of the setting, interactions, and team reflections. At these points, I make note of references to the various sources of data (transcripts, field notes and memos) and indicate where these observations and inferences have multiple points of reference as a measure of triangulation and credibility (Toma, 2006). See Appendix B for a reference to the methods-related abbreviations utilized throughout Chapter 4.

4.0 SUMMARY OF FINDINGS

The major findings of this study will be presented in this chapter by research question. The first two sections examine the two sub-questions supporting the overarching question: 1) *What does the collaborative space look like* and *2) What purposes does the collaborative space offer the team?* First, by describing the team's *processes* and *dynamics*, I explain *how* the team interacts with one another within that space. Second, through the examination of the team's *expressed beliefs* about teaching and learning, I explain *what* the team choses to do collaboratively and *why* they do this work.

Finally, the last section examines the overarching question, *What does the collaborative space contribute to the work of teachers in interdisciplinary collaboration?* This was viewed primarily through the extent of *impact* the collaborative had on both the individuals of the team, and the team itself.

4.1 THE COLLABORATIVE SPACE: PROCESSES AND DYNAMICS

Question 1: What does the collaborative space look like? By analyzing my field notes, analytic memos, and transcripts from observations, interviews, and focus groups, I focused my attention specifically on group *processes* and *dynamics*, which provided a picture of *how* the *Steel Squadron* team works together collaboratively. I initially examined *processes* and *dynamics* broadly as separate categories in my examination, focusing in on observable and expressed processes that the team had in place. These actions described *what* activities, methods and practices the team utilized in their collaborative work. *Dynamics*, on the other hand, tended to describe *how* the team interacted with one another to accomplish the tasks within their processes. The specific dynamics of the team appeared to establish which processes became the norm, which processes were important, and how these processes shifted over time. While the two constructs could be coded as separate entities, it became increasingly clear that these two were intimately intertwined, and provided me with multiple points of reference for a given observed action.

4.1.1 Group processes

Entering Tina's classroom during second period, you will find *Steel Squadron* assembled for their daily team planning time. They've taken what I've observed to be their "assigned" seats at a group of students' desks, and begin discussing where they've left off in their previous meeting. David begins the meeting by directing his colleagues to the Smartboard to examine the planning template he created on his last prep period, and asks for consensus about what their goals will be for the next 40 minutes. They are beginning to plan their upcoming collaborative project which will incorporate all four of their disciplines for their collective five classes of students. The conversations move from topic to topic, and vary by speaker, with multiple conversations sometimes taking place at once. There is laughter and humor, and then moments of silence where the team is deep in thought, contemplating a next move. The team keeps digital record of ideas as they take place, and notes a plan for tasks to be completed for the next meeting.

In my five observations of the team's planning prior to, during, and after implementation, I identified key activities and practices that describe the regular team processes utilized in their planning sessions. In addition, the discussions resulting from the two focus groups and three individual interviews with Tina and Sam, helped to clarify and triangulate these findings. In the table below, I have summarized the key processes evident, including examples of each process:

Table 4. Key processes of *Steel Squadron* team

Key Group Processes	*Examples:*	*Evidence from transcripts and memos:*
Ideating *	Brainstorming design ideas for the 4 distinct parts of the project to be led by each of the disciplines	OBS1-4; FG 1, 2
Setting goals/ Determining next steps *	Goal setting for team planning meetings, the project as a whole, and each teachers' part; also includes logistics associated with timing, permissions, and materials	OBS1-4, M1, S1
Discussing ideas/ Planning *	The *how* and *what* of each part, and any accompanying segments (i.e., parent permission letter, launch, student surveys); Referring to pre-existing resources, and creating their own resource	OBS1-4, FG1, M1, S1
Anticipating results *	Student focused; based upon current student make-up, prior class and collaborative experiences; included the modeling of specific tasks physically by the team during their allotted time	OBS 1-5, M1, S1
Sharing implementation	Sharing *what happened* during the week of implementation, and in debrief after the project concluded	OBS4-5
Reflecting on practice	In conjunction with sharing the implementation; sharing of personal shifts in thinking regarding teaching and learning	OB 3-5, FG1, M2, S2
Resolving issues	Ideating during and after implementation	OBS 4-5, M2, S2

The starred processes occurred primarily in the pre-implementation and implementation phases of planning. The remaining processes occurred during and post-implementation. (To aid in identifying points of triangulation, see Appendix C to reference the abbreviations pertaining to each inquiry activity. These abbreviations will be embedded throughout this chapter.)

4.1.1.1 An iterative process

As observed, these activities appear to take place in an *iterative* way, rather than linearly. Team planning focuses around one idea that has been brought to the table by one of the teachers. However, the process allows movement around foci that are important to the team. In this case, David introduced the project, *Geography of Self*, an idea he found in his “internet traffic” (i.e., websites, blogs, and listservs). The teammates then “play” with the idea conceptually and physically, usually centered around *ideating* (generating more ideas) and *discussion*. Discussion tends to be a dynamic interplay of questions, asks for clarification and information, proposed constraints, requests for consensus, stated predictions in order to anticipate students’ responses, checks upon assumptions, examined examples, references to past examples, and suggestions for instructional moves. In general, the team’s overall process seems to be a fluid movement around the following foci: goal setting, intentional design and planning and accompanying problem solving, and anticipating student outcomes.

In the following sample of dialogue from the second observation of team planning, notice the interchange between posing questions and raising concerns, which is peppered with ideating, asserting positions, and affirming the project’s overarching goals.

Table 5. Sample of dialogue from team planning session

Lines of dialogue:	*1st level codes:*
Tina: We should also talk about them bringing in devices.	Poses idea
David: Not every kid has [one].	Raises assumption
Tina: I know but if you do have it, they can use it. Then they can work on it outside [of class]. But that could cause a complication because, whatever [device] they start [with] they need to have it throughout.	Clarifies idea Identified additional constraint
David: You're saying that they can't even share devices—	Poses constraint
Tina: They have to have the same device the whole time.	Confirms issue
Sam: Do you know how many days you spend on this in [previous similar project]?	Raising question regarding prior implementation of similar project Toward David for expertise
David: A week.	Clarifies
Sam: I mean, four days is just not a lot of time [for them] to get it finished.	Raises concern Considering student responses and reactions
David: We might have to say, hey we have a free day today, let's go back to—	Suggests alternative in line with this thinking
Kevin: But it might be crazy to extend beyond the time we've set.	Expresses doubt
Jeff: I'm okay if it's unfinished.	Asserts position
Kevin: I am too, I just don't think four days is enough.	Asserts position
David: It might be one of those days where each person is finishing up. Some of them may finish this [part] pretty fast, and then they have to go to Tina and say I'd like to work on my writing, or like they take a picture in my class and get done quickly, then they can work on something else.	Suggests solution
Joseph: Keep in mind they won't have anything else [to work on]. This is their job for the next week.	Focuses group
Sam: Yeah that's true.	Agrees
David: That said, for [the next] four days they'll be thinking about themselves. Potentially they could show what they've been working on to their parents.	Setting goals for project as a whole
Tina: Yeah that could be one of our final goals. Share it at home.	Agrees

The iterative nature of the process seems to be intentional, by design. When asked in focus groups, the team described their collaborative planning as a space to try something, fail and learn, then revisit and revise:

> *Joseph: I think part of the fun about the [collaborative projects] we do is we're not afraid to try things new. Either we're not familiar [with it] or the kids aren't familiar with it. If we're going to fail, then we'll fail as a group, and the [students] kind of [learn] that's okay. I'm willing to give it a try and we'll see how it goes for a couple of days. If it doesn't go as planned, it's still such a beneficial activity for those kids to be introduced to it and try it. It could turn into something much, much better. I think that's what all of the team projects are; it's a risk, it's a trial. Let's see what happens, and if it all turns out well, we're all the better for it.* (FG1)

> *Tina: And if they fail, then [the kids] learn from that. We learn from that. We all go back, revisit it, revise it.* (FG1)

> *David: We're kind of prototyping this project. And that's okay. We have a willingness to try and not [necessarily] succeed. Learning happens. To learn through the process, of planning it and actually doing it. I used to say with an old colleague: design the plane as you fly. Make shifts to the plan in the moment. Troubleshoot.* (FG1)

This iterative process is reinforced by the next phase of their design and planning: implementation and ongoing reflection during implementation. As an example, the team had the foresight to have students complete a formalized online survey at the end of their delivered project. In their post-implementation debrief meeting (OBS5), the team intentionally discussed the gathered data to take into consideration student feedback on the project, assess student growth along several team-identified competencies, and determine how their designed goals were or were not being met by the students. Not only did they examine the student specific data, but the team made assessments about the effectiveness of their individual instruction and collective design, and planned to use these reflections to inform future implementation.

The significance of the descriptions of their processes as iterative suggests that the team is driven by a process of experimentation, one that appears to be consistent from meeting to meeting and referenced as productive and positive in group and individual interviews. The team is not merely utilizing their team planning meeting to assign tasks and complete them, but to think deeply and collaboratively about the outcomes for which they are about to put into practice.

4.1.1.2 Support structures

Also indicative of their collaborative process, the teachers reflected on three key support structures necessary for its enactment: 1) common planning time, 2) support of administrator, and 3) the make-up of this particular team.

In focus groups and individual interviews, the team described the importance of the dedicated time for grade-level team planning. The time can be used at their discretion, which means that teams schoolwide can decide how they will use this time collaboratively and for what purposes. During the initial focus group (FG1), the team debunked my assumption that all teams in their middle school used this time in the same fashion. As a school district, the reputation of high-performance led me to believe an emphasis on collaborative approaches might be more widespread. This is not the case. (Section 4.2 will further uncover the team's expressed beliefs as to what sets them apart from the others in their building, which reveals itself as an important driver in this team's work together.) The team emphasized their serious approach toward common planning time, and actually described their current planning schedule as less than ideal (FG1). Comparative to previous years, the *Steel Squadron* had both team planning and their personal prep periods at adjacent periods, which in their opinion, gave them more flexibility in their creativity, design and reflection (FG1). Collaborative design and discussions could extend beyond the 45-minute period, allowing for deeper design, troubleshooting, modeling tasks, and research. While having an integral support structure for their processes, the team acknowledges that there are areas for improving its structure to better meet their needs.

The team also described another critical support for their collaborative work: the building principal (FG1-2; M1, S1). The team asserts to be in communication with their principal often about their ideas, progress, and outcomes. Most ideas are received positively; the team is encouraged to inquire about an idea, and supported to pursue grants and contests for materials. The principal joked with me at the outset of the study that he knows there is "something brewing when all four teammates from the *Steel Squadron* arrive at [his] office." He additionally acknowledged the excitement the team's students have after engaging in the *Steel Squadron's* learning projects. When asked about the extent of the principal's input in their work (FG1), the team stated that the principal is generally perceptive of their new and innovative ideas, and trusts the team to be accountable for maintaining appropriate logistics (i.e., permissions and legalities). Typically, the principal does not physically engage in providing design or implementation feedback, but rather awaits debriefs on the team's project outcomes. In the team's opinion, the flexibility to do the kind of collaborative work they have been enacting the past several years, would not be possible without this support. The principal not only provides a space for teacher flexibility, but also a willingness to let teachers explore their practice, by enforcing the kind of daily instructional and preparation schedule currently in place.

The final support structure in which the team recognized as imperative for the collaborative work that they do *is* the team. When asked in focus groups (FG1, 2) the team as a unit is unlike other teacher groups with which they are associated. In the following section, I expand further on the *dynamics* that drive the team, and in the subsequent section, delve into the *expressed beliefs* of the team, which will help to describe *how* and *why* the team does this collaborative work.

4.1.2 Dynamics

Back in Tina's classroom, the team plans at the four tables. Individually you can see the separate entities that represent the core disciplines (mathematics, history, science and English-language arts). However, the lines become blurred as they begin to interact with one another (OBS1-5). To only study the team's processes (*what* they do in planning) would not provide the entire picture for the collaborative space. In the analysis of interviews and observations, I examined the way in which the team interacted and conversed with one another. In this way, I began to uncover *how* the processes work. Any team can enact a specific process, follow through with it, and deem it a success. A deeper question asks to uncover the *dynamics* that influence the process such that a team can be effective (or, possibly non-effective) in their processes.

Two key group dynamics were apparent as the team collaborates to enact their processes. Examples are provided in Table 6 below, and will be discussed in more detail in the next two subsections.

Table 6. Key dynamics of *Steel Squadron* team

Key Group Dynamics	*Examples:*	*Evidence from transcripts and memos:*
Representing and recognizing different perspectives	Productive discourse drawing upon expressed personality types and expertise	OBS1-5; M1-3; S1-3; FG1,2
Relationship building	10 years of building rapport, evidenced within professional interactions and in classroom situations	FG1-2; M1; S1,3

4.1.2.1 Different perspectives

The first key dynamic draws on the team's strong focus on *discussion*. Processes and dynamics are intertwined here. The team utilizes discussion as a core process, however, the ways in which the team engages in discourse is of interest. I began to think of this process/dynamic as a kind of *productive discourse*, in the vein of Stein and Smith's work in mathematical discourse (2011). This intentional discourse seems to be productive in that it offers the team an opportunity to acknowledge and represent different perspectives, an important purpose for their work together. The observed stances in conversation in all observations and even in focus groups (OBS1-5; FG1-2) revealed a natural and consistent process for: 1) expressing agreement but also disagreement, 2) finding consensus, but also looking for that consensus as a point of respect, 3) expressing clarity *and* confusion, and the space to offer one's rationale and reasoning when asked to clarify, and 4) presenting alternative ideas and counters consistent with professional and respectful argumentation.

In this way, one purpose for the back and forth nature of the team's collaborative argumentation allows for *and expects* for different perspectives to surface and be recognized. When asked directly, the team described this phenomenon as having importance to them:

> *David: Everyone comes in from their own angle. I'd say we go [in] equally, because we all know our different content areas, our strengths. But our styles veer off of each other and we bring that to the team as well.* (FG1)

> *Tina: I'll tell you, I feel safe to put out an idea, [one] that might be a dumb idea, [but] with something valuable in it. If I was in another setting, I might be more reserved, because [that team is] not my safety. This group is supportive; any one of us could come to the group with an idea, and no one's going to make you feel like it's the dumbest idea ever. We talk about planning. We try*

to come at things with each of our different perspectives and contribute in a way that is not threatening to the other three members of the team. (M1)

Joseph: I don't think my subject area is any more important [than anyone else's]. I want to hear what you all are doing. (FG2)

Sam: You probably think our communication style is odd; we joke with each other a lot to some degree, as a safe way to talk. No one takes themselves too seriously; they're not above [any] other person, and no one's feelings get hurt. That really helps because humor lets us freely discuss things. We all know one person has strengths, and weaknesses too, that as a team we can benefit from [both], and at the same point, we can help [each other] get even better. (S2)

Tina: But even through joking, we're not sugarcoating anything by any means. We're very real. We'll tell each other if something is not going to work, but we also suggest how you might come at it with a different angle. We are willing to just try and see what happens. So we're very real with each other too, but in a way that's not patronizing or condescending. We're in this together. (M1)

The team expressed thriving on the fact that each member comes to the table with their specific personality differences and personal expertise. As reflected in the excerpts above, the pieces to the puzzle are integral parts of the team. In the following table, I summarized the descriptions around "personalities" and "expertise" made by the team at various points over the study. These descriptions were impromptu by the members of the team about themselves and each other. It is interesting to note that over the course of data collection, the individuals appeared to agree with each other about the accuracy of these descriptions.

Table 7. Team personality and expertise descriptions

	"structure"				*"function"* (other than implicit connections to one's content areas)
	"personality"		content expertise		
David	ideator free thinker dreamer creative	FG1,2 M1	history technology	FG1,2 M2, S2	▪ ideation and problem solving ▪ <u>technological fluency</u> ▪ <u>connections to global society issues</u> ▪ <u>legalities</u>
Joseph	wordsmith writer creative speaker	FG1,2 L2	language literature	FG1,2 M2	▪ ideation and problem solving ▪ attention to cohesiveness and clarity of ideas ▪ <u>attention to language and presentation of written materials</u>
Tina	logical organizer facilitator writer	M1-3 FG2	mathematics numbers	M1-3 FG2	▪ ideation and problem solving ▪ attention to cohesiveness and clarity of ideas ▪ <u>facilitating dynamics with discussions (i.e., off topic; creative tensions)</u>
Sam	"worrier" skeptic realist creative logical	S1-3 FG2	science experiment-ation	S1-3 M1,3	▪ ideation and problem solving ▪ attention to cohesiveness and clarity of ideas ▪ <u>challenger of ideas (with respect to the broader context, i.e., parents, students, legalities)</u>

To relate to a cross-cutting concept in science, *structure/function*, I paired the expressed descriptions of personality traits and expertise (as "inherent structures" the individual brings with them to the table) with observed actions of individuals in the planning meetings (their "functions"). These actions seem to align with their unique personality and expertise contributions, and illustrate the team's emphasis on needing the "parts" to construct the "whole." Some functions (underlined in the table above) appear to be specific to a particular individual, while all bring their varied perspectives to contribute to the common functions of ideating, problem solving, and attending to clarity.

> *Sam: I'm well aware of the fact that I'm just a tiny piece of the puzzle, and having many more cooks on board is much better. These guys happen to be three very knowledgeable people. Just having another viewpoint, the idea is always better. Just to bounce ideas off of even. [It might be] something you're not completely used to doing, someone else's content. All of a sudden if you talk to someone that is dealing with that on a regular basis, you learn so much from kind of bringing them on board. I think it's more beneficial for the kids as well, from having these other people work on it with you from behind the scenes. [Then] it's like there [are] four people in your room even though you're delivering [the] activity yourself. [In planning] everyone talks about it beforehand and giving some valuable feedback about it.* (S2)

> *Tina: I think that if I had to do [the large project as a unit] by myself, I don't know that I would. I feel like collectively, it has the power. There's something powerful when we say to the kids, we're stepping back from just [one content area], and we're putting it all together. I think that speaks volumes to the kids when they see their teachers working together. I don't think I [would] necessarily [have] the knowledge to do all of it, by myself. Each person brings something different to the table, and then when we put it all together that's when it comes together and works.* (M2)

In these excerpts, both Tina and Sam express value in participating in the collaborative team, particularly in how this act contributes to their individual contexts and impacts students.

4.1.2.2 Relationship building

The second key dynamic is represented by the team relationship that has developed over many years. The team described the combination as happenstance; they were assigned to that hall, that team. In focus groups and interviews, the team described their early teaming explorations between content areas, which after many years expanded into larger group collaborations. They intentionally utilized the common planning time to share and pursue ideas, and develop a rapport that filtered beyond the planning space, into the classroom. Any individual teacher can be found in a colleague's classroom, sometimes for very specific content support, or for more informal, often humorous, team building purposes (FG1-2, M2, S2). The team believes that the result is that students, too, feel the teaming aspect. Students and teachers are part of the *Steel Squadron.* Tina and Sam, in interviews, reflected personally on relationship building and teaming:

> *Tina: Every couple of years there's talk about shifting the teams around. We've told the principal every time, if you switch our team, we'd feel compelled to transfer schools. We've been together so long it's like a marriage. We have learned how to work together, how to make compromises. We know how each other think and that makes it work.* (M3)

> *Sam: I can almost guarantee that I would never say "no" to the team, because I don't think those three would ever bring a bad idea to the table. I honestly feel that strong. And if one of us does say "no", I wouldn't feel bad either. As a team we have years and years of experimenting and experience [in teaching]. I just know that they never do anything that I probably wouldn't be behind. But none of us would just sign off on something blindly; I know what they do in their classes, I know how they deliver their content and I know how they incorporate the kids in everything. That's basically the same way I do things. So in a way, I would be* foolish *to not at least explore their ideas because in the end it ends up benefiting everyone. And for the kids, it becomes that community time where they can all literally bounce from teacher to teacher to teacher, seeing a bigger picture, with a safety-net built in.* (S3)

When directly asked in interviews and focus groups, the team had a difficult time expressing just *what* makes this team work. From an outsiders' perspective, common themes emerge from their descriptions about developing this type of relationship: time, patience, respect, and humor. It appears that their established process of collaboration, which is coupled with a flexible but intentional style of interaction, builds on such patience and respect, and allows for rapport to grow over time. In Section 4.2, I will discuss one final theme that emerged regarding the collaborative space which was alluded to in Sam's reflection above: complementary beliefs about teaching and learning.

4.2 THE COLLABORATIVE SPACE: EXPRESSED BELIEFS

Question 2: What purposes does the collaborative space provide the team? While investigating the collaborative space, in addition to uncovering *how* the team works together via processes and group dynamics, I began to examine underlying *beliefs* of the team, and how these beliefs appear to drive the work of the group, relating to *what* they chose to do collaboratively and *why* they do this work.

4.2.1 Expressed beliefs

Primarily through focus groups and interviews, four key themes around the team's beliefs became apparent: 1) a focus on new and innovative ideas, 2) a focus on student outcomes, 3) use of informal frameworks, and 4) approaches to teaching and learning.

4.2.1.1 New and innovative

I entered the AGW Middle School with prior knowledge of a reputation for collaborative STEM projects implemented by the *Steel Squadron*. In focus groups, the team immediately cautioned me that the project they were designing was "not STEM" (FG1). I asked the team to describe in their own words, what it was then, and what kinds of projects they designed and enacted with their students (FG1, 2). With no input of my own set frameworks for STEM and integration, the following terms and descriptions emerged from the team:

Table 8. Team criteria for pursuing ideas

Idea criteria:	*Descriptor*	*Evidence from transcripts and memos:*
New and innovative – to the students	*Something no one else is doing anywhere; something the kids will not be getting anywhere [in their learning]*	FG1
New and innovative – to the teachers	*Something we can learn about and experiment with in real time with the students*	FG1,2
Connects to the real world	*Relevant and meaningful to the context of today and to their current learning; not connected to "the test"*	FG1,2; OBS3,5; M1
Promotes teaming	*Teachers and students are expected to collaborate to engage in this work, experiment while being immersed in the work, and make meaning at higher cognitive levels*	FG2, S1

A typical collaborative experience for the *Steel Squadron* teachers and students would be "new" and then expanded upon in subsequent years. For example, the *Geography of Self* project itself had been implemented by other teachers elsewhere, but not to the level to which the *Steel Squadron* envisioned. The project was new to the students and the teachers and spoke to a relatively current and relevant issue for how young people portray their identity online to a public audience. It went beyond making a website, as was detailed in the original design, but incorporated the risk of building a website while live, and utilizing one's peers to obtain feedback in real time for content being presented online (OBS 1-3).

Also with the previous year's *Space Kit* project, each year represented a different iteration. Last year, student teams collected real time data in line with designed science experiments. This contrasted with the first year's launch, where the teachers and students focused primarily on launch and navigation. The team expects that each year's projects should reflect issues relevant to students currently, and by design, raise the level of rigor and engagement for both students and teachers (FG1-2).

4.2.1.2 A focus on students

As I listened to the teachers collaboratively plan and share reflections about initial implementation of the *Geography of Self* project, it became increasingly clear that the teachers were highly driven by their knowledge of students in the minute-to-minute decisions that they make (OBS1-5).

I was surprised by this finding, given my own professional experiences. I hypothesized that teachers planning collaboratively might fall into two camps. One might represent a more technical planning session, where step by step enactment is decided, and roles and responsibilities are delegated and then completed. On the other hand, the collaborative space could be driven by opportunities to learn and improving teacher practice, in line with Lave and Wenger's thinking about *communities of practice* (2000). For the *Steel Squadron*, I found a blend of both worlds, but a more prevalent focus on their students in their threads of discourse.

As I observed their planning sessions, I found that the team moved in and out of the technical aspects of design and planning and only slightly touched on *how* they were going to implement a specific part. I struggled to remain quiet, and wanted to know more explicitly about their teaching decisions. Perhaps they would use a grouping strategy for brainstorming, as this would evoke prior knowledge and build upon what we know from the learning sciences. I wondered how they would engage students in productive discourse around digital identity, and why they chose not to discuss these issues in their planning sessions (OBS1-2).

Instead, the teachers were drawn to discuss the design and outcomes of the activities by what they anticipated of their current set of students. On multiple occasions, teachers referred to current students' abilities and perceptions, as well as current levels of perseverance and comfort (OBS1-3) when adjusting an element of the design of the project.

Table 9. Sample of dialogue from team planning session

(continued from Table 3)

Lines of dialogue:	*1st level coding:*
Sam: So something to think about: they are not going to really be working together. These are many small individual projects. Will they be able to finish everything in time?	Raises constraint Considering student responses and reactions
Tina: Maybe we can do a quick survey and find out what they'd like to work on.	Suggests idea
Sam: I'm just wondering if there should be an alternative like for the [Michael's] out there. A lot of this could be challenging.	Suggests idea Considering student responses and reactions
David: Well this is like a real 21st century problem that every kid has. What tools to use, how to get it all done. It's a skill set.	Articulating goals for project
Tina: We'll be working on that for the rest of the year.	Agrees
David: Yes. And some will know and help the others, which will be perfect. Like in art class wouldn't they be confronted with this: Like if [Lily] can't draw, but if [John] can, and [Linda] can paint, and I can do sculpture, and we all end up helping each other out.	Articulating goals for project
Sam: Well, we can still can have pencil and paper here. I just don't want them to shut down. I don't want them to give up.	Suggests alternative idea Considering student responses

Table 9 continued

	and reactions
David: I think the challenge of asking them to do this - I think they are going to want to do this technology. If they're not good at it, they might ask for help. Yeah, I can see what you're saying about Michael. But you know what, maybe that's where we can say "Ask three, then me." There's people in here that know how to do this.	Articulating goals for project Suggesting instructional move
Tina: There are some experts in there.	Agrees
David: You [the students] gotta find out the problem. You have to solve it. Together.	Articulating goals for project Restates the concern as a beneficial challenge
Tina: And they problem solve already.	Agrees Connects to present skill level of students
David: Mhmmm. The problem they're going to have is time. It's going to be classic. Those key kids you mentioned are going to say, "We only have one day left!" But we warn them the entire time on these kinds of projects: time is not your friend. So getting back to the original question, is that one [part] going to take up you four days?	Articulating goals for project Refocused on planning of specific part

In this example, we hear concerns for students' skill levels and accountability, while also not overestimating nor underestimating their ability. While I did not explicitly hear rationales for their approaches to teaching and learning within the context of the observed collaborative planning sessions, I utilized remaining interviews and focus groups to uncover what frameworks, however implicit, they were utilizing to guide their work.

4.2.1.3 Informal frameworks

In interviews and focus groups, I began to ask another line of questions to dig deeper into the working frameworks that the teachers utilized to frame their designs, decisions, goals and outcomes. When asked to answer this in their own words, the team began to list several educational buzz-words such as: *project-based*, *problem-based*, *collaborative*, *interdisciplinary*, and *cross-disciplinary* (FG1). David specifically mentioned that their philosophy for large-scale projects typically follows the Buck Institute for Education's framework for Project Based Learning (PBL) (BIE, 2015), although as educators, they have never been formally trained in the

PBL process. The team asserts they tend to conduct research into instructional strategies informally and individually, and utilize team planning time to share these learnings to make sense of the practices for their context.

KEY KNOWLEDGE, UNDERSTANDING, AND SUCCESS SKILLS The project is focused on teaching students key knowledge and understanding derived from standards, and success skills including critical thinking/problem solving, collaboration, and self-management.
CHALLENGING PROBLEM OR QUESTION The project is based on a meaningful problem to solve or a question to answer, at the appropriate level of challenge for students, which is operationalized by an open-ended, engaging driving question.
SUSTAINED INQUIRY The project involves an active, in-depth process over time, in which students generate questions, find and use resources, ask further questions, and develop their own answers.
AUTHENTICITY The project has a real-world context, uses real-world processes, tools, and quality standards, makes a real impact, and/or is connected to students' own concerns, interests, and identities.
STUDENT VOICE & CHOICE The project allows students to make some choices about the products they create, how they work, and how they use their time, guided by the teacher and depending on their age and PBL experience.
REFLECTION The project provides opportunities for students to reflect on what and how they are learning, and on the project's design and implementation.
CRITIQUE & REVISION The project includes processes for students to give and receive feedback on their work, in order to revise their ideas and products or conduct further inquiry.
PUBLIC PRODUCT The project requires students to demonstrate what they learn by creating a product that is presented or offered to people beyond the classroom.

Figure 5. Essential project design elements

In the example of project-based learning, the team did not present this explicit framework (Figure 5) to me as a physical document, but indicated in a broad sense that they paid attention to some *essential question* of *authenticity*, provided *sustained experiences of inquiry and design*, ample ground for *student choice and voice*, individual and peer *reflection, critique and revision*, and the evolution of a final *public product.* The team would argue, however, that a "final product" is not the true outcome of their collaborative projects. The outcomes are largely centered on students and developing them as productive, engaged thinkers (FG1-2; M1-2; S1,3). The evidence of this construct as an informal framework was therefore apparent, but this began to raise questions for me. How does the team evaluate their collaborative implementation of project-based learning? How do they hold one another accountable in their individual contexts? Would emphasis on an explicit framework improve instruction or bring other pedagogical issues to light?

Along this line, other key constructs surfaced several times throughout interviews and focus groups: *growth mindsets*, *grit*, and *comfort zones.* The team described these terms by name and provided various descriptions of how these manifested in their individual classrooms and in project implementation by the group. Interestingly, these three components also appeared to be modeled by team when engaging in team planning (FG1-2, M1-2, S3). The underlying principle pertaining to these three ideas is that within this team, teacher *and* student are expected to engage in these behaviors and are given opportunities to reflect upon personal feats of persistence, effort, and stretching one's level of comfort. The team appears to share this common mindset as an underlying guiding framework for design, but also for approaching the work that they do. As described in the previous section, the team members each appreciate one another for having such mindsets, and a like-mindedness for experimentation and growth which enables them to do the design and implementation work they set out to do.

Table 10. Informal frameworks used by *Steel Squadron* team

	Team's brief description	*Evidence from transcripts and memos:*
Growth mindset	In line with Carole Dweck's work, growth mindsets pertain to the assumption that all individuals can learn, and that learning is driven by effort. This contrasts with a fixed mindset which assumes people have fixed skills and abilities, and that no effort will improve one's abilities. (Tina)	FG2; M1,2; S2
Grit	Excellence + Resilience + Conscientiousness+ Courage + Endurance = Grit Grit implies having a growth mindset; you must be willing to engage and endure while acknowledging failure, and growth from failure. There is a tenacity involved in the growth mindset in pushing oneself to drive forward with an open mind and explore new boundaries, fearlessly, knowing failure awaits, but pushing past that leads to the growth in many areas are both tangible and intangible. (Sam)	S2,3; M2,3
Comfort Zones	In line with leadership zones, the comfort zone is where learners spend most of their time (safe and predictable). Just outside of the comfort zone, this becomes to zone to push boundaries of your existing skills and abilities, and only then can one learn and grow. Also falls in line with experiencing some cognitive dissonance as one works through a problem or something new. (David)	FG1,2; M1; S3

4.2.2 "We are different"

In exploring the team's implicit frameworks for teaching and learning, several tensions surfaced during the focus groups and interviews with respect to *what* they believe they are accomplishing with collaborative work they do. As stated earlier in this chapter, the team corrected my assumption that a high-performance district does not necessitate the enactment of best practices inclusively (FG1). For example, not all teachers in their middle school utilize team planning time as this team has. The team does not contend they are doing it "right"; however, they are perplexed by the different approaches to teaching and learning within the larger district (FG2, M2, S2).

The first tension appears to be one centered around the predominant testing-culture of the district:

> *David: The four of us are willing to give the students that space [to delve into practices deeply]. I don't know if all the teams in this building are willing to do something for four days that's not anchored to something on the test. They feel they have to do what they have to do.* (FG1)

> *Joseph: I have a belief that no matter what I do in my classroom, my kids are going to do well on the test [from the standpoint of a high scoring district]. Our kids are already successful. I would rather this be a meaningful learning year for them, rather than [covering] what's on that test, which is how others feel about it. Teachers look at their scores, they know their scores. I'm just not focused on the scores - because it's not going to change what's I'm going to do in the classroom.* (FG1)

> *[Joseph looks at Tina, and asks, "Is that bad to say? I just can't let that be my main focus when I'd rather be teaching this way." Tina agrees, and says, "No it's not bad. It's just the way it is.]* (FG1)

> *Sam: I agree. For some, the tests take on a complete life of their own, to where it turn[s] into a live or die situation.* (S3)

Additionally, the team talked about the tension between what they considered "traditional" teaching and more "progressive" teaching, and how this manifests in their district.

> *Tina: Our team is okay with experimenting and failing. Other [teachers] might be focused only on the exact outcomes. We're okay with saying, we don't know, it's tentative. I don't think that every*

teacher is okay with that. I think that in order to make it work you have to have a team that is interested in trying something, not necessarily knowing what's going to happen. Trying something and then using that to learn from. Because I feel like a lot of teachers have to know all the answers up front. (M2)

Sam: What our work does that's different is that [the experiences we give students] play to [their] strengths and are open-ended, providing room for students to show their own strengths in their own ways rather and follow a script. Every student is different. We try to give them a stake in the process so they feel invested in their work. (S2)

David: I can't say that every teacher is good at that. Teachers by default need to be in control. (FG2)

Despite these tensions, the team has informally observed a difference in approaches to teaching among their middle school staff, stemming from the larger culture in their district. While being highly successful on state tests, it seems to the team that the district's teachers perceive current practices (i.e., a more traditional, standardized testing-focused culture) as necessary to get those test results. Also, thinking of the broader system, the team commented that parents typically feel more comfortable with the process as is, and expect to see their children do well. Perhaps this provides little motivation for teachers to take the risk and change their current processes (FG1-2).

In any case, the *Steel Squadron* team feels strongly that they will continue with their course of design and collaboration, and not "compromise" their beliefs about teaching, regardless of the apparent "culture clash" (FG1). Their goals for working collaboratively, specifically for this project, may be less about teaching to a specific standard (i.e., the test, the curriculum), but to team-identified standards that expects teachers *and* students to experiment with their mindsets of experimentation, failing, and learning from failure. In addition, the *Steel Squadron* expects a variety of outcomes to emerge from the projects they design. However, they believe that their approach guides students to develop a mindfulness about the everyday school experience, and uncover transferable practices for life-long learning (FG1,2; M1,2; S1,2).

4.3 IMPACT OF THE COLLABORATIVE

Overarching Question: What does the collaborative space contribute to the work of teachers in interdisciplinary collaboration? The first two sub-questions help to describe an example of *how* and *why* the team under study works collaboratively. The overarching question digs deeper into the influences of the collaborative space on the work of these teachers. Having engaged as they do, how does the collaborative space impact teachers' work? In other words, why work as a collaborative as opposed to individually? How might the collaborative space impact practice and teacher agency to do this kind of work?

4.3.1 Teacher practice

From a lens of teacher practice, the collaborative space seems to provide an *iterative space for teachers to negotiate their beliefs, goals and practice*. By nature of the team's interactions as described in the previous two sections, the space offers team members the ability to bring ideas to the table, actively listen to one another, and engage in productive discourse around a variety of topics. This seems to create a space of *negotiation of practice* that takes place from two perspectives: from *individual to the group*, and from the *group to the individual*. While not explicitly expressed by the team, the overall result appears to be an immersion and reflection of practice.

Several examples of these spaces of negotiation are derived from the team's descriptions of current and past work. In this section, I present several figures to illustrate conjectures of these interactions between the individuals and the collaborative. Each individual can be thought of as having two primary identities: 1) *self*, as related to his or her own disciplinary context, and 2) *collaborator,* within the collaborative space. In the figure below (Figure 6), each individual teacher is represented by a different circle, shown as interacting within the collaborative space. Here as an illustration of *individual to group* negotiation of practice, arrows represent the *inward* sharing of competencies, capacities, knowledge, skills and experiences with the overall group.

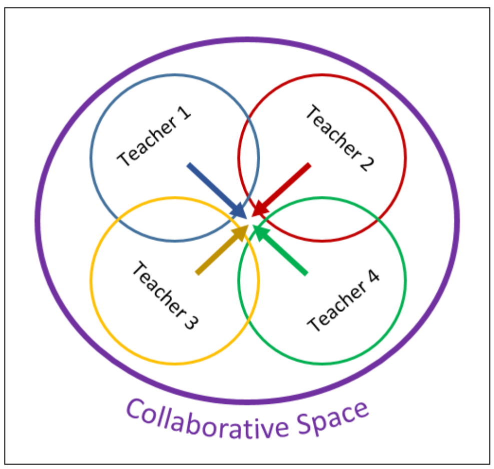


Figure 6. Individual to group negotiation

Two examples of *individual to group* negotiation were described to me with respect to the large-scale projects of *Geography of Self*, and previously, the *Space Kit* project. Recall the personality/expertise summary portrayed in Table 7 which describe the function of the parts within the whole. In both large-scale project examples, each member brings with him or her a set of competencies, capacities, knowledge, skills and experience that can be shared with the team, and thereby impacting the overall design. To guide students' scientific experimentation for the

Space Kit, Sam's expertise in scientific inquiry and Tina's concentration in describing relationships mathematically helped to shape how Joseph and David worked with students in their classes in these areas (FG2, M3). Likewise, much of the technological fluency required of all four teachers and their students in *Geography of Self* relied on David's technology education expertise to provide coaching and resources so that individual teachers could facilitate student learning confidently and effectively (FG1,2; S2).

The figure below (Figure 8) depicts *group to individual* negotiation of practice. Here each individual teacher has left the collaborative space to enter into his or her individual disciplinary space, which represents the classroom and personal practice. Arrows in this scenario flow *outward*, representing the transfer of learning from the collaborative to each individual's practice.

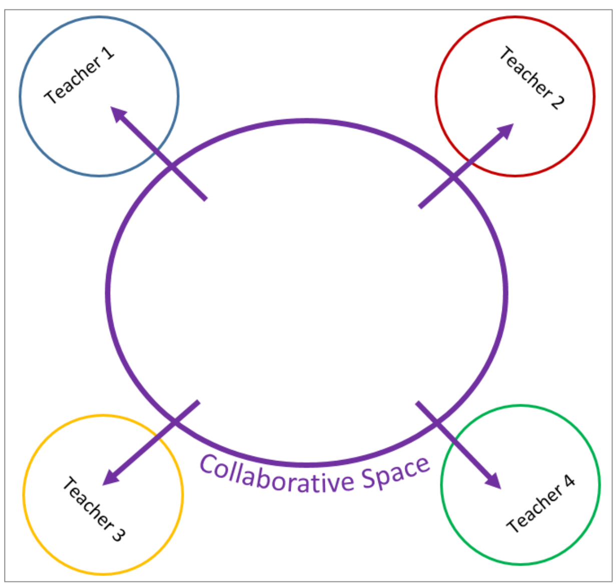


Figure 7. Group to individual negotiation

In one example of *group to individual* negotiation of practice, pedagogical strategies discussed by the group appeared to transfer to one teammate in particular. In one team planning session of the *Geography of Self* project after implementation had begun, Sam raised a potential concern about one of the aspects of his portion of the project. He commented that he would like to engage his students in authentic peer feedback, but was unsure as to which approach to take (OBS3; S1-2). His specific part of the project was largely abstract and artistic in nature (i.e., students drew a map of the islands of their lives incorporating landforms as symbolism, which would then be uploaded with descriptors onto the live website). Sam commented that peer feedback in his science labs takes a different structure; students engage in class argumentation about claims, evidence, and reasoning around core concepts and phenomena, rather than aesthetics and abstractions. David recommended that Sam use the "gallery cruise," of which both Tina and David described having used in the past (OBS3). (This strategy encourages students to publicly display their work, and then cruise reflectively around the classroom to provide and receive feedback from their peers.)

In reflections after the implementation, Sam reported to me that he *did* attempt the strategy as suggested by his colleagues (S2). While he recognized the strategy's benefits for student engagement in feedback, he reflected that his criteria for the project assignment was less clear than he normally would have set for his small-group scientific inquiry labs. He reflected that his presentation of the strategy was lost on the students and the feedback was not as productive as he hoped. This train of thought set into motion a line of inquiry about his personal practice. Sam negotiated his personal practices with those of the team: *What differences exist in how [the different members of the team] organized their small groups, and what expectations do they explicitly set? How do the students perceive [each teacher] individually, even though we do share [similar mindsets and approaches to learning]?* (S2).

Interestingly, when prompted in interviews, the teachers could elicit very specific examples of reflection on individual practice. Within the observed sessions, however, the team planning did not often showcase this as a main process in team planning (as discussed in Section 4.2).

4.3.2 Teacher agency

As I examined how the teachers described their individual practices (particularly with Tina and Sam, through their mathematics and science teaching respectively) and those enacted by the team, I began to consider an additional example of negotiation of practice taking place between the individual and the group. In this case, I am making the conjecture that this interaction appears to be *reflexive* and driven by *teacher agency*. *Reflexivity* suggests that as two entities interact they influence one another mutually. As the interaction continues, individual and collaborative identities flex and change in response to these interactions. In this case, the two "entities" are represented by two configurations that work to shift the identities of the teachers: *self*¸ within his or her individual disciplinary space, and *collaborator*, within the collaborative space (Figure 9). Specifically, I am hypothesizing that these interactions appear to be driven by a high *teacher agency* within both the individual and collaborative spaces.

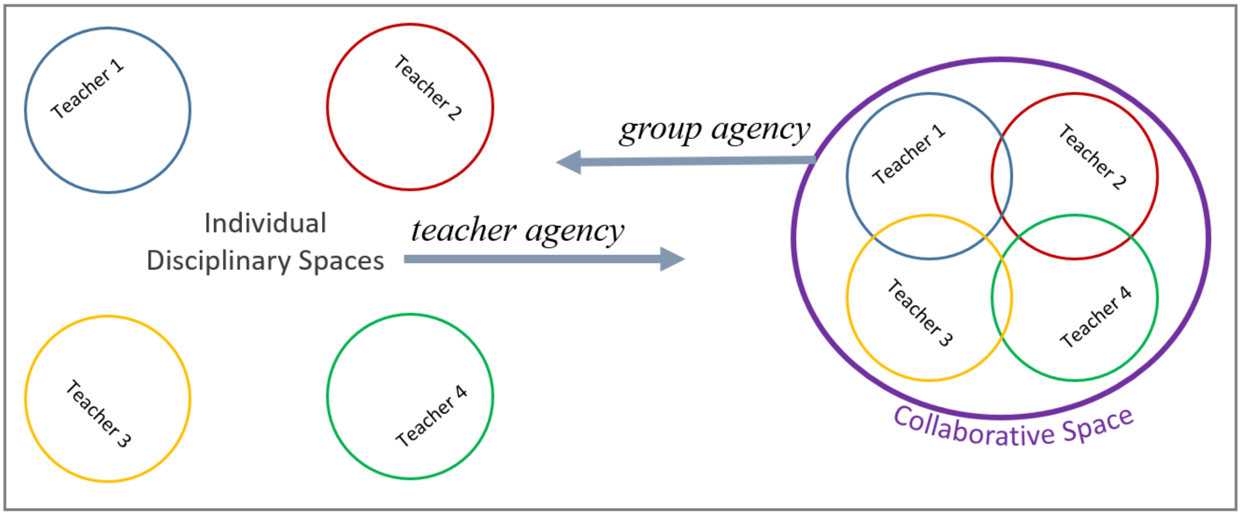


Figure 8. Reflexivity between individual practice and group collaboration

As I interviewed Tina and Sam separately, I uncovered their individual teaching and learning practices that appear to *complement* what is happening in the large group. For example, Sam follows constructivist, inquiry-based learning theory, and engages students in many forms of collaborative, learning experiences. Sam intentionally connects science concepts to broader cross-cutting concepts and mathematics on a regular basis (S1-3). Tina uses the TTLP (Thinking Through the Lesson Protocol) when planning; this tool reinforces the practices for productive discourse (Stein & Smith, 2011) and ensures she is engaging students in high level tasks and talking productively about the tasks that in which they are engaged (M1-3). The same regard for discourse and connected, relevant learning is consistent in the teams' ideals for their collaborative approach (revisit Tables 8 and 10). It may be the case that Tina and Sam bring their teacher agency to engage students in this way to contribute to the collaborative group (both in its processes and outcomes for students). Likewise, hypothetically, the group's agency to enact such collaborative work may reinforce or add to what happens in each individual's practice. In general, the team perceived success of the outcomes of the group project (OBS5, FG2). These outcomes (both positive and negative) may shape individual perceptions of practices to reinforce similar outcomes in the classroom.

In addition to reflexive individual – group interactions, the external context also seems to play a role in supporting and strengthening the agency of the team and each individual, as illustrated in Figure 9 below.

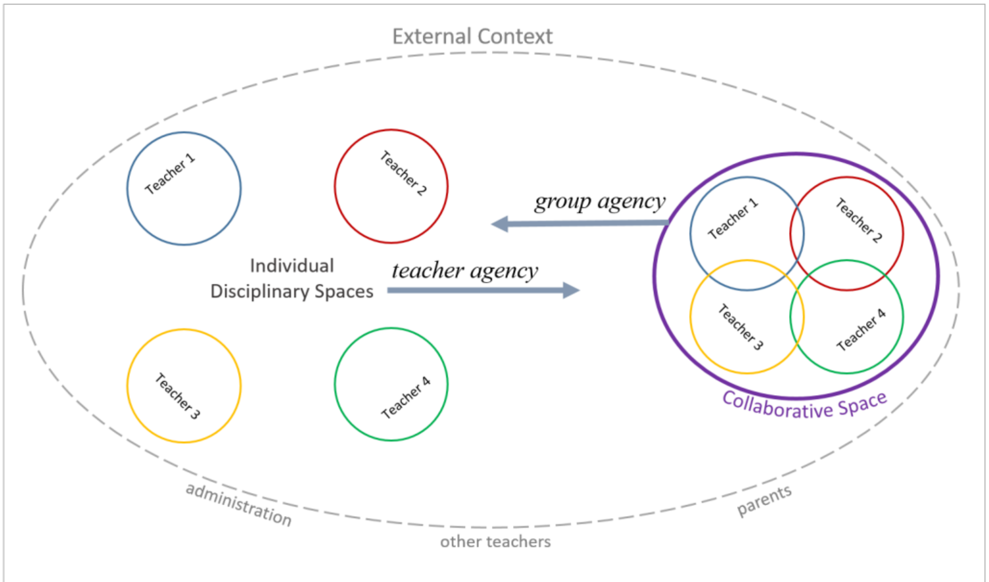


Figure 9. Reflexivity with input of external context

Within the external context exists the supportive principal who endorses common team planning schoolwide and the team's agency to do utilize planning in the way they have demonstrated. The team additionally recognizes the existence of a district and schoolwide culture that represents a more traditional, testing-focused culture dominated by the larger district. This "culture clash," however, appears to motivate, rather than discourage, the team's approach. The external context then appears to reinforce both individual and group lenses for collaborative, cross-disciplinary, and meaningful learning experiences for themselves and their students.

5.0 DISCUSSION AND CONCLUSIONS

In conclusion of this dissertation in practice, this chapter presents discussion around 1) limitations for this study, 2) implications for practice, and 3) areas for future research.

The purpose of this study was to better understand *what the collaborative space contributes to the work of teachers in interdisciplinary collaboration*, and make sense of these findings from the perspective of a problem of practice. One grade-level middle school team participated in observations, focus groups, and interviews pertaining to their upcoming planning and implementation of a collaborative project. The findings presented in the previous chapter answered the overarching question through analysis of data that supported two sub-questions: 1) *What does the collaborative space look like* and *2) What purposes does the collaborative space offer the team?*

In review, the primary findings of this study described the processes, dynamics and expressed beliefs of one interdisciplinary collaborative team to better understand how the collaborative space contributes to their work of teaching. Specifically, I determined that this team of teachers intentionally utilizes the collaborative space to explore the design of non-traditional teaching and learning practices for their students. Therein, teachers enacted iterative group processes guided by complementary, yet flexible practices, ultimately centered around experimentation in design and teaching.

In addition, the team appears to leverage teacher agency, from the perspective of the individual *and* the group, to drive their collective work. In a reflexive dynamic, teacher beliefs, practices, and experiences appear to mutually reinforce and influence group *and* individual practices. While the team appears to utilize the collaborative space to leverage their work, it should be reiterated that the team placed a strong focus on communication and negotiating ideas, as well as designing through the lens of student outcomes. Also of importance, the external context appears to play a significant role in supporting the teachers in their work, which consists of: a supportive administration, productive scheduling parameters, and the apparent clash of schoolwide culture that contradicts their approach, but motivates them to move forward.

5.1 LIMITATIONS

Before discussing the implications raised from this study and its findings, it is important to consider the limitations of this study as related to design, data collection and analysis for a single-sample, qualitative case study.

By design, this study was conducted by one primary researcher within a relatively short timeframe. In an effort to establish credibility, authenticity and limit bias, my aim was to engage in multiple qualitative data collection methods such that I could present thick description of the setting and participant interactions, as well as my methods of data collection and analysis. In addition, I made use of these multiple sources of qualitative data to triangulate my drawn conclusions and recorded these extensively throughout transcripts, analytic memos, and in the excerpts mentioned within this text. Also as a measure of member-checking, I offered my interpretations of evidence to participants during interviews, focus groups, and in written form after inquiry activities.

Given the relative time constraints in conducting a dissertation in practice as part of the EdD program, it was a deliberate decision to study a single case of collaborative, interdisciplinary implementation. This presents several limitations for generalizability outside of this specific context. The examples and inferences presented here represent one instance of practice. In addition, the team under study identified implementation parameters that prevented gathering additional longitudinal data to verify the consistency of data beyond the one instance. A stronger case could be presented with the collection and analysis of practice-related data over a longer period of time.

A second limitation concerns the qualitative nature of data collection in this design. Interview questions were intentionally designed to promote candid responses, and probe for specificity, particularly for prior events. However, all information gathered about past events were not directly observed and relied heavily on teacher recall, and therefore may contain inaccuracies and potential biases.

Due to the nature of the design, researcher observations pertained only to the teacher planning, and *not* of teacher implementation. All reports of implementation outcomes also relied on teacher recall and interpretation, and may lack specific details at the moment of recall. In addition, the extent of the reported information prevented me from making any associations between the effectiveness of group processes on actual outcomes, which may be of interest to stakeholder groups (i.e., teachers and teacher educators). All reported outcomes were self-evaluated by the team, and not verified by any other measures.

Also out of researcher control, informal discussions with the team prior to the beginning of the study provided a general overview of the kinds of projects and goals the team has accomplished in the past. These conversations suggested the possibility of examining how teachers make sense of the terms “STEM” and “integration” more closely, which appears to be a primary issue in the STEM literature. However, as I stayed on course to uncover the specific frameworks the team was utilizing, I found that their work was not necessarily STEM-focused nor definitively integrated, but appeared to evolve out of a conglomerate of informal team frameworks.

Finally, because the design was limited to one group’s practices and experiences, there remain questions about how the collaborative space would afford different groups (i.e., more pedagogically traditional teachers; resource-poor schools; less support of administration). These constraints on timing, design and participant selection may inform future research, as further discussed in Section 5.3.

5.2 IMPLICATIONS

Taking into consideration these limitations, there are two primary implications raised by the findings of this study: 1) Articulating *frameworks for practice* may help teachers to employ *opportunities to learn* within the collaborative, and 2) Understanding the *constraints within the system* may inform sustainability of the collaborative work. Both of these implications will be discussed with respect to the findings presented within this case study, the underlying literature base, and connections to my professional practice. Lastly I will present implications for my personal practice in the area of teacher education.

5.2.1 Frameworks for practice and opportunities to learn

While the *Steel Squadron* team demonstrated having a strong sense of agency to engage students in non-traditional collaborative learning experiences, the team's outcomes appeared to be driven by *implicit frameworks* for collaborative design, integrating across disciplines, and determining assessment criteria for measuring outcomes. It may be important to consider the possible differences between employing implicit and explicit frameworks to guide their work and outcomes.

The conceptual frameworks of Remillard (2005) and M. Brown (2002) described at the outset of this study suggests that teachers interact with curriculum in ways that afford specific learning experiences for students. Curriculum as written is *not* necessarily what students experience; students engage in their learning based upon teachers' decisions made during planning and enactment. Remillard (2005) suggests that there are several factors that influence how teachers engage in this teacher-curriculum relationship. In addition, Ball and colleagues (2008) describe teachers as negotiating their instructional practice dependent on their specific levels of *subject matter knowledge* and *pedagogical content knowledge*, and utilize various frameworks to support their different areas of knowledge. For example, secondary school teachers tend to have high subject matter knowledge within their discipline and lower pedagogical content knowledge, demonstrating a preference for more traditional content-focused practices. Primary teachers, on the other hand, often demonstrate a greater attention to pedagogy and developing student's skills, while lacking strong content knowledge. Having explicit knowledge of one's strengths and weaknesses could be beneficial for identifying areas of improvement and supports for addressing those areas.

One conjecture for this study is that the collaborative space provides an interplay between individuals' knowledge for teaching as they collaborate. As individuals interact within a community of practice it is possible that teachers enter a space of learning by identifying problems of practice and recognizing them as actionable (Horn & Kane, 2015; Lave & Wenger, 2000; Metz, 2008). Horn and Kane (2015) suggest that for teachers to pose productive problems of practice they should utilize frameworks that "provide them with agency [to support collaborative] conversations, consider alternative viewpoints, and deepen individual and collective understanding of teaching and learning" (p. 381).

As described in this study, the *Steel Squadron* teachers demonstrated high agency and expressed perceived success in their implementation. However, it is unclear which explicit frameworks were being utilized, particularly within the constructs of STEM, project-based learning, and integrated endeavors. As a bystander, and teacher educator, I wondered to what extent explicit frameworks could guide this team to be more *disciplined* in their approach to design, instruction, evaluation, and rigor. Were there missed opportunities for learning that the team could take advantage of to move their work further?

In my experiences facilitating professional development sessions, and observing and coaching teachers, I often perceived missed opportunities for instruction, assessment, and/or student learning. Much of this intuition is driven by my own underlying pedagogical frameworks. For example, while observing a teacher conduct an inquiry-based science lesson with seventh graders, I noted that he moved on too quickly after asking a question around a tricky, abstract concept. A small subset of his students provided fast, correct answers, whereas more than half of the classroom appeared not to have engaged in the question. In reflections after, I asked the teacher to reflect upon his formative assessment practices to gauge the relative understandings of his students at that moment. This simple coaching interaction helped the teacher to generate several pedagogical solutions, drawing on key principles about how students learn. My own awareness of inquiry frameworks and formative assessment helped me to identify "look fors" for common challenges in such approaches (Black & Wiliam, 2010; National Research Council, 2000).

In the case of the *Steel Squadron*, I made note of possible "missed opportunities" which prompted me to inquire further into the frameworks driving their work. As an example, consider the possibility of missed opportunities for close inspection of practice as related to integrated instruction and outcomes. The team appears to be enacting some version of an interdisciplinary model, where two disciplines are integrated (Czerniak, 2000; Kurt & Becker, 2011; Stinson, Harkness, Meyer & Stallworth, 2009). In the *Geography of* Self project, students specifically integrated technology with language and arts, within the overarching theme of digital identity. This may fall within a *multidisciplinary approach* (See Chapter 2, p. 18). However, there appears to be some ambiguity, according to the team, as to how deeply integrated these areas are, or through which disciplinary focus. Some teacher teams may decide to integrate *content* so that one subject area helps to strengthen the other; other approaches may lean toward finding commonality among *disciplinary practices* such that students experience fluidity and connection between seemingly different processes. In some sense, the *Geography of Self* project offers students opportunity for *connections* to be made (writing and art as digitally portrayed to a live audience through technology). The missed opportunity here could be in addressing the specificity for how these connections are intentionally designed and enacted. For example, could students explore the intricacies in writing that come with formal and informal norms of expression? This could tap into a sociological view of writing that occurs with the normalcy of communicating by technology. An explicit framework for integration (i.e., what these experiences look like, and how they can be assessed) may better assist teachers in deeper design considerations, and potentially illuminate instructional challenges as a problem of practice worth exploring.

In a more practice-specific example, the *Steel Squadron* quite often explored anticipated student responses, a driver for their design and reflections of the *Geography of Self* project. As these concerns were raised, my instinct was to connect these concerns directly to instructional practice. For example, in the case of the students that needed more direction in the open-ended project, what instructional moves could be employed to maintain the integrity of these goals, but also support students in their growth in these areas of discomfort? I noted that the team more often suggested an enthusiastic trial-and-error approach to these concerns, with the intent of acknowledging these predictable challenges and reflecting upon their results to make improvements later (OBS4-5).

These observations are not to discount the deliberate processes and dedicated use of common planning time that this team has enacted, nor to claim that their efforts were or were not effective. The team *did* appear to engage in productive discussions (OBS1-5), focused by implicit models to drive discussion around their own high standards for their students' engagement. Their recurring focus centered upon discussing and analyzing student outcomes *is* a major component of the domains of knowledge for teaching (i.e., knowledge of students: Ball, et. al, 2008), and these considerations will inevitably have implications for instructional choices made in teaching.

I make the conjecture that the team's individual and collective teacher agency may stem from a confidence in personal teaching expertise that could mask the need to examine practice more closely. In professional development, many teachers claim an expertise ("I already do this") when exposed to a new strategy or one that is focused slightly different than their current approach. It has been my experience that only by slowing down these approximations of practice do teachers challenge their own preconceptions, acknowledge gaps, or strengthen practice. When teachers leave the formal professional development space, what happens in informal settings of collaborative practice, where a facilitator is not there to encourage inspection of practice closer?

In line with Horn and Kane (2015), the collaborative space as a professional learning structure remains a cautionary tale. Educators who engage in the act of collaboration will not all be productive and engage in professional learning with their colleagues. In particular, Horn and Kane suggest that workgroups that are intentionally facilitated by a coach or professional developer often help teachers to be more productive in identifying and pursuing opportunities for learning in their collaborative spaces.

Additionally, the idea of *reflexivity* of individual and group agency could be used to a team's advantage to better understand the frameworks under which individuals and the work group operate. Together they can negotiate meaning, come to collective understanding of the frameworks, and determine how they connect to other competing frameworks. In *Steel Squadron's* case with their drive for experimentation of practice and design, their frameworks can be refined and made stronger as the group negotiates how such frameworks relate to group and individual purposes.

5.2.2 Sustaining the work in light of system constraints

Taking a broad view of the observations of team planning and the accounts described to me in interviews, the *Steel Squadron* reported experiences that exude enthusiasm and confidence and spoke generally of a positive, successful implementation. In final observations of the team's debrief sessions, the consensus was that the team met their goals. Their espoused beliefs envisioned students engaged in a project-based learning experience designed to develop and strengthen students' growth mindsets and push them out of comfort into a purposeful learning zones (OBS1-3). However, their implementation was not completely free of instructional hurdles and unanticipated student reactions. (OBS5, FG2).

Interestingly, feedback emerged from many students indicating that while they were excited about this week of web design, not all students embraced the experience as imagined or conceptualized by the team. Students reported instances of resistance and anxiety given that the project was not graded, nor did it have specified instructions (i.e., the students were being assessed on key skills and practices, and not graded on specific content; the final product was exploratory, where the criteria were largely determined by the students.) The students indicated wanting a grade (in line with their overall district culture) and very specific directions for how to complete the project (in line with the more traditional middle school philosophy in the building). This suggests that the team had well-intentioned, espoused goals that may not be in alignment with the outside system as experienced by the students. General statements about the majority of students earlier in the observations suggested an overestimation of how it would be received by students (FG1; OBS1-2). On the contrary, the team received feedback that not all students thrive in the type of learning environment designed by the team (OBS5, FG2). This finding appears to support the concern about STEM education efforts reaching *all* students, as raised in Chapters 1 and 2. In AGW's context, it appears that only *some* students in the school are receiving opportunities for the kinds of learning experiences espoused of STEM education, regardless of the district's high resources. And, even with the *Steel Squadron's* effort, still not *all* embraced the initiative or understood its value for growth and perseverance.

When I asked the team how to reconcile this apparent discrepancy, the team maintained that resisting the present educational culture is part of the challenge, for students, and for them, as teachers (FG2, S3, M3). They believe they are *not* compromising their beliefs in teaching by continuing to provide students with these meaningful opportunities. The team additionally reflected that they, too, must be intentional about not faltering when the students do, and providing supports to students when they do resist (FG2, S3). It appears that this challenge did not hinder the team's agency to continue to design and implement collaboratively regardless of the stresses on the boundaries (i.e., from students and the overall district).

As a consideration for engaging within the collaborative space, it may be important to recognize the constraints of your system and find the necessary supports within the system to sustain the effort. In this case, the team's agency continues to drive their desire to test the boundaries and provide as many experiences as possible for students to move outside of the district's cultural realm of testing and control. In addition, their intentional, iterative process seemed to support them when troubleshooting, maintaining rigor, and sustaining the project's course.

Given the short time frame of this study, however, it is unclear whether teacher agency and common planning time alone will be sufficient, over time, to resist excessive pressures from the external context. Lessons can be learned from other schools and organizations invested in the work of education reform. In one example, research was conducted at Railside High School to understand their approach to equity-oriented math education reform (Cabana et al., 2014). Railside's reform efforts were sustained by a committed staff via intentionally utilized professional learning communities. These learning communities were focused on establishing group-worthy goals, distributing leadership, and examining practice. The results demonstrated positive cultural shifts in approaches to teaching and learning, for teachers, students, and the community. However, eventual structural and policy changes in the areas of standardization and accountability greatly diminished the efforts led by the pioneering educators. These complex changes negatively impacted teacher agency, instruction, achievement and the cohesiveness and strength of the teacher's professional community. In effect, no new policies and practices were put in place to sustain the work, given the new constraints set upon the teachers (Cabana et al., 2014).

As a connection to the *Steel Squadron*'s agency to drive their efforts, it may be important to acknowledge what processes are in place should changes occur in their context. In the case of shifting team members or changing organizational mandates, will the team's established processes continue to drive the work? Is it important to them to continue the work outside of this team, or encourage others to see the value of these practices for both teacher and student learning? In my experiences with facilitating conversations around developing professional learning communities, one of the primary challenges for educators in sustaining the efforts of educational reform is in establishing a collaborative culture built on shared leadership. This implies a collaborative commitment to common goals, led by the stakeholders mobilizing the effort. In my work, we have found that teacher leaders tend to emerge from the masses. It is a slow process, but one that takes continuous professional development and learning within the system. In this case, the *Steel Squadron* may have an opportunity to grow the work they have started beyond their boundaries.

5.2.3 Implications for practice: teacher education

In this section, I discuss implications for practice as related specifically to my area of practice in teacher education.

First, I revisit the ambiguity of frameworks and educational terms. The context of STEM education set the stage for this study. In this one setting at AGW middle school, it was unclear how the team defined STEM education, or the instructional approaches they were using to design their collaborative, interdisciplinary projects. These findings align with those described in Chapters 1 and 2. The lack of explicit frameworks to guide design, instruction, and evaluation is a widespread issue, even among teams that claim to be "doing STEM" or designing within an interdisciplinary approach. This study provides a description of one context that appears to be thriving in the engaging work of interdisciplinary collaboration. As such, teacher educators may be able to learn from the realities of teacher-initiated processes that evolve over time, particularly when there are ambiguities and clashes in culture.

The challenge with the use of frameworks is that there is a long process associated with their development, research, refinement, and evaluation. As research continues to refine frameworks for STEM education and integration, teacher educators, too, will need to deeply understand these frameworks, and the foundational research supporting those recommendations. For example, to merely state the need for integrated approaches in STEM education would necessitate having a firm grasp of mathematics and science practices, and the productive pedagogy to engage students in these areas (i.e., Ball, 2008; Czerniak, 2000; Honey et al., 2014).

One of the culminating components of my studies in the EdD program focused specifically on teacher learning. Teacher educators, too, have standards for professional development derived on principles for how people learn and engage in authentic practices. Grossman et al. (2009) suggests that educators may be better able to support others in having deep conversations about practice by engaging teachers in “high leverage practices” *in addition to* theories of education. In the case of pre-service and in-service settings, these are those practices that occur with high frequency in teaching and enable teachers to learn more about students and teaching concurrently. In the context of STEM education, it may be helpful to identify those high leverage practices relevant to integration, and further engage teachers purposefully in *representations of practice*, *decomposing practice*, and *close approximations of practice* (Grossman et al., 2009). In this way, professional development opportunities may better be able to provide authentic teacher learning experiences with the intent to examine and improve practice. Grossman and colleagues suggest that these opportunities also help teachers “develop a professional identity built around their role as a teacher. Professional knowledge and identity are thus woven around the practices of teaching” (p. 278).

From a perspective of practice, I have felt fortunate to be able to study authentic teaching through the contexts of actual teachers, classrooms and their students. This process has been a continuous cycle of learning for me, even as the pendulum continues to shift in all areas of education. The professional development arena has provided me with a collaborative space for research, discourse, and experimentation of practice. I believe that in this realm, my organization can also continue to refine its processes for design and collaboration, articulate its frameworks for engaging learners, and determine how to sustain the work of supporting diverse contexts of teachers in their work.

5.3 RECOMMENDATIONS FOR RESEARCH

In light of the discussions above, there are several recommendations for research that could address additional questions unanswered by this study.

How do collaborating teams utilize frameworks to define and implement their integrative approaches? This question addresses the need to examine other contexts who claim to use collaborative, integrative approaches. A focus could be placed on the kinds of frameworks being utilized across settings to determine what similarities and differences exist in approaches to negotiate the meaning of such frameworks. Are groups using implicit or explicit frameworks, and how do these differences manifest in their collaborative efforts?

When do schools determine their approach to be STEM-focused, integrated, and/or collaborative? This question addresses the conundrum of defining approaches that can be construed ambiguously. Here, the practices of several schools who claim to implement these approaches could be compared to understand how approaches and outcomes differ for each approach. What are the commonalities that can be combined to generate a cohesive framework for other educators beginning STEM education reforms?

How do grade-level teams within the same building utilize the collaborative space to enact integrative learning experiences for their students? This question addresses the interesting phenomenon of the "culture clash" discovered during the analysis of this study. It would be important to study two teams within the same context, to understand the possible connection between traditional and non-traditional belief systems, and their impacts on collaborative approaches to teaching and learning.

For each of these questions, it would also be important to commit to extensive study with a team of researchers and multiple analysis measures. These studies could examine collaborative teams over time to assess consistency of practices, changes that occur with respect to different foci, and differences between individual and group practices. In addition, these studies could provide opportunities for careful observation of implementation and the gathering of evidence of actual outcomes. At different levels of the education system, the issue of effectiveness of STEM approaches still remains. Further study may help educators to understand the effectiveness of integrating the STEM disciplines (science, technology, engineering and mathematics) on student's learning in each of the subject areas.

Lastly, based on these more comprehensive studies, research would be helpful to address the teacher educator perspective. *What tools can be designed for use in professional development to facilitate new teacher learning and foster collaborative planning and implementation?* As I look forward to my growing capacity in the teacher education space, such studies may begin to evaluate the effectiveness of such tools to support teachers in their work for integrated approaches to STEM education. This work may also provide models for other teacher educators in pre-service and in-service learning environments to work collaboratively to uncover complementary (or contradictory) messages regarding STEM in these two arenas. Collaboration in this sense, not only becomes an end result for student learning and teacher planning, but an important practice at the level of research for disseminating and discussing critical findings for moving education forward.

APPENDIX A

METHODS PROTOCOLS

A.1 OBSERVATIONS

For this study, a collaborating teaching team will participate in three observations of their common planning time, already taking place in their normal schedule.

Introductions and Stating Purpose

Researcher will state the purpose of the study and the observation, and request that the session be audio recorded, and that the researcher be allowed to take notes. Researcher will inform participants that information gathered during the observation will be kept anonymous and confidential. Researcher will share information gathered in the observation during the follow-up focus group session.

State: “I am interested in understanding how teachers work together to plan and implement their STEM focused lessons, projects or units. After this initial observation of your planning, we’ll start off together in a focus group, and then some of you will be able to participate in individual interviews surrounding the implementation of your collaborative project. You may also identify artifacts of your planning and teaching around your lessons, which can be shared during interviews. You will also be asked to complete a written implementation reflection. At the end of the study we will come back together as a group for one final focus group."

Data Recording Procedure

Researcher will audio record the session and will take field notes during the observation. All recordings will be transcribed.

Field Notes Guide

Table 11. Foci for observation field notes

<table>
<tr><td>Actions that take place as part of the groups planning process:
Sharing of ideas
Goal setting
Evaluation
Other emerging actions</td></tr>
<tr><td>Belief statements made about:
STEM
Teaching
Learning</td></tr>
<tr><td>Challenges that emerge (current or in reference to past) and solutions to these challenges</td></tr>
<tr><td>Impressions about roles and leadership of each member
Who talks often
Who initiates
Who facilitates
Other</td></tr>
<tr><td>With respect to upcoming lessons:
Stated goals and plans</td></tr>
</table>

Completion of Observation

- Discuss next steps, including the upcoming protocol for focus groups and establishing timeline for other upcoming study activities.
- Ask for any questions.
- Researcher will compile additional notes by studying the transcripts of the audio recording.

A.2 FOCUS GROUPS

For this study, a collaborating teaching team will participate a preliminary focus groups which will occur at the beginning of the study. A second focus group will take place with the same teachers at the conclusion of the study.

Introductions and Stating Purpose

Researcher will re-state the purpose of the study and the focus group, and request that the session be audio recorded, and that the researcher be allowed to take notes. Researcher will inform participants that information gathered in the interviews will be kept anonymous and confidential. Researcher will provide notes at a time shortly after the interview for review by the participant.

Establishing Norms

Researcher will establish focus group norms with participants prior to beginning session. Participants will agree upon norms for engaging in the focus group, which will include: turn taking and respecting others' opinions. In addition, participants will be made aware that the study is interested in people's views, and that there are no right or wrong responses.

Data Recording Procedure

Researcher will audio record the session and may take field notes during the focus group. All recordings will be transcribed.

Conducting the Focus Group

The structure of the focus group will center around several questions, with guiding prompts. The goal is to not only ascertain answers to these questions, but to observe group dynamics when individuals are responding to the questions and to one another.

Guiding Questions

Table 12. Focus group guiding questions

Primary question	Follow up questions
Tell me about how your teaching team works together. What typically happens in your meetings?	• Do they plan together? Teach together? Have common planning time? How often? • What prompts the planning? Who establishes the focus? One individual? Administration? • What kind of structure follows in your meetings? What kinds of "activities" happen in your meetings? Review of previous teaching events? Sharing of strategies? Discussions of student work? • What focuses do you work on? • After you meet and come up with [your goals/action items], what happens next? • How would you describe the interactions between your team and others in your building? How would describe how other teams collaborate in your building?
What would you say are the characteristics of a team that works well together? What would I see in your team?	• Please provide an example.

Table 12 continued

Tell me what happens with [planning] when it doesn't work well.	• Please provide an example.
Finally, tell me about your work with STEM.	• What would you say is your team's thinking around STEM? How would you define it? • What are the important characteristics of STEM to you as a team? • What kinds of things do you do with students to engage them in STEM? • What are you most looking forward to this year together? What are your STEM goals?
Probes: • What do you mean by [ ] ? • Can you elaborate on that? • What would be an example of that? • Can I check that what you are saying is [ ] ?	

<u>Completion of Focus Group</u>

- Discuss next steps, including the upcoming protocol for interviews and revisit timeline for upcoming research activities.
- Ask for any questions.
- Researcher will compile additional notes by studying the transcripts of the audio recording.

A.3 INTERVIEWS

For this study, two teachers will be identified to participate in interviews in conjunction with the implementation of the team's collaborative project.

Each identified teacher will participate in: one pre-implementation interview and one post –implementation interview. Both teachers will be asked the same sets of main questions for each type of interview.

<u>Introductions and Stating Purpose</u>

Researcher will state the purpose of the pre-implementation interview, and again, request that the interview be audio recorded, and that the researcher be allowed to take notes. Researcher will inform participant that information gathered in the interviews will be kept anonymous and confidential. Researcher will provide notes at a time shortly after the interview for review by the participant. For post-implementation interviews, researcher would have had time to read the teacher's post-implementation reflection.

<u>Data Recording Procedure</u>

Researcher will audio record the session and may take field notes during the interview. All recordings will be transcribed.

<u>Conducting the Interviews</u>

Each set of main questions will have follow up questions, and a general list of probes to facilitate the interview.

PRE-IMPLEMENTATION INTERVIEW

Table 13. Pre-implementation interview questions

Key questions	**Follow up questions**

On [date] you will be implementing [ ]. Can you tell me what you are planning?	• What is your focus? Goals?
	  ○ Content goals?
	  ○ Process goals?
	  ○ STEM specific goals?
	  ○ Integrated goals?
	• How will you know that you've met your goals?

How have you planned [ ] collaboratively with your team?	• How did this go? What's the process that you used? • What did you collaboratively agree to accomplish? • What connections were made to [other disciplines]? • What plans do you have for debriefing with your team?
What are your concerns or expectations at this time before doing [ ] ?	
Probes: • What do you mean by [ ] ? • Can you elaborate on that? • What would be an example of that? • Can I check that what you are saying is [ ]?	

POST-IMPLEMENTATION INTERVIEW

Table 14. Post-implementation interview questions

Key questions	**Follow up questions**
So you've just completed your [ ]. Tell me about it. How did it go?	• Remind me what you were trying to accomplish [or cite from the pre-interview]. What were your content/process/STEM/integration goals?

Table 14 continued

	• What was achieved? How did you go about assessing that? • In reading your reflection, I have a question about [ ]. Can you elaborate on this? Can you provide an example of what you noticed here?
If you think about the plan you had in place, what would you say changed about your plan?	• Prior to beginning the [ ]? • During the actual [ ] ? • Tell me about your thinking process in making these changes. ○ What outcomes were you hoping to see? • How do you feel about these decisions now that the lesson's over?
Remind me again what you planned collaboratively with your team [or cite from the pre-interview].	• Do you feel that you met these goals? Why or why not?
What do you feel were your roadblocks in your implementation? What do you feel are the supports that helped you implement [ ] like this?	
Probes: • What do you mean by [ ] ? • Can you elaborate on that? • What would be an example of that? • Can I check that what you are saying is [ ]?	

Completion of Interviews

- Discuss next steps, including the next phase of the study. For the upcoming post-lesson teacher, explain the collection of the post-lesson reflection and establish time for post-lesson interview.

WRITTEN TEACHER REFLECTION

Table 15. Written teacher reflection questions

Reflection Questions for Post-Interview
1. Think about at least one key instructional moment of the collaborative project during the last week. What were your stated goals and expectations for your lesson(s)?
2. Describe what happened with respect to teaching, and how the students responded to it.
3. Think about what you originally planned. What modifications did you make prior to beginning the lesson(s)? What modifications did you make on the spot? What questions surfaced for you while teaching?
4. What was surprising? Challenging?
5. What questions do you now have to inform future teaching of the project or in general?

- Revisit timeline for upcoming research activities.
- Ask for any questions.
- Researcher will compile additional notes by studying the transcripts of the audio recording.

APPENDIX B

INQUIRY ACTIVITIES REFERENCE PAGE

Table 16. Inquiry activities references

Activity	Planning Phase	Date	In attendance		Reference
Observation	Pre-implementation	11/10/2016	Researcher Tina Sam	David Joseph	OBS1
Observation	Pre-implementation	11/11/2016	Researcher Tina Sam	David Joseph	OBS2
Focus Group	Pre-implementation	11/16/2016	Researcher Tina Sam	David Joseph	FG1
Observation	Pre-implementation	12/6/202016	Researcher Tina Sam	David Joseph	OBS3
Interview	Pre-implementation	12/15/2016	Researcher Tina		M1
Interview	Pre-implementation	12/15/2016	Researcher Sam		S1
Observation	Implementation	12/20/2016	Researcher Tina Sam	David Joseph	OBS4
Interview	Implementation	12/26/2016	Researcher Sam		S2
Interview	Implementation	12/28/2016	Researcher Tina		M2
Observation	Post-implementation	1/3/2017	Researcher Tina Sam	David Joseph	OBS5
Focus Group	Post-implementation	1/12/2017	Researcher Tina Sam	David Joseph	FG2
Interview	Post-implementation	2/5/2017	Researcher Sam		S3
Interview	Post-implementation	2/6/2017	Researcher Tina		M3

APPENDIX C

SAMPLE ANALYSIS DOCUMENTS

The following three pages include the following sample analysis documents:

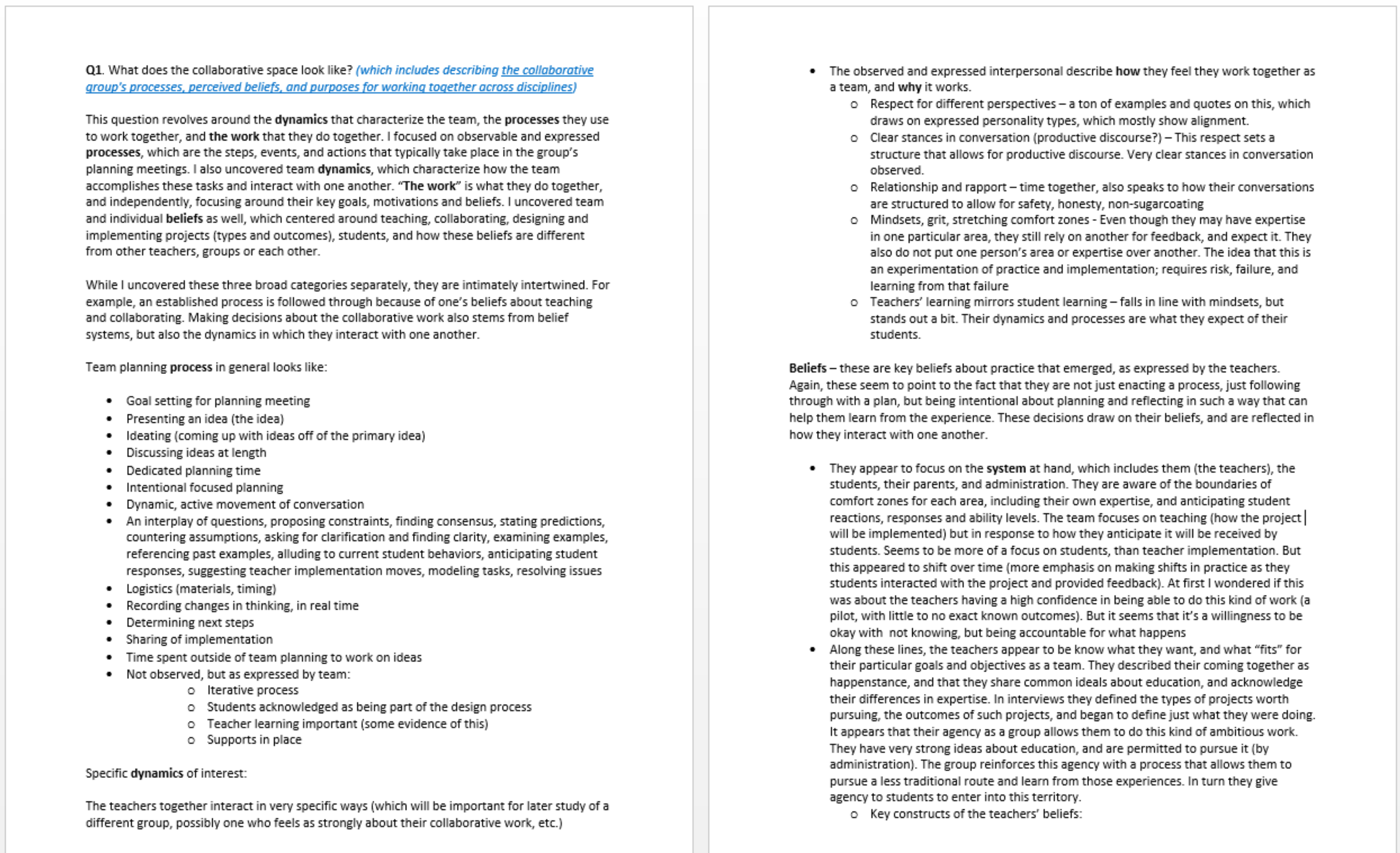
- First level analysis: coding transcript (Figure 10)
- Second level analysis: codes to categories (Figure 11)
- Analytic memo (Figure 12)

	16-DEC-20 OBS	Group processes	Group dynamics	Team planning foci	Beliefs about practice/terms	Group → Individual
1	[00:00:43] Jeff: So how's your activity?	Setting purpose of meeting: asking each to share				
2	David: That's because some-- some of them I'm getting-- I'm at the point where just to get something done on paper I'm just telling them, like one or two correct information things, after that start your final project. Or else they're not going to have anything done. Because they're either taking that long, or they're having such a hard time. That was just that period. So I have some more classes.	Sharing implementation	Reflecting upon differences among classes- possible rationalizing the difference with the team	Sharing implementation	Reflecting upon differences among classes; what happened in first class may be different later in the day	Individual: balancing telling them to do certain tasks, and planning forward Concerned about timing
3	Tina: Did they—					
4	Sam: They're coming up-- Like [Student A] came up and showed me, he had a baseball, and I'm like, do you have your five symbols, five landforms? He says, what are you talking about? I was like-- [makes a face]. I didn't act that way but-- He's like, what do you mean? Wow. I said you have to have 5 landforms. He's like: I think I have them, and then he showed me, and said he counted like- He didn't-- I couldn't-- There wasn't a lot of effort. I said, where are your 8 symbols? He said well I have-- and he said, well, don't these 5 count? I said no, you have to have 8 different symbols that are different from landforms. And I got worried, because if he missed it, oh my, they-- And [Student B] like, I-- You saw what she did? She got the idea, but she's not going to fit in the criteria. Each one of those circles was a landform. Like she wanted to have five circles, and was like, I'm done! And she showed it to me, and I said, why do you think you're done? And she said-- So in her eyes she had like 564 landforms.			Sharing student examples	Assessed student work as not having a lot of student effort; another as not being able to fit in everything (new code here – this is different than predicting what they would do) Assessed his own teaching: concerned that the students as a whole must've missed the point Revealed questioning to students as part of his assessment/facilitation	
5	David: [laughs] Well there we go, we tell them 5 different landforms.					
6	Sam: Believe me I told you that because, I said, what you have here, you have one, so if you like add in a mountain, then you have 2. They all can't be the same. And she's like: I don't care about that, I just have a shopping problem. So I'm going to put my shopping problem here, and she had a little shoe and feet, and that's great. But, I want you to think of the other criteria too.		Sharing how he worked with student to deal with issue, step by step with team		Asking questions to facilitate understanding of task with students	
7	David: Anything else you want to change on here? Did you brainstorm—		Asking what other strategies he used			
8	Sam: Oh yeah, they have lists.					
9	David: [Listing] Their full name, the names of people who are important to you, life changing events... They have that?		Probing for other strategies			
10	Sam: They all have-- They are struggling with life changing events.		Shares other struggle for students (life changing events)			
11	David: Oh are they? Kevin: They are asking me , what would my life changing events be—		Surprised by struggle			
12	Joseph: There aren't many life changing events for them to have.		Suggests students would have difficulty			
13	Tina: Well I wouldn't necessary say there aren't any life changing events.		Counters suggestion			
14	Sam: That's my point. It's hard for a thirteen year old because that age group—					
15	David: Well, they probably have a lot for favorites.		Redirects to other criteria (Problem not solved)			

Figure 10. Example of first level analysis: coding transcript

	A	B	C	D
1	**Q1. What does the collaborative space look like?** ***(which includes describing the collaborative group's processes, p***			
2	**for working together across disciplines)**			
3				
4	**Group processes**			
5	Presenting the idea			
6				
7	Ideating	Ideating (project idea, implementation strategies, outcomes)	OBS1	
8		Ideating (project idea, implementation strategies, outcomes)	FG1	4
9		Ideating (project idea, implementation strategies, outcomes)	FG1	4
10		Remix borrowed ideas	FG1	46
11		Play first, learn, hands on	FG2	48
12		Involve student ideas for foci/tasks in project	FG2	51
13		Connecting their situation to other schools	OBS5	134
14				
15	Discussing ideas	Clarifying unclear ideas/goals/roles	OBS1	
16		Confirming ideas, coming to consensus	OBS1	
17		Drawing on prior team implementation	OBS1	
18		Posing alternatives/counter ideas	OBS1	
19		Posing alternatives/counter ideas	L1	101
20		Paying attention to what other teachers are doing out	FG1	71
21		Skepticism of ideas	FG1	60
22				
23	Anticipating results	Considering constraints	OBS1	
24		Drawing on student experiences/abilities	OBS1	
25		Finalizing (goals, tasks)	L1	2
26				
27	Process structure	Self reflective during the process	FG1	38
28		Iterative, revisit, revise/ fail, learn from failure	FG1	43
29		Iterative, revisit, revise/ fail, learn from failure	L2	52
30		Iterative, revisit, revise/ fail, learn from failure	FG2	35
31		Iterative, revisit, revise/ fail, learn from failure	FG2	35
32		Piloting/protyping	FG1	46

Figure 11. Example of second level analysis: codes to categories



Q1. What does the collaborative space look like? *(which includes describing the collaborative group's processes, perceived beliefs, and purposes for working together across disciplines)*

This question revolves around the **dynamics** that characterize the team, the **processes** they use to work together, and **the work** that they do together. I focused on observable and expressed **processes**, which are the steps, events, and actions that typically take place in the group's planning meetings. I also uncovered team **dynamics**, which characterize how the team accomplishes these tasks and interact with one another. "**The work**" is what they do together, and independently, focusing around their key goals, motivations and beliefs. I uncovered team and individual **beliefs** as well, which centered around teaching, collaborating, designing and implementing projects (types and outcomes), students, and how these beliefs are different from other teachers, groups or each other.

While I uncovered these three broad categories separately, they are intimately intertwined. For example, an established process is followed through because of one's beliefs about teaching and collaborating. Making decisions about the collaborative work also stems from belief systems, but also the dynamics in which they interact with one another.

Team planning **process** in general looks like:

- Goal setting for planning meeting
- Presenting an idea (the idea)
- Ideating (coming up with ideas off of the primary idea)
- Discussing ideas at length
- Dedicated planning time
- Intentional focused planning
- Dynamic, active movement of conversation
- An interplay of questions, proposing constraints, finding consensus, stating predictions, countering assumptions, asking for clarification and finding clarity, examining examples, referencing past examples, alluding to current student behaviors, anticipating student responses, suggesting teacher implementation moves, modeling tasks, resolving issues
- Logistics (materials, timing)
- Recording changes in thinking, in real time
- Determining next steps
- Sharing of implementation
- Time spent outside of team planning to work on ideas
- Not observed, but as expressed by team:
    - Iterative process
    - Students acknowledged as being part of the design process
    - Teacher learning important (some evidence of this)
    - Supports in place

Specific **dynamics** of interest:

The teachers together interact in very specific ways (which will be important for later study of a different group, possibly one who feels as strongly about their collaborative work, etc.)

- The observed and expressed interpersonal describe **how** they feel they work together as a team, and **why** it works.
    - Respect for different perspectives – a ton of examples and quotes on this, which draws on expressed personality types, which mostly show alignment.
    - Clear stances in conversation (productive discourse?) – This respect sets a structure that allows for productive discourse. Very clear stances in conversation observed.
    - Relationship and rapport – time together, also speaks to how their conversations are structured to allow for safety, honesty, non-sugarcoating
    - Mindsets, grit, stretching comfort zones - Even though they may have expertise in one particular area, they still rely on another for feedback, and expect it. They also do not put one person's area or expertise over another. The idea that this is an experimentation of practice and implementation; requires risk, failure, and learning from that failure
    - Teachers' learning mirrors student learning – falls in line with mindsets, but stands out a bit. Their dynamics and processes are what they expect of their students.

Beliefs – these are key beliefs about practice that emerged, as expressed by the teachers. Again, these seem to point to the fact that they are not just enacting a process, just following through with a plan, but being intentional about planning and reflecting in such a way that can help them learn from the experience. These decisions draw on their beliefs, and are reflected in how they interact with one another.

- They appear to focus on the **system** at hand, which includes them (the teachers), the students, their parents, and administration. They are aware of the boundaries of comfort zones for each area, including their own expertise, and anticipating student reactions, responses and ability levels. The team focuses on teaching (how the project will be implemented) but in response to how they anticipate it will be received by students. Seems to be more of a focus on students, than teacher implementation. But this appeared to shift over time (more emphasis on making shifts in practice as they students interacted with the project and provided feedback). At first I wondered if this was about the teachers having a high confidence in being able to do this kind of work (a pilot, with little to no exact known outcomes). But it seems that it's a willingness to be okay with not knowing, but being accountable for what happens
- Along these lines, the teachers appear to be know what they want, and what "fits" for their particular goals and objectives as a team. They described their coming together as happenstance, and that they share common ideals about education, and acknowledge their differences in expertise. In interviews they defined the types of projects worth pursuing, the outcomes of such projects, and began to define just what they were doing. It appears that their agency as a group allows them to do this kind of ambitious work. They have very strong ideas about education, and are permitted to pursue it (by administration). The group reinforces this agency with a process that allows them to pursue a less traditional route and learn from those experiences. In turn they give agency to students to enter into this territory.
    - Key constructs of the teachers' beliefs:

Figure 12. Example of analytic memo

BIBLIOGRAPHY

AGW Community (2016). Retrieved from http://agw.org/ (*name changed)

AGW School District (2016). Retrieved from http://www.agwsd.org/ (*name changed)

Arizona STEM Foundation (2013). *The STEM immersion guide*. Retrieved from http://stemguide.sfaz.org/

Ball, D. L. & Cohen D. K. (1999). Developing practice, developing practitioners: Toward a practice-based theory of professional education. In G. Sykes and L. Darling Hammond (Eds.), *Teaching as the learning profession: Handbook of policy and practice*, (2-32). San Francisco: Jossey Bass.

Ball, D. L., Thames, M. H., & Phelps, G. (2008). Content knowledge for teaching: What makes it special? *Journal of Teacher Education*, *59*(5), 389-407

Barakos, L., Lujan, V., & Strang, C. (2012). *Science, technology, engineering, mathematics (STEM): Catalyzing change amid the confusion*. Berkeley, CA: Center on Instruction

Becker, K., & Park, K. (2011). Effects of integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students' learning: A preliminary meta-analysis. *Journal of STEM Education: Innovations and Research*, *12*(5/6), 23.

.Black, P. & Wiliam D. (2010). Inside the black box: Raising standards through classroom assessment. *Phi Delta Kappan, 92*(1), 81-90

Bowen, G. A. (2009). Document analysis as a qualitative research method. *Qualitative Research Journal*, *9*(2), 27-40

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

Brown, A. L., & Campione, J. C. (1996). Psychological theory and the design of innovative learning environments: On procedures, principles, and systems. In L. Schauble and R. Glaser (Eds.) *Innovations in learning: New environments for education* (pp. 289-325). New York: Routledge.

Brown, M. W. (2009). The teacher-tool relationship. In J. T. Remillard, B. A. Herbel-Eisenmann, & G. M Lloyd (Eds.) *Mathematics teachers at work: Connecting curriculum materials and classroom instruction* (pp. 17-36). New York: Routledge.

Cabana, C., Shreve, B., Woodbury, E., & Louie, N. (Eds.). (2014). *Mathematics for equity: A framework for successful practice*. Reston, VA: Teachers College Press.

Change the Equation (2016). Design principles and rubric. Retrieved from http://www.changetheequation.org/

Coburn, C. E. (2005). Shaping teacher sensemaking: School leaders and the enactment of reading policy. *Educational Policy*, *19*(3), 476-509.

Committee on Prospering in the Global Economy of the 21st Century (U.S.), & Committee on Science, Engineering, and Public Policy (US). (2007). *Rising above the gathering storm: Energizing and employing America for a brighter economic future*. Washington, DC: National Academies Press.

Czerniak, C. M. (2013). Interdisciplinary science teaching. In L. Norman & S. Abell (Eds.) *Handbook of research on science education*, (pp.537-559). New York: Routledge

Dayton Regional STEM Center (2011). *A framework for quality STEM education*. Retrieved from http://daytonregionalstemcenter.org/stem-framework-101/

Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher*, *38*(3), 181-199.

Dowden, T. (2007). Relevant, challenging, integrative and exploratory curriculum design: Perspectives from theory and practice for middle level schooling in Australia. *The Australian Educational Researcher*, *34*(2), 51-71.

Drake, S. M., & Burns, R. C. (2004). *Meeting standards through integrated curriculum*. Alexandria, VA: ASCD.

DuFour, R. & Eaker, R. (1998). *Professional learning communities at work.* National Educational Service: Bloomington, ID.

Engeström, Y. (1999). Activity theory and individual and social transformation. In Y. Engeström, R. Miettinen, & R.-L. Punamäki (Eds.) *Perspectives on Activity Theory* (pp. 19-38). Cambridge: Cambridge University Press.

Engle, R. A., & Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and Instruction*, *20*(4), 399-483.

Fuhrman, S.H., Cohen, D.K., & Mosher, F. (2007). *The state of education policy research.* Mahwah, NJ: Lawrence Erlbaum Associates.

Fulton, K., & Britton, T. (2011*). STEM Teachers in professional learning communities: From good teachers to great teaching*. Arlington, VA: National Commission on Teaching and America's Future.

Gardner, D. P., Larsen, Y. W., & Baker, W. (1983). *A nation at risk: The imperative for educational reform*. Washington, DC: US Government Printing Office.

Grossman, P., Hammerness, K., & McDonald, M. (2009). Redefining teaching, re-imagining teacher education. *Teachers and Teaching: Theory and Practice*, *15*(2), 273-289.

Guthrie, J. T., Wigfield, A., & VonSecker, C. (2000). Effects of integrated instruction on motivation and strategy use in reading. *Journal of Educational Psychology*, *92*(2), 331.

Hakkarainen, K., Paavola, S., Seitamaa-Hakkarainen, P. (2013). Sociocultural perspectives on collaborative learning: Toward collaborative knowledge creation. In C. E.Hmelo-Silver, A. M. O'Donnell, C. Chan, & C. A. Chinn (Eds.) *The international handbook of collaborative learning* (pp.57-73). New York: Routledge.

Hansen, M., & Gonzalez, T. (2014). Investigating the relationship between STEM learning principles and student achievement in math and science. *American Journal of Education*, 120(2), 139-171.

Henderson, C., & Dancy, M. H. (2011). Increasing the impact and diffusion of STEM education innovations. In *Invited Paper for the National Academy of Engineering, Center for the Advancement of Engineering Education Forum, Impact and Diffusion of Transformative Engineering Education Innovations.*

Honey, M., Pearson, G., & Schweingruber, H. (Eds.). (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. Washington, DC: National Academies Press

Horn, I. S., & Kane, B. D. (2015). Opportunities for professional learning in mathematics teacher workgroup conversations: Relationships to instructional expertise. *Journal of the Learning Sciences*, *24*(3), 373-418.

Horn, I. S., & Little, J. W. (2010). Attending to problems of practice: Routines and resources for professional learning in teachers' workplace interactions. *American Educational Research Journal*, *47*(1), 181-217.

Hurley, M. M. (2001). Reviewing integrated science and mathematics: The search for evidence and definitions from new perspectives. *School Science and Mathematics*, *101*(5), 259-268.

Lave, J. & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* Cambridge: Cambridge University Press

Little, J. W. (1993). Teachers' professional development in a climate of educational reform. *Educational Evaluation and Policy Analysis*, *15*(2), 129-151.

Loucks-Horsley, S., Hewson, P. W., Love, N., & Stiles, K. E. (1998). *Designing professional development for teachers of science and mathematics.* Thousand Oaks, CA: Corwin Press.

Mason, T. C. (1996). Integrated curricula: Potential and problems. *Journal of Teacher Education*, *47*(4), 263-270.

McBride, J. W., & Silverman, F. L. (1991). Integrating elementary/middle school science and mathematics. *School Science and Mathematics*, *91*(7), 285-292.

McClain, M. L. (2015). *The effect of STEM education on mathematics achievement of fourth-grade underrepresented minority students* (Doctoral dissertation, CAPELLA UNIVERSITY).

Menter, I., Elliot, D., Hulme, M., Lewin, J., & Lowden, K. (2011). *A guide to practitioner research in education*. Los Angeles: Sage Publications.

Mertens, D. M. (2010). *Research and evaluation in education and psychology: Integrating diversity with quantitative, qualitative, and mixed methods*. Los Angeles: Sage Publications.

Metz, K. E. (2009). Elementary school teachers as “targets and agents of change”: Teachers' learning in interaction with reform science curriculum. *Science Education*, *93*(5), 915-954.

Morrison, J. S. (2006). *Attributes of STEM education: The students, the academy, the classroom*. TIES STEM Education Monograph Series. Baltimore: Teaching Institute for Excellence in STEM.

National Academy of Sciences & National Research Council (1989). *Everybody Counts. A Report to the Nation on the Future of Mathematics Education*. Washington, DC. Mathematical Sciences Education Board.

National Center for Education Statistics (2016). Retrieved from https://nces.ed.gov/

National Research Council (US), Committee on Highly Successful Schools or Programs for K-12 STEM Education. (2011). *Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics*. Washington, DC: National Academies Press.

National Research Council (2000), *Inquiry and the national science education standards: A guide for teaching and learning.* Washington, DC: National Academies Press.

NGSS Lead States (2013). *Next generation science standards: For states, by states*. Washington, DC: The National Academies Press.

Pennsylvania Department of Education (2016). Retrieved from http://www.education.pa.gov/

President's Council of Advisors on Science and Technology (US). (2010). *Prepare and Inspire: K-12 Education in Science, Technology, Engineering, and Math (STEM) for America's Future: Executive Report*. Executive Office of the President, President's Council of Advisors on Science and Technology.

Remillard, J. T. (2005). Examining key concepts in research on teachers' use of mathematics curricula. *Review of Educational Research*, *75*(2), 211-246.

Resnick, L. B., Stein, M. K., & Coon, S. (2008). Standards-based reform: A powerful idea unmoored. *Improving on No Child Left Behind: Getting Education Reform Back on Track*, 131-32.

Roth, K. J. (1994). Second thoughts about interdisciplinary studies. *American Educator*, *18*(1), 44-48.

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

Saldaña, J. (2009). *The coding manual for qualitative researchers*. Los Angeles: Sage Publications.

Sanders, M. E. (2012). Integrative STEM education as best practice. In H. Middleton (Ed), *Explorations of Best Practice in Technology, Design and Engineering Education*, 103-117.

Scott, C. (2012). An investigation of science, technology, engineering and mathematics (STEM) focused high schools in the U. S. *Journal of STEM Education*, *13*(5), 30–39.

Smithsonian Science Education Center (2017). *The laser model.* Retrieved from https://ssec.si.edu/laser-model

Stein, M. K. (Ed.). (2000). *Implementing standards-based mathematics instruction: A casebook for professional development*. New York: Teachers College Press.

Stein, M. K., Grover, B. W., & Henningsen, M. (1996). Building student capacity for mathematical thinking and reasoning: An analysis of mathematical tasks used in reform classrooms. *American Educational Research Journal*, 33(2), 455-488.

Stein, M., & Coburn, C. (2008). Architectures for learning: A comparative analysis of two urban school districts. *American Journal of Education*, *114*(4), 583-626.

Stein, M. K., & Smith, M. (2011). Practices for Orchestrating Productive Mathematics Discussions. *National Council of Teachers of Mathematics*, 20191-1502.

Stinson, K., Harkness, S. S., Meyer, H., & Stallworth, J. (2009). Mathematics and science integration: Models and characterizations. *School Science and Mathematics, 109*(3), 153-161.

Thomas, D. R. (2006). A general inductive approach for analyzing qualitative evaluation data. *American Journal of Evaluation*, *27*(2), 237-246.

Thomasian, J. (2011). *Building a science, technology, engineering, and math education agenda: An update of state actions*. Washington, DC: NGA Center for Best Practices.

Toma, J. D. (2006). Approaching rigor in applied qualitative research. *The SAGE handbook for research in education: Engaging ideas and enriching inquiry*, 405-423.

Vygotski, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Wenger, E. (1999). *Communities of practice: Learning, meaning, and identity*. Cambridge: Cambridge University Press.

Wenger, E. (2000). Communities of practice and social learning systems. *Organization*, *7*(2), 225-246.

Yin, R. K. (2014). *Case study research: Design and methods*. Los Angeles: Sage Publications.