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Understanding integrated STEM science instruction through the experiences of teachers and students

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ABSTRACT

Integrated STEM education comprises an exploration of the interconnections between science, technology, engineering and mathematics in order to reflect on how each discipline operates within real world contexts. Students benefit from the integrated STEM approach because it values students' real-life experiences and hands-on applications that mirror professional STEM work. However, Integrated STEM instruction remains ill defined, with many gaps in the existing research. The school setting central to this study was a suburban public middle school with a nationally recognized integrated STEM program. Through the use of hermeneutic phenomenological inquiry, I focused on both teachers' and students' experiences of participation in one integrated STEM model. I analyzed data using thematic moment clusters and event mapping to look at patterns of experiences across time. I found that participation in this integrated STEM model included six common experiences: (1) project-based learning, (2) flexible instructional time, (3) consistent co-teaching with two or more teachers, (4) social skills development, (5) extensive use of computer-based technology, and (6) the use of school spaces beyond the classroom for instruction purposes. The students viewed their involvement in the integrated STEM model positively and many noted an interest in pursuing a STEM-related career in the future. The teachers reported an enhancement of their professional repertoire through consistent planning, co-teaching and observational practices. After five years of enactment, challenges that persisted for this integrated STEM team included pressures to adhere to state and district demands, as well as the need for non-traditional spaces to engage students in creative ways. This model provides further evidence of the need to reorganize school content, space, and time.

UNDERSTANDING INTEGRATED STEM SCIENCE INSTRUCTION THROUGH EXPERIENCES OF TEACHERS AND STUDENTS

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CHAPTER 1: INTRODUCTION

With societal issues such as climate change and the urgent demand for non-sustainable energy sources consumption looming over future decades, it is vital that we expose students early on in their academic careers to real-world problems. Multi-faceted perspectives allow for a more nuanced understanding of phenomena. Students are better equipped to confront and solve complex personal, social, and global dilemmas when they can draw from differing disciplinary outlooks during formal classroom instruction (Beane, 1991; Bybee, 2010). This study sheds light on how one integrated STEM educational model sought to prepare students for the demands of the 21st century world while also addressing standards and district level requirements.

The National Research Council (NRC, 2014) broadly defines integrated STEM as a way to build connections between and within subject areas related to science, technology, engineering, and mathematics. For the purposes of this study, I define integrated STEM models as team teaching efforts that center on interconnecting content in order to build engagement and relevance through overlapping learning explorations that feature hands-on components.

Integrated STEM education deviates from STEM education *per se* by emphasizing interconnections between subject areas and the rich contextualization of content through real-world applications (National Research Council (NRC), 2014). Critical thinking is both a goal and a characteristic that undergirds integrated STEM teaching and learning. The abilities to engage in technical discourses, discern credible sources of information, and interpret statistical and other representations are fostered through integrated STEM models. This innovative approach has the potential to spark a lifetime of personal interest and professional STEM pursuits.

Although the notion of integrated STEM education assumes many forms, research to inform curriculum development in this area is seriously lacking. The National Research Council (2014) investigation on STEM integration in K-12 settings reported:

> The research base includes a relatively small number of studies, with limited samples and often with potential problems with selection bias (e.g. only students who already do well in STEM or are interested in STEM participate) […] In order to advance research on integrated STEM education, researchers need to consider a range of designs and methodological approaches (p. 63).

Schroeder, Scott, Tolson, Huang, and Lee (2007) conducted a meta-analysis of science teaching strategies and their impact on student achievement. The team noted a lack of studies connecting pedagogical content knowledge (PCK) and student learning outcomes: "How students should be taught and specific strategies for teaching science effectively have not been addressed in recent years" (Schroeder et al., 2007, p. 1437). Wang, Moore, Roehrig, and Park (2011) call for further investigation of new forms of STEM integration that "go beyond simply blending of traditional types of understandings" (p. 2).

Connecting science and students

Science teaching from a normative perspective involves textbooks and lecture-based instruction focused on facts, with experiments that more closely resembled recipes than scientific discovery (Krajcik & Blumenfeld, 2005). Tsai (2002) explains this style of science teaching as "transferring of knowledge; giving firm answers; providing clear definition; giving accurate explanations; practicing tutorial problems; presenting the scientific truths or facts" (p. 774). Krajcik and Blumenfeld, (2005) note the resultant boredom in the classroom from this style of teaching. Disengagement is a symptom of a larger need to restructure schooling to connect with students on a deeper level that leverages their personal interests and sense of community.

Traditional science teaching approaches often fail to comprehend the students' world beyond the school grounds. In order for teaching to fully resonate, students must find personal value in the science concepts presented in class. Bridging the gap between school and home requires a representation of science that offers the opportunity to create layers of meaning. Price and McNeill (2013) describe three intersectional layers of meaning, namely "meanings in person, in intent, and in practices" (p. 504). "Meanings in person" relate to the fact that humans are shaped by their experiences, which in turn influence current and future learning (Taylor, 1990). "Meanings in intent" refers to the ongoing negotiation between personal history and the current context in which meaning is taking place (Taylor, 1990). "Meanings in practice" includes both actions and discourses that are used to convey particular meanings within a setting (Price & McNeill, 2013; Taylor, 1990). Roth and Mcrobbie (2010) discuss the overlap in perceptions that occurs between people as they co-participate in shared meaning-making practices. "Individuals become members of communities in which ways of seeing, knowing, and representing are common" (Roth & Mcrobbie, 2010, p. 517).

Students need support as they interpret the role of science while simultaneously interpreting their roles as democratic citizens within a societal structure. Hurd (2002) refers to this pedagogical approach as a lived curriculum that "means figuring out how to access, synthesize, codify, and interpret science information into a working knowledge that can be used in personal and civic contests" (p. 502). A lived science curriculum, therefore, includes the combination of students' experiences as well as community engagement. A lived science learning experience necessitates that students confront their prior conceptions and background experiences as part of an evolving meaning-making experience.

Teachers need to enhance their modes of instruction to captivate students on a level that respects their lifeworlds. Heidegger, a prominent philosopher in the field of phenomenology, defined lifeworlds as “our being within the world” (Heidegger, Macquarrie, & Robinson, 1962). These lifeworlds frame our interpretations of what is observed and shared with others. Identity stems from our lifeworlds, which are produced as a result of social interactions and reflections upon experience. The ways that we understand our self in relation to others should be considered an inextricable element of the process of teaching and learning. Discovery of the natural world requires acknowledgement of the individual lifeworld that serves to inform and construct our knowledge. Kozoll and Osbourne (2004) support this assertion in the following: “If a union between science and the self is achieved, we can fully realize the potential science has to contribute toward this broader educative process” (p.158).

Much of this disconnect between student lifeworlds and science instruction stems from the construction of science as a purely objective discipline. Laboratory practices and the tools associated with science position it as separate. McComas, Clough and Almazroa (1998) attempt to recast science teaching in a more authentic light in the following description of the nature of science:

> The nature of science is a fertile hybrid arena including the history, sociology, and philosophy of science combined with research from the cognitive sciences such as psychology into a rich description of what science is, how it works, how scientists operate as a social group and how society itself both directs and reacts to scientific endeavors. The intersection of the various social studies of science is where the richest

> view of science is revealed for those who have but a single opportunity to take in the scenery (p. 512).

Our positionality as gendered, classed, and racialized beings influences our engagement with science. Without acknowledgement of these aspects of our identity we cannot carry out the endeavor of honest scientific discovery. Brickhouse and Potter (2001) describe identity as "one's understanding of herself (sic) in relation to both her (sic) past and potential future. Identity refers to ways in which one participates in the world and the ways in which others interpret that participation" (p. 966). Nespor (1994) points out how the structure of science curricula and the associated discourses used to convey content could impact the student science learner's identity formation. Nespor (1994) found that a physics classroom that focused heavily on standardized testing outcomes and discourses of rigor promoted a narrow physicist identity that was viewed as both unachievable and undesirable among students from non-dominant backgrounds. By non-dominant, I refer to those students who do not identify as white, heterosexual, Christian, -abled, or native English speakers or belong to a low household income bracket (Sensoy & DiAngelo, 2015).

Science teaching has the potential to inform the self, support individual growth and provide a means to dismantle structural oppressions that play out in our schools. Integrated STEM education expands the notions of science curricula beyond the borders of the traditional subject silo. Integrated STEM offers a broadened view of science teaching and learning that values a wider array of lifeworld experiences. Rather than presenting a narrow bundle of science content, students are exposed to content that is embedded as part of a problem that requires a solution. As a result, the role of teacher shifts from ultimate knower to facilitator. As part of integrated STEM instruction, teachers "model problem solving and encourage reflection, communication skills, autonomy, and self-monitoring. They teach students to see problems as opportunities and model the notion that interaction among colleagues is important for creative problem solving" (Madden, Baxter, Beauchamp, Bouchard, Habermas, Huff, Ladd, Pearon, & Plague, 2013, p. 542).

Subject area teaching "requires knowledge of teaching strategies, methodological issues, the curriculum and how to bring the topic alive for students" (Hobbs, 2012, p. 282). Within integrated STEM models, teachers collaborate to build a collective sense of competence and confidence. Like students, each teacher possesses a unique lifeworld that shapes the content and pedagogical approaches that he or she implements. They can enhance their practice by sharing classroom experiences as well as personal histories that also inform them as individuals. Through these professional interactions, students are also exposed to authentic collaborative interactions. A community of learning can emerge as a result, which offers opportunities to connect content more broadly. Since scientific discoveries often involve the interaction and collaboration of many investigators, actual scientific work is further illuminated through integrated STEM educational models (Grinnell, 2011). Thus integrated STEM education serves as one way to present a more unified view of science and lifeworlds.

The model's significance

The model examined in this study offered one interpretation of integrated STEM curricula and instruction. The team of teachers responsible for the model's creation and implementation intended to address content area skills by creating a collaborative environment with opportunities to engage in real-world dilemmas.

This integrated STEM team is nationally recognized due to its innovative approach to teaching and learning. The science teacher in this team received outstanding teaching awards from STEM organizations. Notable, The National Aeronautics and Space Administration

(NASA) invited him to the Jet Propulsion Laboratory during the landing of the Mars rover Curiosity in 2012. He communicated with his students while at the site and used the opportunity as inspiration for curricula. This integrated STEM team continued to maintain a relationship with the NASA representatives. Each year the team completed a Mars rover project that involved the creation of a model using Lego robotic educational materials. The students completed a "mission" that involved putting their rover creation to use. Each year the students took part in a series of engineering design projects that addressed real-world challenges using the latest technologies. Students organized each "mission", tracked their its progress, and then created some form of product. For example, in the first year of implementation the students constructed a product with a practical use and actually sold this product online. This integrated STEM team also partnered with a variety of organizations and invited community members to be part of the learning experience. Engineers, architects, and scientists interacted with the students and often evaluated final projects.

Hundreds of educators visited the district to learn more about how this particular model of STEM integration functioned. Educators from six states and three countries have attended professional development sessions run by this teaching team. A total of 78 sessions took place over a five-year timeframe. Many of the participants were P-12 stakeholders who expressed interest in the development of integrated STEM models in their home districts. Another noteworthy aspect of the model is its length of implementation. This integrated STEM model existed for a period of over five years. The teaching team created the model using primarily locally-sourced resources and with minimal oversight from the district. Many K-12 educators desired to know about the components that enabled their long-term success.

The team also promoted their program on digital platforms such as Twitter. One teacher boasted more than 1,000 followers on Twitter, ranging from NASA to Lego to a wide array of educators. All the team members Tweeted regularly to showcase classroom activities. The Tweets included videos of student participating in engineering design projects, pictures of students engaging in science instruction, and Re-tweets of other organizations that offer integrated STEM activities or events. Through active communication, the team shared a glimpse of what daily instruction was like.

Positive parent feedback was one source used to evaluate the effectiveness of this integrated STEM model. According to administration, parents of students who had previously expressed a sense of disengagement with school reported that a new enjoyment of school coincided with involvement in this integrated STEM model. Student attendance remained high throughout the year. At one point, during a 10-day unit, the school reported that not a single student who was in the team was absent. The middle school rated slightly above the state average on standardized benchmarks. Science achievement on statewide tests revealed that 72% of the students rated as proficient at this middle school, while the state average was reported as 69%. The same trend is also seen for mathematics, where proficiency rates are 47%, while the state average was reported as 44% (retrieved from www.data.nysed.gov, 3/16/17). These results indicate that students are able to demonstrate content area proficiency while also adapting to the challenges associated with a blended STEM curriculum.

This district, referred to as VCM in this study, is a suburban public school located in the Northeast United States with an overall enrollment of more than 3,000 students. The percentage of students with disabilities hovered around 16%, higher than the national average of 13% (http://data.nysed.gov, retrieved 1/4/16). The district gained a reputation for supporting students with disabilities and many families chose to live in the district due to the services provided. The racial demographic is mostly white and over 40% of students in the district are considered economically disadvantaged and receive free or reduced lunches. While the district supported the efforts of the teachers, the program was not heavily funded by external grants. Based on the student population and district demographic, the outcomes of this study are transferable to other social contexts.

Methodological approach

Integrated STEM models remain loosely defined, with daily practices not well understood. I selected a methodology that centered on the experience of participation in one such model to better understand how it functioned. Creswell (2007) explains that an inquiry is appropriate for phenomenological study if "it is important to understand several individuals' common or shared experiences of a phenomenon. It would be important to understand these common experiences in order to develop practices or policies, or to develop a deeper understanding about the features of the phenomenon" (p. 60).

Investigation into the essence or "essential meanings" of a phenomenon is central to the phenomenological approach (Kafle, 2011, p. 189). A dissection of surface level appearances facilitates a deeper interpretive understanding, with a focus on contextual aspects.

The integrated STEM black box

Black and Wiliam (2010) refer to the classroom as a "black box" that is not well understood by educational reformers. The act of teaching is frequently distilled into a series of inputs and outputs. Entering the classroom are teachers, students, performance demands and fixed resources, as well as a host of other contextual factors. Students are expected to leave the box with content-area competence and improved test scores. This simplified view of schooling minimizes the complexities of the classroom. Students come to class with a myriad of prior experiences that shape them as learners. Teachers must continually adapt to satisfy the needs, not only of the student, but also of multiple stakeholders. We assume that teachers “make the inside work better” by creating learner-focused environments and pedagogical decision making that engages students deeply with the content (Black & Wiliam, 2010, p. 82).

This study informs the literature base by extending the black box metaphor to investigate one integrated STEM classroom. The team of teachers consisted of five general education teachers, one special educator, and one paraprofessional who collaborated during the integrated STEM instruction. The student participants were 101 individuals with various degrees of STEM interest and ability. The demands imposed on the team took the form of district initiatives such as content-area literacy, state content-area curricular guidelines, and national standards. The resources available included technological devices such as laptops and small amounts of funds for field trips and professional development for teachers. A traditional public school was the location of this integrated STEM model and this setting presented challenges to the implementation, from both a physical and philosophical standpoint. The teacher team navigated physical limitations of space and time. They reinvented instructions within a school community in which many members still valued traditional methods such as lectures and seatwork. This study was an examination of how teachers introduced innovations to the curriculum and instruction despite these formidable barriers. Student feedback helped to better understand the value of integrated STEM instruction from the perspective of the learner.

The originators of the black box metaphor, Rowan, Correnti and Miller (2002), describe the need to refocus research efforts as follows:

The time had come to move beyond variance decomposition models that estimate the random effects of schools and classrooms on student achievement. These analyses treat the classroom as a black box and […] do not tell us why some classrooms are more effective than others (Rowan, Correnti, & Miller, 2002, p. 1554).

The aim of my research was to expand what is known about integrated STEM models through the close examination of one interpretation of an integrated STEM teaching model. I hope to shine a light on how one integrated STEM team circumvented constraints and accessed resources to develop a curriculum that successfully engaged the vast majority of students who encountered it.

Statement of research questions

(1) Who is involved in this integrated STEM model and how do they perceive participation?

a. In what ways do participants characterize this integrated STEM model?

(2) What are the experiences that comprise one integrated STEM curriculum and instruction model and how is instruction implemented?

(3) How does this integrated STEM teacher team collaborate to address student needs as well as school and state standards?

a. How did the team initially develop and how has it evolved since its inception?

(4) In what ways do contextual factors related to the school and community shape this interpretation of integrated STEM education?

One integrated STEM model was examined for this study but the focus was on the science teaching aspect. I shadowed the science teacher and observed his lessons. My data was therefore concerned with science teaching and learning and how it was situated within an integrated STEM context.

CHAPTER 2: REVIEW OF RELEVANT LITERATURE

"Far from being a single, well-defined experience, integrated STEM education includes a range of different experiences that involve some degree of connection" (NRC, 2014, p. 3). The vagueness of this description is indicative of the lack of common language in the educational field. The National Research Council (NRC) defines integrated STEM education as a descriptive framework that involves attention to goals, outcomes, nature of the integration, and implementation. I situated my findings in relation to previous research on integrated STEM classrooms. I then categorized this review into student and teacher engagement within integrated STEM spaces. I reported on both the affective benefits of integrated STEM instruction and conceptual understandings. I then focused on prior findings that involved the role of the teacher in the development and enactment of such models. Lastly, I situated this review in the methodology of phenomenological inquiry. I drew from scientific research, educational research and specifically science educational research to inform my study.

As the NRC concluded, there is no single formula associated with integrated STEM models of instruction. It is important to note the factors both inside and outside of the classroom that shape how integrated STEM models are enacted. Since integrated STEM models assume a "range of experiences" I seek to also justify the use of phenomenology as a credible methodology in the field of science education based on its attention to lived experiences (NRC, 2014). I included in this literature review pertinent findings that connect integrated STEM education with my methodological framework of phenomenology (see Figure 1). I contend that in order to better understand integrated STEM, a focus on the daily interactions, activities, and spaces where these models function is required. Phenomenology enables the participants to articulate their experiences and interpretations of these experiences.

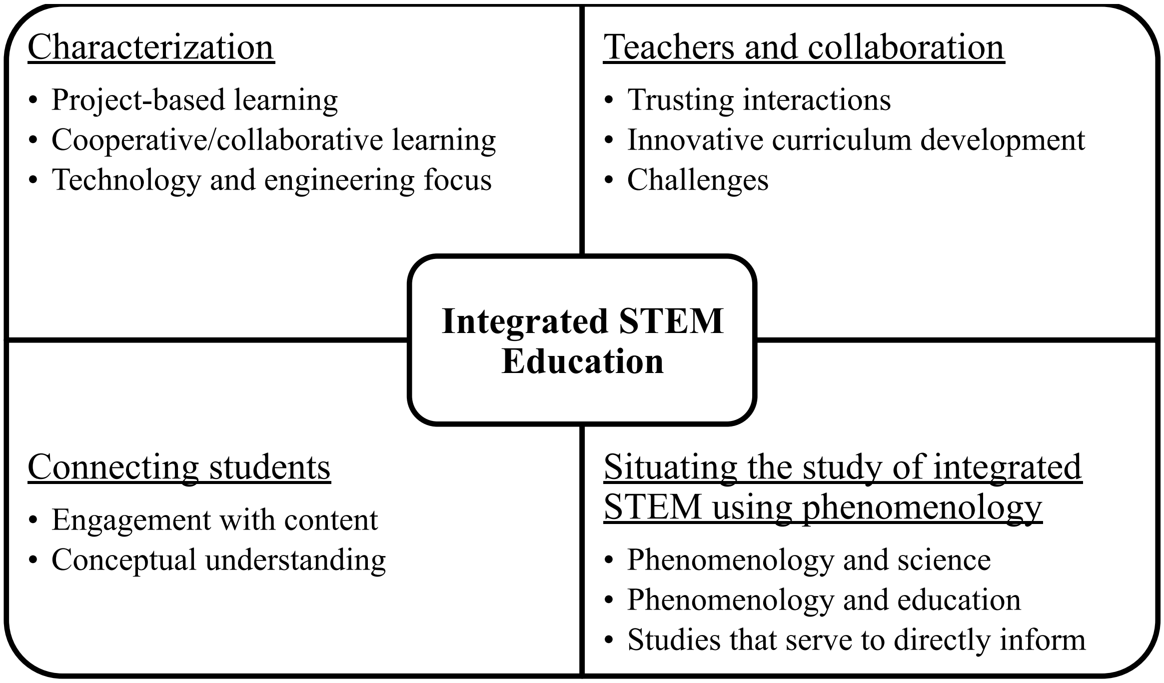

Figure 1: Meta-structure of literature review

STEM education versus integrated STEM

The term STEM first began to gain popularity in the 1990s as a broad classification term used by the National Science Foundation (NSF). Since that time, the term STEM has been readily adopted by the educational sector. An emphasis on STEM subjects is typically associated with rhetoric regarding global competitiveness. It is argued that increases in quality STEM education can better prepare a 21st Century workforce to maintain a robust American economy. An onslaught of STEM educational materials has been created in recent years to address perceived deficits in student achievement and understanding. However, many of these STEM related materials only focus on one or two subjects at a time. For instance, collaboration between science and mathematics in K-12 education has been a national focus since 1960s as seen in curricular materials and standards. Interestingly, the public does not necessarily recognize the STEM acronym as it relates to education and policy. The term STEM connotes stem cell research or parts of a plant to many Americans (Keefe, 2009).

Integrated STEM education focuses on bringing together all STEM disciplines through explicit content area connections. The focus of integrated STEM education research focuses on the development of curriculum and instruction that relates closely to the real world. This approach prepares students as future citizens to approach societal complex problems. Bybee described STEM literacy as including: "conceptual understandings and procedural skills and abilities for individuals to address STEM-related personal, social, and global issues" (2010, p. 31). Much of the literature associated with integrated STEM focuses on student interest in the classroom as well as other affective factors.

Integrated STEM may also be considered more representative of the actual work of scientists. Scientific discoveries are becoming more interdisciplinary in nature and require collaborative efforts. For example, "Biological research is in the midst of revolutionary change due to the integration of powerful technologies along with new concepts and methods derived from the inclusion of physical sciences, mathematics, computational sciences, and engineering" (NRC, 2009, p. vii).

The field of integrated STEM education lacks a consistent use of terminology to unify the field. Many researchers have cited this gap in common language as a barrier to successful implementation (Chowdhary, Liu, Yerrick, Smith & Grant, 2014; Lederman & Niess, 1998; Nowacek, 2007). Since integrated STEM instruction spans grade levels and contexts, quantifying it becomes even more problematic. Boix Mansilla (2005) defined defines "integrated understanding" as:

> The capacity to integrate knowledge and modes of thinking drawn from two or more disciplines to produce a cognitive advancement, for example explaining a phenomenon,

> solving a problem, creating a product, or raising a new question in ways that would have been unlikely through single disciplinary means (p. 16).

Beane (1995) brought to light the humanistic nature of integrated instruction as follows: "The central focus of an integrated curriculum is the search for self and social meaning" (p. 616). Lederman and Niess (1998) add that models can be applied to multiple science subject areas such as biology and chemistry, or those outside the science domain, such as literacy, technology, and mathematics. Integrated STEM models blend subjects yet maintain the epistemological integrity of each. Connections are made explicit and at times one subject might momentarily dominate the instruction, depending on the students' needs and backgrounds. Thematic instruction relies on a common topic of interest that anchors the teaching of each subject. For the purposes of this investigation, the term "integrated STEM education" will be used to refer to both the curricula and instruction that involves explicit connections, either within or between content areas, with a focus on real-world contextualization.

Contrasts with traditional approaches

Gutstein and Peterson (2005) explain that in many classrooms students participate in whole class discussions driven almost entirely by the teacher. Teachers model a problem-solving technique or tell students about an increment of content while students listen passively. Once the formal teaching piece is complete, students are then asked to represent their knowledge by completing independent problem sets that contain the material just covered by the teacher. "The goal of this form of teaching is for students to produce correct responses to a narrowly prescribed problem" (Gutstein & Peterson, 2005, p. 32). Since students' conceptions of the world are not taken into account, it becomes nearly impossible for the teacher to anticipate and adjust instruction based on student needs. In traditional school settings, content knowledge takes precedence over contextualized, conceptual understanding (Davidson, Miller, & Metheny, 1995). The broader application of subject area content is often ignored as pressure mounts to cover extensive topics.

Traditionally, classroom authority was weighted more heavily in favor of the teacher. Lemke (1990) used the term “triadic dialogue” to refer to this power play, which results in a repetitive questioning process of teacher-posed question, student response and teacher evaluation. In the past, teachers gained classroom control through the use of classroom questioning. Authoritative discourse perpetuates the view that the teachers’ role is to impart knowledge, while students’ passively absorb information to later recall (Chin, 2006). “Behaviors like attentive listening to the teacher and respecting the teacher as a knowledge authority are regarded highly and position the enactor of these behaviors at a higher status” (Ryu, 2015, p. 349).

The subject silo model, meaning that each discipline is taught separately without coordination with other content areas, long dominated the way in which teaching and learning was carried out within school systems. This social construction became deeply entrenched in the American academy movement of the 18th and 19th centuries. At this time, subject offerings in schools expanded in an effort to prepare more well-rounded future citizens (DeBoer, 1991). Subject areas in the sciences began at this time to branch into various disciplines such as chemistry, botany and astronomy. A new wave of courses appeared in almost every subject area and included outliers ranging from needlework to surveying. With this diversity of offerings came skepticism from the public regarding the utility of such courses. At this time subject areas were forced to vie for heightened status to ensure compulsory inclusion in the public school system. The Harvard Committee of Ten (NEA, 1894) placed heightened importance on discipline-specific curricula

(NRC, 2014). Subject areas that were more objective in nature such as science and mathematics, relying on empirical evidence, were perceived as highly valued within the traditional paradigm.

Integrated STEM characterization

While not widely applied in schools, integrated STEM education has actually been in existence since the 1800s (DeBoer, 1991). Educational researchers first conducted formal investigations into integrated models of curricula and instruction in the 1940s. In response to reports such as a *Nation at Risk* and the National Science Foundation's 1983 report on *Science for all Americans*, educational reformers at the time recognized the contextualization of science subjects as an educational priority (Fensham, 2009; Gardner, 1983). In an effort to combat student disinterest, studies of integrated models conducted during the 1990s and early 2000s tended to focus on affective aspects of learning. Findings from this period bolster the credibility of the integrated model to improve students' engagement in learning tasks (Venville, Wallace, Rennie, & Malone, 2002). Based on an ever-growing body of research, integrated STEM education continues to maintain a prominent role in science teaching and learning. The National Science Foundation (NSF), American Association for the Advancement of Science (AAAS), and the National Research Council (NRC) have all endorsed the application of interdisciplinary science teaching in education (AAAS, 2009; Palmer, 2011).

Project-based learning

Project-based learning (PBL) involves situating concepts within a series of high interest student learning tasks. Students find PBL investigations engaging because there are obvious connections between the classroom and the real world. The focus is on problems that plague society today without defined solutions. PBL instruction draws on constructivist learning theories that students generate knowledge when space is provided for students to construct their own understandings. PBL is an approach that is derived from John Dewey's philosophy about the meaning of school (Krajcik and Blumenfeld, 2005). Dewey advocated for learning that involves active engagement in authentic inquiries. PBL is also informed by more recent findings from cognitive development experts, such as the work sponsored by the National Research Council on *How People Learn* (Bransford, Brown, & Cocking, 2000).

Krajcik and Blumenfeld (2005) noted that PBL instruction typically started by posing a compelling question. Students then explored multiple solutions to this problem. Teachers, students and community members worked together to identify solutions. Through a collective effort, PBL situated learning in social contexts. During the investigative phase, students were also encouraged to use technologies to develop and share solutions. Lastly, a product was created as an external representation of the learning process. The students presented these products to their peers/community and received feedback.

Krajcik and Blumenfeld (2005) connected PBL approaches with four major science-learning ideas: (1) active construction, (2) situated learning, (3) social interactions, and (4) cognitive tools. The active construction of concepts gives agency to the learner to develop mental models of understanding and revise these models on the basis of new information. Project-based learning involves a hands-on component that engages both the mind and the body. Science endeavors are conducted within specific socio-cultural milieus that influence discovery outcomes. Situated learning provides context and acknowledges the societal implications of science. Consequently, students are more prepared to apply their learning to new situations and draw more readily on prior understandings. PBL necessitates the sharing, using, and debating of ideas within a learning community. Cognitive tools "can amplify and expand what students can learn" (Krajcik & Blumenfeld, 2005, p. 319). Cognitive tools assume many different forms, from a graph to a 3D model. Technology constantly advances to offer new cognitive tools. Technology can directly support PBL during data collection, data analysis, and product presentation phases.

Cooperation versus collaboration

Panitz (1999) shed light on the differences between interactive learning approaches. He separated social classroom interactions into two distinct groups, namely cooperative learning and collaborative learning. Panitz defined cooperation as "a structure of interaction designed to facilitate the accomplishment of a specific end product or goal through working together in groups" (Panitz, 1999, p. 3). Since PBL results in the creation of a tangible product, this form of student engagement is characterized as a cooperative learning task. Teachers might pose the following questions when designing a curriculum with a cooperative learning orientation: (1) How do we teach social skills? (2) How do we promote problem solving and manage conflict? (Brody & Davidson, 1998, p.8). Social skill building is another aspect of a PBL curriculum. Students negotiate with one another to create solutions to complex problems. When competing ideas emerge in the group setting, students need to have the capacity to navigate alternative views to generate the best possible project outcome.

Johnson, Johnson and Holubec (1991) found five elements of cooperative learning tasks. They explained that students needed to feel a sense of positive interdependence with their teammates. Teachers facilitated positive interdependence by assigning specific roles to each student as well as overall shared goals, resources, and rewards. Face-to-face promotive interaction was another element that enabled students to learn from one another through open verbal discussion. Teachers can promote this form of interaction by organizing the classroom space in such a way that students can face one another. Individual accountability was another aspect of cooperative learning mentioned by Johnson et al. (1991). It involved monitoring by both the teacher and the team. Students learned ways to interact positively with their peers to carry out learning tasks. Lastly, student groups reflected on their ability to interact through group processing activities. Students identified effective interactions and offered suggestions to strengthen their team.

The process of collaborative learning extends beyond the co-construction of an end product. Collaborative learning is considered both a classroom technique and a philosophy (Panitz, 1999). In terms of this method, individual ability and contributions are respected during the formation of consensus. There is a notable shift within cooperative learning contexts that disperses the teachers' role as knowledge authority and redistributes this power to the students. Collaborative learning-oriented questions include: (1) What is the difference between using language to learn and learning to use language? (2) How do we interact with students in such a way that we ask only real questions rather than those we already know the answers to? (Brody & Davidson, 1998, p.8). Constructivist theories ground both cooperative and collaborative learning approaches. Teachers support the learning process by designing curricula that allow for the active construction of knowledge within a social interactive environment.

Social constructivists view meaning making as a collective experience, requiring continual input from participants and constant evaluation. Roth (1997) exemplified such a perspective through a case study involving a group of primary school students constructing structures as part of an engineering design project. At the start of the learning task, the teacher encouraged the students to bring materials from home that could assist them in the construction of their structure. By week three, only one student (Tom) had brought a single hot glue gun but was unwilling to share his tool with his classmates. Once Tom's classmates observed the capabilities associated with glue gun use, many other students also brought hot glue guns. By week six there were seven glue guns present in the classroom. The influx of hot glue guns brought with it a greater atmosphere of collaboration; even Tom now readily shared his hot glue gun with others. In order to ensure successful use of the tool, novice glue gun users relied on more experienced users for guidance. With only two outlets in the classrooms, the students had to work cooperatively to develop an equitable system of glue gun use. Creativity of glue gun use was also observed; one student discovered that the glue gun could be used for a time after being unplugged. Through social engagement in the design project, the students interacted in ways that enriched each other's understanding. The classroom community evolved due to the introduction of this novel tool, which transformed "where and how people worked and collaborated, which interpretations members attributed to the tool, which practices the tool afforded, and what and how the members designed" (p. 138).

Researchers such as Krajcik and Blumenfeld (2005) focused on project-based learning as it relates to science teaching and learning. Due to the contextualized nature of PBL investigation, the integration of multiple subject areas is an inherent aspect. Based on growing research support regarding the benefits to of PBL instruction to the learner, the expansion of such approaches beyond the science classroom is gaining traction. Project-based learning and student cooperation/collaboration are only two elements that characterize integrated STEM models. In recent years, science learning theories have been adapted to other learning areas in an effort to develop project-based models.

Herro and Quigley (2016) researched two middle schools that adopted approaches to curricula and instruction that involved all the major content areas. STEAM integration involved the addition of the arts into the STEM education model, which allowed for the integration of creative elements of expression and contextualized understanding of science and math content (Herro &

Quigley, 2016). One school system designed STEM integrated education curricula such as STEAM, while the other district had more traditional structures. Through narrative inquiry methods, the researchers collected data from teacher participants following a STEAM lesson. At the innovative school, the students were tasked with creating a digital fact sheet for a local zoo after first researching and video conferencing with a zookeeper. The sixth-grade participant teacher, Sabrina, found that with the STEAM approach she attended more to student collaboration and choice. Sabrina struggled to effectively scaffold instruction, collaborate with other teacher team members, and communicate assessments with parents. In the traditionally structured district, the students developed proposals for an outdoor classroom. The teachers from this district enjoyed interacting with the greater community as part of the STEAM exploration. A major theme was revealed in both districts: the STEAM teaching approach was not an "add-on" to the curriculum, a new curriculum, a specialized program or an entirely new pedagogical approach. Instead, the teachers "remixed education" to alter, appropriate or shift existing curricula and pedagogy to enact new (STEAM) teaching with varying levels of success (p. 196).

Technology and engineering

Technology coursework underwent many transformations in the past decades. Industrial arts, the precursor to technology education (before the mid-1980s) included the physical manipulation of materials such as sawing wood to construct a birdhouse. The meaning of the term "technology" expanded widely to prepare students for the 21st century. Technology offerings now include computer science, such as the manipulation of coding software, and engineering programs such as Project Lead the Way (NRC, 2014). The Next Generation Science Standards (NGSS) is the first national reform document that incorporated engineering education into the p-12 level. The engineering curriculum gained popularity among districts as the newest STEM discipline to be integrated. Models of instruction have been developed to guide practitioners but remain in the initial stages. Bybee (2011) argued that science and engineering had many overlapping aspects:

> With the exception of their goals – science proposes questions about the natural world and proposes answers in the form of evidence-based explanations, and engineering identifies problems of human needs and aspirations and proposes solutions in the form of new products and processes – science and engineering practices are parallel and complementary (Bybee, 2011, p.6).

McCulloch and Ernst (2012) focused research efforts on a novel teaching intervention intended to bolster STEM integration through T and E approaches. Through a partnership between pre-service teachers and the Department of STEM Education at North Carolina State University (NCSU) and researchers at the NCSU Center for Applied Aquatic Ecology (CAAE), a middle school curriculum was developed for estuarine ecosystems. The STEM project centered on an engineering challenge, namely to work out how to keep instrumentation free from barnacles when sampling. After conducting research on the ecosystem and its inhabitants and gaining familiarity with the instrumentation used by aquatic ecologists, the students worked in small groups to engineer an apparatus that would deter barnacles. During the piloting of the project, the students developed very different solutions to the problem posed. When confronted with additional factors such as extreme weather conditions, they applied their knowledge and skills to design and redesign their products. The work of McCulloch and Ernst (2012) exemplified the fact that technology and engineering can be seamlessly incorporated into science and mathematics curricula through the use of authentic, inquiry-based design projects.

A semester-long study of a middle school mathematics classroom by Ardito, Mosley, and Collins (2014) found that cognitive and affective benefits could be gained from a robotics curriculum package. A sixth grade teacher used LEGO Mindstorm robotics in association with Pace University to develop a mathematics curriculum that satisfied New York State standards requirements while also advancing students' ability to work cooperatively. Student teams paired with undergraduate mentors trained in the use of robotic equipment that served to guide the learning process. Evidence of learning was gathered through student blog posts and interviews, and standard assessment data revealed scores comparable to those not participating in the project. The participating students tended to score slightly above the comparison group in statistics and fewer students were designated "below" state benchmarks. The participating classroom teacher reported: "Every student has gotten better at being able to cooperate with other students. I would do all this work again just to have that happen" (p. 81).

Cunningham and Carlsen (2014) outlined five guiding principles necessary for effective professional development when they incorporated engineering practices into science instruction. The recommendations indicated below are arguably also related to other STEM disciplines: (1) engage teachers in practices, (2) model pedagogies that support those practices, (3) give teachers experiences as both learners and teachers, (4) develop teachers' understanding of the fundamentals of and interconnections between disciplines, and (5) help teachers to understand societal relationships.

Cunningham and Carlsen (2014) provided examples of design projects such as a pollinator device for model flowers in an elementary classroom or a stream sampling apparatus for high school environmental science students. The process followed during the design and development phases remains relatively stable, despite differences in context. Cunningham and Carlsen (2014) suggested that professional development experiences should allow for modeling of the project from start to finish in an hour. In the case of engineering, one shift from science instruction included a focus on an optimal product that was tailored specifically to the needs of a client. In order to anticipate naïve conceptions and potential areas in need of differentiation, teachers should also engage in the curriculum materials from the perspective of the learner. In the majority of cases, the teachers also required further information on other disciplines in order to implement the curriculum with accuracy. Cunningham and Carlsen (2014) argued that teachers must also acknowledge that disciplines exist within a greater social context. Cultural, ethical, economic, and environmental considerations should be woven into STEM-related curricula and thus afford greater accessibility to students with diverse backgrounds.

Transforming student learning

When content is covered hastily and in a decontextualized fashion, students do not adequately process and internalize the information in meaningful ways. Content becomes discrete bundles of facts that do not relate to a common conceptual framework and eventually slip away. Extended time to engage in learning tasks necessitated mastery and dynamic transfer (Bransford, Brown, & Cocking, 2000).

Integrated STEM models of instruction equip students to tackle complex problems early on in their science education, thus eliminating the mystique associated with advanced STEM coursework. By instilling greater feelings of self-efficacy, students are more likely to envision their futures as science practitioners and feel confident about their skills and knowledge. Based on an ever-growing body of research, integrated STEM education continues to maintain a prominent role in science teaching and learning. The NSF, AAAS, and the NRC have all endorsed the application of interdisciplinary science teaching in education (AAAS, 2009; NRC, 2003; Palmer, 2011).

Wang, Moore, Roehig, and Park (2011) described integrated STEM education student outcomes as follows: (1) deepened student understanding of each discipline by contextualizing concepts, (2) broadened student understanding of STEM disciplines through exposure to socially and culturally relevant STEM contexts, and (3) increased interest in STEM disciplines by increasing the pathways for students to enter the STEM fields.

Fostering STEM interest

The National Research Council's 2011 report on successful K-12 STEM education describes effective instruction as "capitalizing on students' early interest and experiences, identifying and building on what they know, and providing them with experiences to engage them in the practices of science and sustain their interest" (p. 18). In Wang et al.'s (2011) study of a STEM integrated curriculum at the middle school level, this sentiment was mirrored, with participating teachers giving very positive feedback on the affective aspects of learning. The students indicated more confidence in their abilities and were less fearful about making mistakes. Furthermore, student interest was piqued by the curriculum design. They were learning about STEM disciplines in a manner that was perceived as having lower stakes and being more enjoyable overall.

Burghardt, Hecht, Russo, Lauckhardt, and Hacker (2010) studied the role of student interest in integrated STEM instruction at the middle school level. The researchers found heightened interest in the treatment group compared to those participating in the control without explicit mathematical connections. High, Thomas, and Redmond (2010) investigated a group of middle school students who constructed a prosthetic arm as part of an engineering design project. Based on pre- and post-evaluation, the students expressed an increased interest in pursuing STEM careers. This echoed the results of Lou, Shih, Diez, and Tseng (2011), who observed Taiwanese female high school seniors engaged in PBL. The activities involved the construction of a solar electric trolley with high-speed capacity and a novel design. Lou et al. (2011) describe PBL as "a skill that places the learner in a meaningful learning situation that is focused on the solution to a problem taken from a real situation" (p. 197). With assistance from an online support platform, the students followed a series of six design stages that ultimately resulted in their final product. They developed problem-solving skills throughout the duration of the project, designing and redesigning their products for optimal results. The research team found that the students had a strong theoretical understanding but struggled to practically apply these skills during the trolley construction phase, relying on the online platform to supplement their understandings. They also gained cooperative learning skills as they developed and carried out the design process. The female students who participated in this study reported heightened interest in STEM-related future careers as a result of the PBL approach.

Freeman, Alston, and Winborne (2008) explored first year undergraduate motivation during participation in the Learning Communities for Science, Technology, Engineering, and Mathematics Academic Achievement (LCSAA) project at four historically Black colleges. The project included thematic interdisciplinary connections, as well as a collectively graded integrative essay assignment. The project focused on collaborative learning that evoked active learning. The researchers found that the students responded positively to the collaborative element of the project and overwhelmingly recommended that it be continued in future years. The researchers reported increases in motivation associated with self-efficacy, intrinsic motivation, task value, and control of learning beliefs. Innovations that evoke a sense of community have the potential to transform students' educational experiences.

Understanding STEM content

When properly supported, integrated instruction can strengthen the teaching of science concepts. Levy (2013) researched students' understanding of water flow rates based on the height and diameter of the pipe, and resistance. The researchers selected 15 children of kindergarten age to participate in this study and they were asked to participate in the hands-on construction of a water system. The researcher sought to determine whether the design task improved understanding of the topic, an ability to find interrelatedness between the three variables, and capability to transfer knowledge to real world scenarios. The students assigned to the treatment group had significant gains in understanding the general rules associated with water flow rates. Furthermore, "different from the control group, the builders all showed a budding ability to coordinate two rules in predicting and explaining water system behaviors in the post-test" (p. 556).

Robinson, Dailey, Hughes, and Cotabish (2014) selected a sample of elementary level gifted and talented students from five low-income schools who were participating in a STEM intervention. The College of William and Mary provided the teachers with curriculum materials that aligned with state standards. The teachers received explicit instructions on how to implement curricular units as well as embedded mentoring support from a knowledgeable instructor throughout the school year. The teachers assessed the students' knowledge of science content and concepts using pre- and post-tests, which were included as part of the curriculum. The teachers measured science process skills using a performance-based task. In all instances, the students participating in the STEM-focused intervention achieved a statistically significant higher level than their comparison counterparts. In all three cases, integrated models resulted in improvements in the quality of the education for learners from non-dominant backgrounds. Engaging students from diverse backgrounds is important for the advancement of STEM fields. Exposure to integrated models beginning at the primary level and progressing throughout the secondary level can strengthen students' understanding, leading to greater preparation for the rigors of higher education and the world of work.

The current literature base on integrated STEM education offered only tentative outcomes with regard to the impact of STEM integration on student achievement, knowledge of content, ability to identify connections, and problem-solving capacities. There are several factors that have impeded the study of STEM integration in the past, the first being the mode of assessment used as part of the evaluation process. Many studies relied on standardized testing results to draw conclusions regarding the effectiveness of STEM integrated curricula. Standardized tests do not honor interconnected knowledge sources and therefore offer limited utility for those advocating for STEM integration in the classroom. There is a dearth of assessments that reflect the integrated STEM knowledge context. The lack of a common language for interdisciplinary STEM education also causes barriers to research. For instance, there is no consensus on what comprises STEM integrated thinking or associated learning goals. In order to fully understand student growth in the area of integrated thought, study durations need to extend over time. While gathering data on student achievement remains problematic, even less is known about curriculum development and implementation. Methods to weave integrated STEM content into lessons in such a way that they impact learning remain elusive. Of the studies conducted in the area of STEM integration, the results suggested improvements in conceptual understanding yet these findings varied by classroom context, assessment structures, and prior exposure (NRC, 2014).

Teachers' roles and interactions

A teacher's identity is constructed, in part, through connections to content area subjects such as "math" or "science". A myriad additional factors also contribute to notions of self, such as emotions and discourses. Gee (2000) defines identity as acting like a "kind of person" within a particular context. He teases apart this perspective by looking at identity through four different lenses that all relate in various ways to socio-cultural meaning making. Identities are distinguished by biological factors such as sex, institutional components such as role or job, discourse identities or expressions of personality, and affinities displayed through experience. Nature can be overrepresented in an effort to de-emphasize the power of institutional forces on shaping this perceived identity status. Authorities and structures that result in a place or position define institutional identities. Discourse identities involve the construction of identity through language or how others actively describe individuals. Affinity identities are activities that individuals actively engage in that also serve as descriptors. Hobbs (2012) contends that there is a close connection between teacher identity and teacher agency. She further asserts that teachers should be encouraged to explore their changing identities.

Hobbs (2012) conducted a study of teachers who were teaching subjects that were not part of their teacher preparation. Hobbs interviewed 10 teachers with a range of practical experiences. Some teachers reported reduced levels of confidence when asked to teach content outside their areas of certification. Others found that while the experience of teaching 'out of field' was challenging, they also developed new areas of interest. Experienced teachers reflected that the transition to a new subject area was smoother due to the pedagogical knowledge and skills they had amassed over time (Hobbs, 2012).

Berliner (1994) distinguishes teaching experience from expertise. Experience is the opportunity to build teaching expertise over time, while expertise refers to the ability to apply extensive pedagogical knowledge to inform classroom decision-making. Teaching experts deviate from notice teachers in their ability to “perceive events and process their meanings differently; have different knowledge structures available to solve problems; and are more flexible, effortless, evaluative and confident in their instructional behavior” (Rich & Almozlino, 1999, p. 614). Expert teachers set goals for students based on a nuanced understanding of the curriculum, time, and strategy. The type of goals set for students are also influenced by the disciplines that they teach.

Building trusting interactions

A supportive professional community offers space for teachers to reflect upon their dynamic teacher identities and expand their experiences. One cultural aspect of schools found to have lasting positive impacts at all levels from leader, to teacher, to student, involved trust. Collective trust is defined as, is “a stable group property rooted in the shared perceptions and affect about the trustworthiness of another group or individual” (Forsyth, Adams, & Hoy, 2011, p. 22). These shared beliefs assume that each member is competent, trustworthy, and willing to communicate with others (Adams, 2012). Trust is directional in nature; it can flow from principal to faculty and faculty to principal. Adams (2012) investigated collective trust as an indicator of capacity at an urban district in a southwestern state. Using structural equation analysis, the researcher found that “combined collective trust was a viable social indicator of instructional capacity” (p. 373).

Grossman and Wineburg (2001) examined the difference between congenial versus collegial relationships at schools. Congenial relationships involved an exchange in pleasantries through polite conversations limited to topics outside the classroom. In contrast, professional learning communities (PLCs) engaged in co-constructing teaching knowledge through frequent dialogue. The development of individual teachers relied heavily on embedded collaboration. PLCs provided support through interactive engagement in professional problems of practice.

McLaughlin and Talber (2006) described the shift from congenial interactions to the creation of authentic professional learning communities. The researchers presented three tiers of reform that began at novice level. The novices found collaboration uncomfortable and resisted the presence of other teachers in the classroom. Intermediate levels of collaboration involved some connections between peers. The teachers began to exchange expertise on curriculum and instruction but conversations were limited in scope and practice. The dialogue between members of teaching teams focused primarily on talk about non-school matters or tangential school topics such as field trips. When students were discussed, conversations were framed in a deficit model, meaning they focused on the students' shortcomings (Cooper, 2001). However, advanced collaboration centered on student learning outcomes and supported the continual improvement in practice.

Innovative curriculum development

Gardner and Southerland (1997) investigated a science and literacy courses for non-majors at the undergraduate level. The researchers found two primary ingredients for successful integrated science teaching. The first ingredient the authors noted was talent. The teachers needed the necessary pedagogical content knowledge to accomplish set learning goals. Building integrated connections required an additional skill set. In order for rich collaborations to take place, the teachers had to share a common vision of learning outcomes. Respect and passion for each others' subject areas was also perceived as vital, as well as the openness to learn and share with one another. Time and resources were cited as the second component of interdisciplinary success. Collaborative integrated work required extensive planning. The schedules had to allow for adequate time, both during and after instructional periods. Interdisciplinary benefits extended to both teachers and students. The teachers reflected deeply upon their practice through dialogue with other professionals.

Wang et al. (2011) documented three middle school STEM teachers as they implemented curricula with university-level professional development support. All the teacher participants believed that STEM integration seemed natural, with many fruitful intersections to embed content connections. Both the physical science and engineering teachers struggled to adequately combine technology during STEM integrated activities, citing a lack of resources and professional capacities. In the future, the physical science teacher hoped to flip her classroom so that students had prior exposure to content knowledge before the application process. The mathematics teacher found integrating the STEM curriculum most challenging to design and implement. He perceived mathematics as a tool that could assist in problem solving. He relied on the other teachers to contextualize and ground his work. He struggled to find places of mathematical connection with project-based approaches. He viewed mathematics as merely a tool for application within other STEM contexts and reported difficulty covering the curriculum and fully participating in integrated STEM projects.

Shen and Jackson (2013) also studied a math-focused practical application task that involved measuring the volume of a tree (MVOT). The study involved the use of a referent, or an item found in the natural world, that could be used to generate a mathematical model. A very similar learning process was undertaken as part of the MVOT activity, in which students were urged to first brainstorm their ideas, plan how they intended to measure the volume of the tree, use simple equipment, analyze their measurements during a sense-making portion, and then finally present to the rest of the group. The research team argued that the benefits of such instruction were fourfold: (1) engagement through exploration of the students' world, (2) stimulation of critical thinking skills through the use of open-ended questions, (3) group collaboration, and (4) improvement in understanding scientific methodologies. "This kind of activity is analogous to what scientists do" (p. 230).

Dalke, Cassidy, Grobstein, and Blank (2007) discussed the interactions of a biologist, a psychologist, a computer scientist, and a feminist literary scholar who developed curricula alongside K-12 partners. These authors contended that structured learning environments did not promote 21st century thinking. Conformity to particular patterns of organization to achieve formulated goals opposed innovative teaching and might actually stand in the way of learning.

During the professional development portion of Dalke et al.'s (2007) study, the higher education collaborators introduced a range of content areas to apply emergent pedagogical practices that are exemplified through self-guided study of topics spanning from ant behavior to racial segregation. K-12 teachers tested a computer program that simulated the behaviors of ants in a virtual colony. Activities during the summer highlighted how individual decisions can have community impact. Teachers created lessons to conduct in their own classrooms during the school year that incorporated emergent pedagogies. The lessons learned by the participants included that learning goals that were open to multiple interpretations worked best. Assessments required a dynamic nature as well, with opportunities to assess during activities and to offer the application of new ideas and skills in new ways.

Chowdhary, Liu, Yerrick, Smith & Grant (2014) tracked three secondary science teachers as they participated in professional development experiences and developed lessons centered on interdisciplinary science inquiry (ISI). As part of the experience, each teacher was paired with a scientist in a field of interest, ranging from aquaculture to cancer research. When the participants completed the apprenticeship component of the professional development session, the researchers invited each teacher to participate in sessions throughout the school year as they developed curricula and taught lessons rooted in their research experiences.

Chowdhary et al. (2014) found that implementation of the ISI curriculum varied greatly among each teacher participant and impacted the strategies used to convey ISI content in the classroom. While one teacher fully embraced the ISI model reflected in both his content and pedagogy, other teacher participants' lessons contained more teacher-centered elements and focused on low order cognitive learning tasks. Differences in perceptions of student ability stemmed from differences in teaching ideologies and school infrastructures. When faced with the challenges associated with interdisciplinary curriculum development, many teachers reverted to pre-existing structures due to familiarity and ease. Current teacher certification systems value single-subject area expertise. Teachers without extensive background in research, real-world contexts, or other disciplines might feel insecure or hesitant to implement models that stretch their own abilities and comfort levels (Fensham, 2009).

Education policies as obstacles to innovation

Time for science instruction during the school day has become increasingly limited due to recent reform measures. The No Child Left Behind Act focused more on math and English Language Arts (ELA) performance and, as a result, districts allocated more instructional time to these areas. With the passing of the Common Core State Standards in math and ELA in 2010, these subjects were emphasized at primary grade levels and scant time was offered for science education. Science instruction accounts for about 178 minutes per week at the elementary level, compared to 503 for ELA instruction (NRC, 2011). 28% of districts reported that they reduced science instruction minutes by 75 per week (NRC, 2011). Legislation such as "No Child Left Behind" and, more recently, "Race to the Top" placed greater emphasis on teacher accountability and high stakes testing. Potential mentor teachers felt the pressures of testing and succumbing to the "teach to the test" attitude (Dolphin & Tillotson, 2015, p.35). Furthermore, during instructional periods teachers felt obligated to cover topics associated with standardized tests, taking away time for deepening the students' connections with the content and building conceptual understanding.

While the NGSS promotes the integration of science and engineering as part of the collective vision for science education, antiquated institutional structures serve to hinder innovation. The subject silo model continues to prevail as the most common school organization scheme.

School-related implementation challenges

School structures can further limit the ability of integrated STEM models to persist because they conflict with current systems of planning time, resource access, and scheduling. Stohlmann, Moore, McClelland, and Roehrig (2011) found that educational leaders also struggled to decide which students would have access to this new instructional model and how to physically accommodate the new programming.

Venville, Rennie, and Wallace (2004) provided an illustrative example of infrastructural constraints on teaching practice. Teachers who developed a 12-week project for gifted and talented students in grades eight through 10 involving the construction of solar boats were considering adapting the curricula for future years because of time limitations. The team of teachers decided that in future years, students would select from a pre-determined set of options in the circuit-building phase of the project. "Teachers have to perform a balancing act between open-ended and closed problems, allowing students to find appropriate solutions within the time available" (p. 133). While the logistics may seem superficial, decisions can have a significant impact on learners as well as on the vitality of the program.

Given the highly compartmentalized structure of teaching and learning, assessment of student work within integrated settings becomes especially challenging. Nowacek (2007) studied a first-year undergraduate disciplinary model of instruction that intertwined humanities, in this case literature, history, and religious studies. All three instructors were instrumental in the design and implementation of the course using a co-teaching model that illuminated bonds between each disciplinary perspective in an organic manner. While the professors coordinated the logistics of the assignments, such as due dates and type, no unified effort was made to design assessments that reflected the interdisciplinary nature of the course. "The assignments served disciplinary rather than interdisciplinary goals" (Nowacek, 2007, p. 376). The students tended to gravitate towards one particular disciplinary perspective and lacked the capacity to fully synthesize aspects of content, methods of argumentation, and ways of knowing from each subject area. Practitioners and researchers alike have a tendency to cling to traditional evaluation and assessment systems that may be inappropriate for interdisciplinary modes of instruction (Venville et al., 2002). New frameworks that embrace interdisciplinary paradigms must be developed in order to properly assess student learning and evaluate model effectiveness.

The implementation of integrated STEM models requires serious commitment on the part of the teacher in the form of planning, gathering materials, garnering support from parents and the administration, and fostering community partnerships. When teachers are not provided with appropriate time for such efforts, opportunities for critical reflection and practice modification are often neglected. Baird's (1999) study confirmed this through a phenomenological investigation of a group of secondary science teachers' teaching experiences and how they described science teaching. The participants perceived science teaching as complex, with not enough time dedicated for reflection.

Professional development and support

McEwin and Greene (2010) generated a series of recommendations to facilitate collaboration in schools. They suggested that: (1) daily common planning periods must be carved out of the school schedule. (2) Schedules should be flexible in nature in order to facilitate high interest and developmentally challenging curricula. (3) Opportunities to teach core subjects (math, science, social studies, and ELA) must be paramount. (4) Whole class instructional approaches should be replaced by inquiry-based, cooperative learning activities. (5) Lastly, advisory councils should be implemented to provide greater student agency.

Participation in extensive, embedded professional development can counteract reliance on traditional patterns of instruction. Pedagogies associated with different disciplines can vary significantly. Professional development providers should acknowledge differences and provide opportunities for teachers to practice unfamiliar pedagogies. Science teachers require additional skills sets in areas such as scaffolding support, questioning strategies, and group work to foster new approaches to thinking (Cunningham & Carlsen, 2014). Bybee (2010) promoted the development of model STEM units for elementary, middle, and high school levels to provide a clear vision of STEM education for educators, policymakers and the public. Ideally, aligned assessments would accompany each model STEM unit, as well as continuous professional development experiences for staff.

Using phenomenology to study classroom contexts

Despite substantial challenges, innovative models continue to be developed in the hope of transforming science teaching and learning. To illuminate the inner workings, I viewed models of innovation as phenomena to be both observed and interpreted. I investigated how one particular innovative model developed and persisted. Through phenomenology, first-hand experiences can be conveyed through the voices of the participants. The integrated STEM black box can be further illuminated through this attention to experience.

I offered a brief overview of the philosophy undergirding phenomenological inquiry, as well as the key persons involved in the development of this field. I then divided up the broad field of phenomenology to highlight studies that closely related to the research questions posed as part of this inquiry. Phenomenology has been used in the literature in two distinct ways, namely as a philosophy of knowledge and as a methodology (Ostergaard, Dahlin, & Hugo, 2008). Meaning making is inextricably connected to how we are situated as individuals in the world. The setting of experience contains both spatial and temporal aspects. The world at large represents the setting in which experiences continuously take place (Szybek, 2002). As players in the world we react to our surroundings in nuanced ways that inform our minds. For instance, Szybek (2002) used the example of a barefoot professor to illustrate our need to find connection and intentionality in observations. If a professor walked into a lecture hall barefoot, students might react by whispering to peers or giggling. However, if this same professor walked along a beach barefoot, there would be no response from those nearby. Our subjectivities are constantly at play, informing our senses (Szybek, 2002).

Husserl, a German philosopher, is credited with the development of phenomenology and its associated methods. Husserl sought to find the "essence" of experience through "phenomenological reduction" (Cooney, 2012). This phenomenological reduction amounted to bracketing prior conceptions of an experience or personal inferences in order to deduce a true meaning. Many offshoots of phenomenology emerged as a result of Husserl's work, including phenomenological psychology. Husserl was also the first to coin the term “lifeworld”, or the experiences that make up a person’s being. Heidegger, a former colleague of Husserl, as well as others such as Merleau-Ponty and the American Gadamer, used the same lifeworld phenomenological research approach as this study adopts (Cooney, 2012). This new cohort of phenomenologists rejected Husserl’s notion that an objective “essence” could be extracted from an experience. Using the term “*Dasein*”, which translates into “being there” or “man’s existence”, Heidegger argued that being and the world act as a unified whole that allows for the generation of meaning (Horrigan-Kelly, Millar, & Dowling, 2016). Interpretative phenomenology, or the search to understand the meaning of experience, began to gain traction among philosophers. Heidegger developed the term “pre-understanding” to illuminate the inseparable connection between meaning and the world. The development of hermeneutic phenomenology was based in part on the works of both Husserl and Heidegger (Cooney, 2012).

Historically, hermeneutics was used to interpret ancient biblical texts such as the New Testament. Modern hermeneutics is attributed to theologian and philosopher Schleiermacher (1768-1834), who defined hermeneutics as an attempt to avoid misunderstanding (Schleiermacher & Bowie, 1998). Schleiermacher argued that personal attributes, even seemingly trivial aspects, collectively contributed to our interpretations of the world (Schleiermacher & Bowie, 1998). We create notions of reality through interpretation of life experiences. The generalizability of these interpretations is limited to firsthand experience. For instance, we cannot apply our own interpretations of the world to make broad conclusions about phenomena we have not yet personally experienced.

Phenomenology in science

Researchers explored the use of phenomenology to learn about the natural world. Johan Wolfgang von Goethe, a poet and naturalist from the 19^{th} century used phenomenology to understand plant development and color. Goethe employed a linear method to observe and analyze his findings but also incorporated more intuitive aspects that rejected common Western science practices. Goethe viewed theory and phenomena as one and his theory became known as non-dualism. "Goethe resisted the reductionist tendencies of natural science and preserved a genuine interest in actual experience and the many ways in which a phenomenon may appear to us" (Ostergaard, et al., 2008, p. 95). Goethe's work inspired the science curriculum and instruction associated with the Waldorf schooling approach.

Phenomenological inquiry extends beyond natural phenomena to learn more about social relationships within science settings. Phenomenology has been applied more recently in the scientific field to understand the lived experiences of people in the field of health services, nursing in particular. Carr (2006) explored nurses' views of the practice of nursing. Nurses act on their knowledge in differing ways based on the contextual cues from the patient, collaborators, or environmental factors. Carr (2006) stated: "The clinical environment cannot easily be controlled" (p. 334). Carr studied how nurses "know nursing" and how they interpret their work as their perspectives are informed by culture, organization, experience, and level of education. Due to sensitive human engagement, gathering data can be problematic for researchers. Carr suggested two practical approaches: direct observations with participant follow up and recorded footage with discussion of transcripts. Regardless of approach, phenomenology allowed for a focus on the lived experiences of nursing professionals.

Phenomenology in education

I found that there were parallels between the clinical environment of nursing and the educational environment of schooling. Ostergaard et al. (2008) explained that teachers engage in a “double focus” during instructional periods that involve both the content and the learner. Meaning assumes multiple forms that relate to the context and individuals involved in the learning process. Taylor (1990) describes meaning as being comprised of three components: meaning of a subject, meaning of something, and meaning in a field. The first aspect refers to meaning based on the perspective of each participant involved, the second element relates to content, while the third aspect relates new meanings to other meanings and experiences. Meanings evolve and morph based on the contextual factors that shape the process and therefore cannot be disconnected from the places and persons in which they are situated (Price & McNeill, 2013). Teaching and learning is a human process that involves interactions of multiple forms that are carried out within a particular community. Phenomenology puts into focus how cultural interactions play out in the classroom.

Sloan and Bowe (2014) studied the process of curriculum development by lecturers in higher education settings. The researchers conducted the study using an interpretive phenomenological frame rather than attempting to objectively describe this experience. Interpretative phenomenology, also referred to as hermeneutic phenomenology, posits that use of language acts as a proxy for experience. Researchers use an iterative process to make meaning through close reading of data, analytic writing exercises, and a global look at results. Sloan and Bowe (2014) identified four primary structures of experience related to curriculum development from the lecturer’s perspective: lived space, lived body, lived time, and lived human relation. Using Van Manen’s methodological frame, the researchers categorized participant statements about experience. Phenomenology offers an alternative to positivist research but questions arise as to what constitutes lived experiences. One criticism of educational research using phenomenology is the tendency to privilege practical experience, or knowledge "on the job", over other forms that might emerge within informal spaces (Barnacle, 2004).

Phenomenology in science education

Ostergaard, et al. (2008) found three major veins of phenomenological inquiry that pertain to the field of science education: (1) phenomenology *of* science education, (2) phenomenology *in* science education, and (3) phenomenology *and* science education integrated. Each vein of research featured the classroom participants: teachers, students and the content covered as part of the learning experience. Studies of phenomenology and science education typically inform the literature base through a focus on the teacher's experiences, students as persons, and the activities of learning and teaching. In alignment with the purpose of this study, I focused this literature review on phenomenology *in* science education. The findings related to phenomenology in science education pertain to the following three categories: (1) teachers and their experiences, (2) students as persons, and (3) activities of teaching and learning.

Teachers and teaching experiences

Baird (1999) conducted a study of science teachers and applied journaling activities as a hermeneutic reflective practice. Baird (1999) asked a group of secondary science teachers about their experiences and how they would describe science teaching. Baird found that science teachers reflected primarily on their interactions with students and secondarily on the subject areas taught. Participants with reflective capacity tended to persist in their positions longer than those who did not engage in hermeneutic reflections on a regular basis.

Koopman (2015) also employed phenomenology to study the lifeworlds of Black physical science teachers. Koopman (2015) found that phenomenology optimized the ability to investigate teachers' physical science knowledge over multiple points in their lifetime to better understand how they carried out instruction. Educational studies require an empathetic researcher willing to interrogate their own preconceptions. Phenomenology allows the researcher to deeply understand a participant's perspective through close attention to actions that are taken for granted. Kooperman (2015) posed two primary arguments in support of using phenomenological methods for educational research. First, this method provides a glimpse into the inner consciousness of participants but humbly admits the impossibility of fully knowing a person completely. Secondly, the author also claimed that "lived experience is an attractive and trustworthy methodological passageway into the consciousness of an individual and hence to insight into the process of human inquiry" (Koopman, 2015, p. 7).

Students as persons

Bazzul (2015) inquired about student lifeworlds as they pertain to the science classroom. She drew from critical science education scholars such as Roth (1998), who contended that student experience was valued in disproportionate ways based on membership in certain social groups. Lifeworlds, conceptions based on prior experiences that combine to understand our current experiences, are leveraged during formal instruction as part of school. Bazzul (2015) encouraged science teachers to reflect on how they privilege certain student lifeworlds above others based on socio-cultural factors. By embracing a wider array of student lifeworlds, science accessibility can extend to students with intersectional areas of difference that have been historically marginalized by the field. Students previously disenfranchised in the science classroom by positivist science notions and westernized pedagogies may begin to feel a greater sense of belonging. Since each student's experiences vary, science teachers must be "open to different ways of doing and learning science" (Bazzul, 2015, p. 449). In order for teachers to enact lasting change, they must be willing to acknowledge lifeworlds as social constructions and value a wider array of science conceptions.

Historically, the lifeworlds of students from dominant group positions have been privileged over students from non-dominant backgrounds in the science. Kozoll and Osbourne (2004) used phenomenology to investigate disconnects between lifeworlds and science education from college-aged migrant workers. One participant, Hector, perceived the experience of learning science as incompatible with his identity and conceptions of self. In order for Hector to feel valued as a science learner, teachers must take into account not only how he understands science on a conceptual level, but also how he views science in relation to self (Kozoll & Osbourne, 2004).

Activities of teaching and learning

Each human being views the world through a unique lens that is informed and adapted by interactions with nature and other people. Szybek (2002) found that teachers presented scientific information as “pure science” first and then offered opportunities for students to apply this knowledge in some real-world context that the teacher then evaluated. Through the use of phenomenological inquiry, Szybek (2002) described science instruction as a two-staged event in which the students are first prompted to learn by using equipment and materials presented by the teacher. The second step of the event comprises a verbal exchange between the teacher and the students. During the lesson, the science teacher revises the students’ language through a translation process to align their words more closely to conventional science language. Szybek (2002) analyzed an interaction between a student and pre-service teacher during a lesson on the properties of plastics. The student was asked to burn a sample of plastic and then report his findings. During the exchange the student, Arash, exclaimed: “We couldn’t bend it.” The teacher then repeated this phrase, “You couldn’t bend it” and then extended this conversation by adding, “it was not formable” (Szybek, 2002, p.542). The second utterance by the teacher connoted the translation from student language to technical science language. The teacher did not acknowledge the student’s prior descriptors of “it burned. It started to smell. It got black” (Szybek, 2002, p.542). The student’s experience was deemed valuable only when there was some science counterpart that the teacher could supplement. Szybek (2002) suggested that this two-staged process of science teaching actually created the impression to students that their lifeworlds were somehow not useful or invalid.

The Science-Technology-Society (STS) movement of the 1980s and 1990s positioned science instruction as deeply connected to everyday life. One major tenet of the S-T-S model was as follows: science was to be taught in a greater interdisciplinary context, not simply as an isolated body of knowledge but as a part of the entire body of human knowledge, which encompasses the arts, literature, mathematics, and the social sciences (Fensham, 2009, p. 186). However, during standards overhauls in the mid 1990s, lengthy lists of content-based expectations largely replaced S-T-S curricula. The pendulum now swung back in the opposite direction once again with the national acceptance of the NGSS. This reform document encouraged science teachers to explore connections between science and engineering practices. Integrated STEM models align with these new guidelines due to the focus on relationships both within and between science and engineering subject areas. Integrated STEM moves classroom conversations beyond science and engineering to involve both math and technology. Integrated STEM contextualizes these content areas by drawing from socio-historical aspects of knowledge. Integrated STEM education also features multi-modal approaches to learning that allows for the expression of scientific knowledge as part of the understanding process. Given these elements of integrated STEM instruction, its implementation in science classrooms can further blur the lines between science and the lifeworld.

Bevilacqua and Giannetto (1995) discussed the role of hermeneutics in science education. The authors argued that hermeneutics “can be relevant for science education and history of science” (p. 2). Hermeneutics has its origins in textual analysis, such as that exemplified in Galilei’s metaphor of nature as a book. However, Bevilacqua and Giannetto (1995) contend that science as a hermeneutic practice extends well beyond isolated textual analysis. In order to forge a bridge between lifeworlds and science worlds, we must explicitly teach the historical contexts in which science texts were created. Multiple interpretations of a phenomenon based on an individual lifeworld is more aligned with the actual process of scientific inquiry. Bevilacqua and Giannetto (1995) advocated for students to be able to use their own subjectivities to think about how science information is lodged within historical contexts. Building the capacity to understand scientific concepts in alternative ways is based in part on the recognition of lifeworlds. Scientists also engage in connecting science with their own lifeworlds. Through engagement in multiple texts such as research papers, debates, and biographies, hermeneutics can assist in the learning process through ontological phenomenology of science throughout time.

For the purposes of this study, I focused on the phenomenology of science education as a tool to understand the experiences of teachers and students. This vein of research applies an anthropological framework that grounds teaching and learning as a social process based on human interactions that take place during the co-construction of science knowledge. Phenomenology is well suited to the study of science teaching because it gives credence to the profession’s rich complexity and innate humanness. Like Black and Wiliams (2010), I believe that educational research is preoccupied by the need to report learning outcomes and neglects shedding light on teaching and learning experiences. Without a strong understanding of what it is like to engage in innovative science teaching, I do not believe we can reshape the science education terrain.

Methodologies that directly informed the study

Johnson's (2016) dissertation on student failure during engineering design challenges aligned with the goals of my research endeavor. Johnson's (2016) study explored how students engaged in engineering curricula, how they responded to failure, and how teachers reacted to failure responses. In Johnson's (2016) work, he recorded footage of students engaging in engineering design challenges using two differing curricular approaches. He used an event mapping strategy to depict each stage of the inquiry, specific learning activities, and time taken to accomplish each task. Based on the event maps, he then coded the type of failure observed and compared across data sets. He applied a hermeneutic phenomenological frame to capture failure experiences and offer interpretations. Johnson's (2016) research resonates with this endeavor in terms of the use of specific methodological tactics. I created an event map of recorded classroom observations to gather a more global sense of the teaching and learning over time. Central to the phenomenological approach is investigation of the essence or "essential meanings" of phenomena (Kafle, 2013, p. 189). Practitioners could find this approach useful to gain a better understanding of integrated STEM teaching and learning experiences. Hermeneutics continues to gain traction in the science education field as a means to improve reflective practices and the teaching of phenomena. Like Johnson, I engaged in the hermeneutic circle to identify subjectivities and interpret findings. I also found the iterative process of the hermeneutic circle useful to describe interactions I observed during integrated STEM instruction periods. A phenomenological study allowed me to gain insights into how STEM integrated team teaching operates within a specific learning community. Information gleaned from this study might inform other educators who are in various phases of implementation. This study provided a glimpse into how the members of one integrated STEM team engaged with each other, their students, and the broader community.

This literature review directly informed my research questions by illuminating how integrated STEM is interpreted within the field of education in general and science education in particular. By understanding how integrated STEM models were characterized in the field, I sought to draw parallels in my own study that would either affirm or contradict prior results. The development and implementation of prior integrated STEM models shed light on the potential advantages to students engaged in this approach to learning. I focused my study on the experiences of one integrated STEM model over a period of five years. I synthesized literature related to the development of integrated STEM models, as well as implementation challenges. I found it important to know how teachers prepared for interactions by leveraging their personal and professional experiences. The role of context weighed heavily in my study because of the phenomenological framework used. In order to develop a set of tentative and localized truths as a result of my investigation, I looked to tease apart contextual factors that enable long-term success. I used prior studies to compare my results to look for common barriers of success or opportunities for growth. I intended with this study to access prior findings in an effort to shed light on the ingredients necessary to carry out integrated STEM instruction to the benefit of the learner, teacher, and school district.

CHAPTER 3: METHODOLOGY

The purpose of this study was is to examine how one integrated STEM team approaches teaching and learning, what essential elements they include as part of the model, and how this particular teacher team of teachers designs and develops lessons over time. The ways in which teachers, students, and other community members interpreted this integrated STEM was also an area of inquiry. In prior chapters, I defined and explored other integrated STEM models and presented potential barriers to implementation. This chapter elaborates on the study site, participants, and forms of data collected. I support my methodological decisions since they align both with both the research questions I have posed and the theoretical framework guiding the present analysis.

Integrated STEM models of instruction make explicit the connections, both between and within the subject areas. Integrated STEM richly contextualizes the content area by attaching real-world significance to concepts. However, integrated STEM has been widely interpreted due to the lack of defining language associated with its practice. The term integrated STEM itself contains multiple meanings that are often detached from any context. Thus, I found it necessary to more closely examine the iterative experience of integrated STEM within a contextualized setting.

I viewed the integrated STEM teaching and learning as an anthropological phenomenon. Indeed, contemporary phenomenologists have argued that participants and contexts cannot be separated. Both the context and participation within the context shapes our understanding of a given phenomenon. In this study, the integrated STEM model represented the study context, while the teachers and students were considered participants. I investigated the experience of first-hand participation within a single integrated STEM context, while also understanding its overall function. My study closely investigated a single, eighth grade team to understand their daily commitments to integrated STEM both for teaching and learning. This particular integrated STEM model was selected due to its national reputation. Furthermore, teachers developed this model almost entirely on their own and sustained implementation for over five years. I subsequently extracted a series of localized truths related to this experience to create an informed description of the model. While many of the contextual factors associated with this study site are entirely unique to this school setting, other aspects of this context may resonate with other STEM educators in a broader context. For instance, national standards and assessments are the same for a number of district. The experience of teaching and learning, while specific to one school, still offer critical insight for those attempting to develop an integrated STEM model in the future.

Phenomenology as a research tradition

When exposed to new situations, individuals always incorporate their own conceptions of the world. Indeed, daily interactions with others are highly influenced by the context in which one is situated. Phenomenology refers to the “ways of being in the world,” as described by Heidegger (Horrigan-Kelly, Millar, & Dowling, 2016). Therefore, phenomenology focuses on the lived experiences of participants, striving to understand the aspects of existence that are taken for granted within a particular social context. Van Manen (2016) has considered phenomenological inquiry as an attempt to capture a particular moment in time, free from generalization.

Moreover, phenomenology is not only a research approach, but has philosophical origins. Husserl introduced phenomenology between 1859-1938 and he is widely considered the father of the modern phenomenology movement (Kafle, 2013). Phenomenology has since diverged into several different sub sectors of thought, including transcendental, hermeneutic and existential. Hermeneutics essentially refers to the art of interpretation. While hermeneutics began as a process to understand texts from thousands of years ago, we all engage in the constant interpretation of our surroundings and the interactions that occur every day (Horrigan-Kelly, Millar, & Dowling, 2016). To make sense of phenomena, we make comparisons that rely on our own subjective outlook. Kerdeman (1998) has clarified hermeneutic phenomenology in the following:

> Understanding arises in the intermediate space between perfect familiarity and absolute strangeness. On the one hand, a context of pre-understandings always funds interpretation. Without at least some familiarity with what we are trying to interpret, understanding will never get off the ground. At the same time, interpretation would be unnecessary if everything already was familiar (p. 246).

Phenomenology allows us to make sense of complex human interactions. The health field readily adopts this methodological framework to understand the relationship between care providers and patients. For example, Starks and Trinidad (2007) have focused on understanding primary care providers' (PCP) experience making decisions with patients who are considering preventative screening for prostate cancer. The research question asked "What is the lived experience of PCPs as they discuss prostate cancer screening with their patients?" This investigation involved a "thematic description of the common elements of the experience," including the difficulty that PCPs face when discussing this sensitive topic. Since phenomenology centers on experience, the audience for this type of inquiry includes other practitioners within the field. In many ways, the field of education parallels the social interactions that take place in a health care setting.

Phenomenology acknowledges the duality of science teaching as rooted in both content and social interaction. Teachers must focus on their relationships with students, while simultaneously assisting students' learning (Ostergaard, Dahlin, Hugo, 2008). Science education studies that adopted similar conceptual and methodological frames typically focus on teachers, students or activities associated with teaching and learning. Baird (1999) adopted a phenomenological method to examine teachers' views of science teaching over the span of 18 months. In this endeavor, Baird (1999) asked teachers to reflect on their practice in written form. Baird (1999) then followed up by conducting semi-structured interviews with participants to further clarify. Johnson (2016) used classroom observations and student journaling activities to inform his study about failure during elementary engineering design challenges.

Phenomenology emerged as an appropriate research method for this study because of the attention placed on the experience of teaching and learning as social engagement. The purpose of this study is to display how participants engage in integrated STEM teaching and learning within this particular context. Since this study focused on a small group of teachers in a single district, phenomenological inquiry made it possible for participants to express their opinions. My theoretical framing of this study is based on Heidegger's concept of Dasein, or ways of being in the world (Horrigan-Kelly, Millar, & Dowling, 2016). I viewed the integrated STEM model as the phenomenon that provided context for the participants acting within this socially constructed space.

Participant experiences were both immediate and retrospective. Since this model was enacted over multiple years, a number of teachers participated in multiple years. The teacher's Interpretations of experiences intermingled the past and present. One year was never the same as the next. The model evolved over a period of 5 years, and therefore was subject to multiple interpretations. For example, during conversations with Jeremy in years prior to the study he described participation in this integrated STEM model as a group of teachers that were interested in trying something new (Personal communication, 9/13). On the last day of the study, 3 years after this initial comment, Jeremy referred to engagement with this model as "a group of teachers who work together." There is a noticeable shift in characterization. Over years of reflection, Jeremy changed his description to represent the value of personal connection over curricular innovation. Understanding how participants interpreted both their professional and personal experiences over the span of time has the potential to indicate ways in which to sustain integrated STEM models. Particular truths surfaced through the contextualization and reexamination of participant interpretations. Hermeneutics offered the analytical tools to understand the relationship between experience and the contexts that influence participation.

I used hermeneutics to guide my own interpretations of the phenomenon of integrated STEM. This model is a combination of actions and context that cannot be separated, but rather situated by the researcher. I used practices such as memo-ing and bracketing of inferential statements to reduce the influence of my own interpretations. I leveraged hermeneutics to gain awareness of how personal bias plays a role in my own analysis. My position as a former middle school science teacher, field supervisor and doctoral candidate all informed my interpretations during this study. I also identify as a white, cis-gendered, and from a middle class background. This study urged me to revisit my notions of effective teaching and learning as well as my own biases throughout the process of data collection and analysis. The hermeneutic circle of interpretation enabled me to understand the interconnection between participant experience and context.

Situating the methodology

Phenomenology shares commonalities with other qualitative methodologies such as discourse analysis and grounded theory. Strategies for data collection are also quite similar to ethnographic or grounded theory research: interviews and observations are considered primary sources of data.

Methods of analysis also overlap with other qualitative approaches. Starks and Trindad (2007) have noted that phenomenological inquiry involves synthesizing multiple participants' views on a certain lived experience and then reporting on commonalities within the data set. The bracketing of personal biases represents an effort to explicitly identify and incorporate them into the work in an honest manner. Discourse analysis and grounded theories both use a similar process of de-contextualization and re-contextualization, that meaning data initially generated is reviewed in an iterative process to reveal meaning. Both ethnographic research and discourse analyses also are conducted with similar audiences in mind, including practitioners, educational leaders and curriculum developers.

The areas where phenomenology diverges from other qualitative methods are particularly useful for the purposes of this study. Phenomenology aims to organize findings through common experiences, as well as instances of deviation (Creswell, 2007). Phenomenology does not generate theoretical conclusions like ethnography, but rather to sheds light on an experience of interest to a field. Therefore, research questions focus on the lived experience of a phenomenon rather than on how language shapes identity or how social interactions occur within particular contexts (Starks & Trindad, 2007). "In phenomenology reality is comprehended through embodied experience" (Starks & Trinidad, 2007, p. 1374). Phenomenology was also the best choice due to the scope of this study. Creswell (2007) has suggested conducting multiple interviews with five to 25 individuals as part of phenomenological inquiry. I collected data from seven teachers and 10 students with common shared experiences. Typically, ethnographic studies include a wider range of study settings and a greater number of participants. Phenomenological inquiry allowed me to focus entirely on a single integrated STEM model in a school renowned for its success in innovative STEM instruction.

Hermeneutics was used as an analytical tool to interpret both the experiences of participation in and the overall function of the model. Since integrated STEM focuses on contextualizing the curriculum, this model differs depending on the site of enactment. I used phenomenology to highlight the work of integrated STEM teaching and learning from the view of the participants.

While the educational culture is hyper-concerned with achievement gains, learning outcomes and growth measures, my research was positioned differently. My work adds to the literature base through the rich narration and interpretation of lived experiences within complex school contexts. This investigation dissected the practice of one integrated STEM model to extract the experiences deemed essential and responsible for its long-term success. This inquiry can support others interested in knowing how one integrated STEM model functions on a daily basis. Educators in STEM fields can use this information to assist them as they adopt their own programs in K-12 settings. Teacher educators will also be equipped to convey integrated STEM practices to pre-service teachers.

The primary research questions I investigated are:

(1) Who is involved in the integrated STEM model and how do they perceive their participation?

a. In what ways do participants characterize the integrated STEM model?

(2) What are the experiences that comprise the integrated STEM curriculum and instructional model?

(3) How does the integrated STEM teacher team collaborate to address student needs within the context of both school and state standards?

a. How did the teacher team initially develop the integrated STEM model and how has it evolved since its inception?

(4) In what ways do contextual factors related to the school and community shape the participants' interpretation of integrated STEM education?

Research Design

Research setting

This inquiry occurred at a suburban district a few miles outside of an urban area in the Northeast United States called VCW District. At the time of my research, the total enrollment for the VCW district was 3,500 students with three elementary schools, one middle school and one high school. The high school is Maple Tree high school and the middle school is Elm Tree middle school. For the 2015-2016 school year, the district approximated 725 middle school students were in attendance. Graduating classes typically contained 250 pupils. The district's racial composition was predominately white; only 2% of students were considered limited language proficient (https://data.nysed.gov, retrieved 3/31/16).

The current superintendent served the district as an educational leader for over 10 years and holds a doctorate in educational leadership. She gained a reputation throughout the area for being a visionary through the development of district-wide strategic planning sessions in which the community assumed an active role in building the vision, mission and core beliefs statements of the district. The vision and mission of the district focused on 21st century skill building. The district recently gained many national accolades for its integrated STEM work at all levels. Specifically, at the middle school central to this study the teaching team received state STEM educational awards. The district has provided professional development experiences to other K-12 teachers, administrators and higher education institutions on a consistent basis. The teachers involved in this study were active participants in these professional development events, speaking to interested administrators, teachers and business people and allowing them to observe classes. The 8th grade teachers in the teaching team also acted as consultants for schools interested in developing a similar program. I purposely selected this district for my dissertation project due to their willingness to adopt innovative teaching and learning approaches that attract international audiences of educators.

Negotiating entry

During my first semester as a Ph. D. student in the Fall of 2013, I supervised student teachers in secondary science. One of the students I supervised was placed with Jeremy in his eighth grade science classroom. During this time, I briefly gained some exposure to this integrated STEM model. At the start of the 2013 school year, Jeremy traveled to NASA's jet propulsion lab. Students worked on a Mar's rover project that involved coordination with multiple subject areas. I observed the graduate student conduct lessons in Jeremy's classroom on four separate occasions. I briefly met the other teachers on the team at this time. During these interactions, I was impressed by the active learning practices employed by Jeremy and the team. After the supervisory period ended, I did not communicate with Jeremy until August 2015 when I began to formulate a research agenda for my dissertation. At this time, I reconnected with Jeremy to gain a sense of his willingness to participate in this research project. I periodically maintained communication via email and phone until a face-to-face meeting was scheduled on September 23, 2015 with Jeremy's entire 8th grade teaching team. I provided the team information regarding the study and gained informal approval from them to proceed. The following week, I submitted an application to the assistant superintendent of the school to receive permission to conduct a formal research study in the district. On October 7, 2015, I participated in a learning tour of the district, facilitated by the superintendent, to glean more information about the shared vision and mission. The learning tour included a short presentation by Jeremy and an observation of his teaching team during periods of student instruction. The district granted access to the study site in December of 2015 after I submitted a formal proposal for review. In early February of 2016, the institutional review board (IRB) accepted my application and I began the process of gaining consent from both teachers and parents. In March of 2016 I met briefly with Jeremy to answer any questions that he or the team might have regarding the project. I personally recruited all participants and obtained written consent from teachers. For student participants, I obtained written assent from minors due to their vulnerable status. I presented information regarding the project directly to the students and provided them ample time for questions and elaborations. I also sent information home to the parents of potential student participants in an effort to gain formal consent. I made my contact information readily available so that participants could communicate concerns at any time. After receiving consent from the teachers on the team, I organized a meeting with all of the teachers and students. I received student assent and parent consent in early April of 2016. I managed all sensitive information through the use of password-protected technologies and secured physical spaces.

Study participants

This eighth grade team consisted of one science, one math, one social studies, one special education and two ELA teachers, as well as one teaching assistant (see table below). During the timeframe of my study, the district assigned 101 students to this integrated STEM team referred to as the “orange team.” The counterpart “blue team” applied more traditional instructional methods not ascribed to STEM integration.

Jeremy, the science teacher, is one of the founding members of the integrated STEM team and acted as team spokesperson. He completed his student teaching at this district and has taught at the district for over 20 years at the same grade level. A variety of local and national STEM organizations have recognized Jeremy for his outstanding teaching. The district has employed Annie, the math teacher, for 14 years at the middle school. Previously, she taught for 6 and a half years in the district of the area in which she was raised. Calvin, the social studies teacher on the team, has taught at the district for 13 years at the eighth grade level and also coached a number of middle school sports teams. The two English Language Arts (ELA) teachers, Noel and Terri, both taught in total 8 years each.

The team also included a special education teacher and teaching assistant. Sam, the special education teacher, was usually integrated into the math and ELA classrooms, while Deb, the paraprofessional, tended to support the science classes. Sam enjoyed math and previously was a carpenter. He spent two years away from the team on another assignment in the high school. Deb has worked in the district for 11 years. I made assumptions about racial categorizations for all participants. All teachers on the team resembled the school's majority white racial demographic according to my visual assessment.

I selected 10 students at random to engage in semi-structured interviews during the study duration. I never formally inquired about students' grades, Individualized Education Plan (IEP) status or demographic information. I described participants' race using a visual assessment while in the field. I never required students or teachers to self identify according to race, gender, or ethnicity. Jeremy noted that the selected students appeared to be fairly representative of the class based on ability and background. I conducted interviews directly following observations of in-class student engagement, such as presentations or design challenges. The purpose of the interviews was to understand how students experience their learning and how they describe their learning to others. Students articulated their experiences by answering open-ended questions such as, “What is it like being on the orange team?” or “What is science like this year?” I conducted interviews during study hall, just outside the flex classroom. I noticed two of these students spending time in the resource room with Sam and two other students described themselves as ESL learners. One student of Color mentioned that she struggles with ADHD. She was one of only three female students of Color of the 101 pupils that comprised the orange team. I had no knowledge of student IEP or ESL designations unless students actively shared this personal information with me. A majority of the students interviewed had participated in a similar interdisciplinary experience as a seventh grader (see Table 1).

Study participants	
Pseudonyms	**Role**
Jeremy Ford	Science teacher
Annie Oldfield	Math teacher
Calvin Mitchell	Social Studies teacher
Terri Holly	ELA teacher
Noel Paul	ELA teacher
Sam Perry	Special Education teacher

Calvin Mitchell	Social Studies teacher
Deb Williams	Teaching assistant
Dina	District Superintendent
Aaron	Student
Abe	Student
Caiden	Student
Frannie	Student
Hank	Student
John	Student
Lee	Student
Sarah	Student
Sean	Student
Zara	Student

Table 1: Study participants (pseudonyms)

School setting

The teaching team spent the last two years at the district's only high school in anticipation of an updated facility. The high school was located several miles outside of a large urban area and just down the street from the middle school. An electronic sign in the opening circle of the high school displayed digital messages of the day's events. The board posted graduating seniors and their college selections. Many of the students highlighted on the screen planned on attending local community colleges. The parking area in the front of the building near the entrance of the school provided spaces for visitors, principal, and the student of the month.

The front façade of the high school was composed of beige brick and seemed expansive due to the lack of large windows. There were banks of doors, mostly glass, with dark metal frames. Four feet from the entrance was a dark metal pole with an intercom and buzzer with metal finish. Green grass outlined the perimeter of the building. A thick glass pane separated school visitors from the attendance clerk just inside the initial set of doors to the school. There was a notebook to sign in with a pen attached that was accessible by both the visitor and attendance clerk.

In the school foray there was a seating area for guests with two older looking couches configured in the shape of an L. There was a fifty-gallon fish tank with ten large koi fish with white and orange patches. The hallway to the left led to the administrative office area that housed the district superintendent as well as the student-run credit union kiosk. Directly in front of the opening doors were about fifteen feet of floor space and a brick wall on the adjacent side. Many days I observed a plastic table set up for military recruitment, fundraising, and other special events in this area. A hallway on the right-hand side led to academic high school classrooms as well as the cafeteria. The library was located just around the corner of the brick wall and on the left; the auditorium was on the right-hand side.

One wing of the high school was carved out for the eighth graders down the hall from the main entrance and past the newly renovated library. The team described classroom space by function rather than content (see Figure 2).

Figure 2: Icons representing each class

The "Lab" referred to laboratory or site of exploratory investigations. Jeremy, the science teacher, primarily used the lab space. The "Archives", as the name connotes, acted as a place for locating and examining primary historical texts and housed Calvin, the social studies teacher. The "Think Tank" referred to site where students are expected to cognitively engage and then apply their thinking to complex concepts. Annie, the mathematics instructor generally occupied this classroom. "Flex" is a space for students to work independently on a wide array of school related tasks. The "Flex" space served as a classroom for ELA instruction as well as study hall and Terri's home base. The "Hub" functioned as the communication center of the model, where students learned various forms of expression. I found Noel mainly in the Hub classroom. Since space was tight given the influx of eighth grade students, these classrooms also housed foreign language classes as well as study halls. Below is a mockup of the classroom floor plan for that houses this eighth grade team.

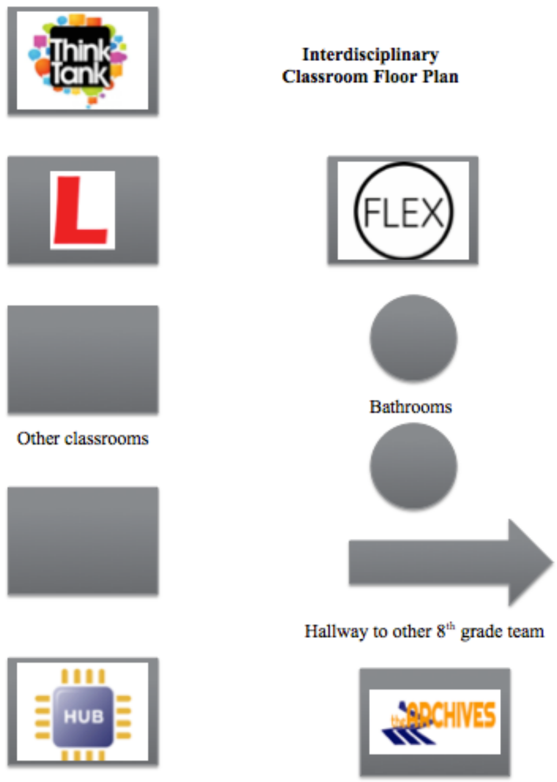

Figure 3: Classroom layout

Classroom layout

All the classrooms have a very similar aesthetic with off-white walls and tiled patterns on the floor, 20' by 30' approximately in dimension. The left side of the "Lab" classroom contained a large white board, often blank or with minimal writings. Just beyond the whiteboard on the same side, a small sink area situated with two grey cabinets above and below. Jeremy stored some chemicals and science materials in this section of the room. Smart boards or interactive white board were placed on the right hand side of the classroom with whiteboards on either side as well as Jeremy's desk. The American flag placed on the upper left hand of the white board marked the entrance and an analog clock hung just above the door. A series of Spanish posters with various phrases were tacked to the wall above the Smart board. Students could be found seated at traditional laboratory tables, with a black tabletop finish and thick wooden legs. Students sat two to a table, with standard chairs with metal legs and minimal back support. Two tables were pushed together to create a space for four students. The students were seated in three rows. A line of windows provides a view of yet another grassy courtyard. Beyond the courtyard is a row of wispy young willow trees outlining the red brick wall.

Data collection

I observed and recorded a number of science lessons and also conducted semi-structured interviews with teachers and students after the implementation of these lessons. I also did fieldwork from April 1, 2016 until June 21, 2016. I recorded a total of 1,383 minutes of instruction as well observations of planning and lunchtime, and one professional development session that featured the participants. The length of time at my study site corresponded with that of other qualitative researchers who have investigated similar topics. For instance, Anderson (2009) collected data on five separate occasions for a period of 90 minutes over the course of 14 weeks in the second half of the academic school year for her work on micro identities. Ryu (2015) recorded 25 biology classroom sessions and interviewed 20 students as part of a study that investigated the positioning of diverse learners.

In alignment with other phenomenological studies, I collected data from seven teacher participants and ten students with shared experiences. Creswell (2007) has suggested conducting multiple interviews with five to 25 individuals. In my study, data from alternative sources was gathered to better understand the studied phenomenon. Data was also collected from ten students and the district superintendent. I interviewed each team teacher at least twice and took field notes during planning sessions and lunch conversations. I attended two professional development sessions conducted by the district and generated a series of field notes from these events as well. I interviewed students once formally, and then observed their engagement in classroom learning experiences (see Table 2). I observed episodes of classroom interactions to describe school activities. During observations and interviews, I maintained a daily record of contextual aspects that I perceived to be significant in a spiral bound notebook. I noted the number of students, gender demographics, teachers and room configuration for each day. After the observations, I followed up with participants to gain a sense of how they explained classroom occurrences. Extended memos were created immediately following each day spent at my study site. These memos included rich descriptions of the context, including participant actions and appearances. The process of memo-ing allowed me the time to "unpack" the events of each day and capture the details of daily social interactions more fully than was described in my notebook.

Name	**Role**	**Data collection sources**
Jeremy Ford	Science teacher	Formal interviews, debriefs, professional development (PD) events, plan periods, lunches, observations
Annie Oldfield	Math teacher	Formal interviews, debriefs, PD events, observations
Noel Paul	ELA teacher	Formal interview, group interview, plan periods, lunches, observations
Terri Holly	ELA teacher	Formal interviews, group interview, plan period, lunches, observations
Sam Perry	Special education	Formal interviews, plan periods, lunches, observations

	teacher	
Calvin Mitchell	Social Studies teacher	Formal interviews, plan periods, lunches, observations
Deb Williams	Teaching assistant	Formal interviews, plan periods, lunches, observations
Dina Seri	District Superintendent	PD events, observations
Sarah	Student	Interviews, observations
Aaron		
Lee		
Hank		
Cayden		
Frannie		
Abe		
Sean		
Zara		
John		

Table 2: Data collection

I started the data collection phase by interviewing all of the teaching staff independently to gain an understanding of their personal experiences in engaging in the integrated STEM model. I formulated two separate protocols for semi-structured interviews with teachers and students. The questions were open-ended, as outlined in Patton (1990), and focused on the experience of teaching and learning (see Appendix). Examples of questions include, “What is it like to be on the orange team?” and “How would you describe the orange team to a friend?”. The protocols served as a conversation starter with the expectation that the conversations would differ based on the day, lesson and participant. I conducted interviews on a regular basis after a period of observation so that participants could reflect on the learning activities that occurred during the observation period. I taped these interviews using a handheld device. I wrote notes during interviews to gather non-verbal cues, such as hand gestures and eye contact. For the teaching staff, I primarily conducted interviews during lunch breaks or planning periods. In an effort to respect my participants’ time, I tended to keep the interview sessions short. Usually interview sessions were conducted for a period of around 30 minutes. If I felt that I needed more information, I would simply schedule another time to talk. Student interviews were conducted after lunch during study hall periods.

I observed the classroom multiple times per week on a consistent basis. The teacher and student interviews were interspersed throughout the week. My observations focused on lessons with directly applicable science components. Often Jeremy would include reflections during these recorded observations, taking the opportunity to insert remarks during student group time. Participant observations recorded real-time interactions for the purpose of my interpretation, while teacher and student interviews aimed at understanding how participants conceptualize these experiences through verbal communication. I also accessed the team's public Twitter feed as a way to understand how experiences were represented in digital public spaces. Equipment used to record video footage included a camcorder with a tripod. I took notes during sessions to capture additional contextual information that occurred outside of the recorded view.

I completed the training required by the Office of Research Integrity and Protections at the university. In December of 2015, the school district granted approval to conduct my dissertation investigation with willing teachers and students. I maintained open communication with Jeremy, primarily via email, to update him on the status of the approval process. I personally recruited all of the participants and obtained written consent from teachers. I managed all sensitive information through the use of password-protected technologies. All printed materials were secured in a private, locked cabinet. Both teachers and students were provided with pseudonyms that were used during data analysis.

Data analysis

The extended memos I generated from the first few months at my study site focused heavily on descriptions of place. While continuing to collect data, I also began to transcribe interview segments from teachers and students. Three weeks after my entry onto the site, I began to transcribe the semi-structured interviews verbatim. While transcribing each interview, I was prompted to recall particular details of each conversation. I noted the impressions I formed as a result of responses to the interview questions. For instance, in my first interview with Annie on April 5, 2016, I commented in the transcript, "You can sense that she looks back warmly on the formative periods of the project, smiles a lot." Field notes, transcription and memo-ing were all executed while simultaneously observing lessons and interviewing the study participants.

As I gained familiarity with the research site, my written notes became increasingly more interpretative. In the last two weeks of my ten-week data collection period, I reflected on the social interactions I observed while in the field. I asked probative follow-up questions and looked for patterns occurring across multiple data sets that I had previously collected. The following is an excerpt from my extended memo from June 2, 2016.

> One aspect of this model that is divergent from others that I've seen is the use of technology. In my view, technology at this school is really unfettered access to the Internet and a computing system. Engineering is also not outlined in any formal way but sometimes becomes the "group project" or the "hands on" component. Art is the reference to the arts which encompasses the English language arts as well as the social sciences portion. In other models, art education is brought in to projects for a creative element. Science and math are the least contested part of the model, ties into Venville's work (Extended memo).

I began the process of transcribing interviews in April of 2016 and spent a period of several months transcribing the audio files verbatim and including contextual notes from memos and handwritten notes from the field observations. I also created research memos during periods of transcriptions to help me interpret my findings. On August 3, 2016, I stated, "It's also been helpful to listen to the first round of interviews again now that I've transcribed almost all of them. I am grasping different aspects now." I then placed all of my raw interview data into the software package, Atlas Ti, for thematic collation coded using moments of experience. This was the first time during the research endeavor that I formally analyzed the data I had gathered. Using only the interview data at this point, I searched more globally for patterns of experiences, as recounted by participants. I highlighted passages from my data and assigned 75 codes. At this stage, repeating sets of experiences (such as project-based learning) surfaced.

After examining my study using a broader scale, I refocused on the specifics involved in daily teaching interactions. I chose to analyze video footage from August until November to construct an event map of the teaching and learning episodes. On August 11, 2016, I commented:

> I am beginning to reference the video segments that I gathered. They are serving as invaluable to catch the nuances of the room and its players. For instance the small details of the room are starting to leave my memory. These videos are very helpful for contextualizing the details that I want very much to keep part of my work." I then combined the two data sets to inform my tentative findings.

During these months of data analysis I looked at multiple forms of data to steadily construct both descriptions and interpretations. I also shared my initial results with the teacher participants based on the themes extracted from the transcripts of interviews and observations. Jeremy responded during one such meeting, "I can tell you've been spending a lot of time thinking about this" (10/27/16). From November of 2016 until May of 2017, I generated several written renditions of my findings. I continued to refer to my data sets by re-reading the transcribed interviews, reviewing the classroom footage and re-listening to audio of the interview sessions.

Field notes, memos and transcriptions are all products of the hermeneutic circle the iterative interpretative process I used that involved periodic and overlapping episodes of reading, writing and interpretation. Ginev has noted that, "for hermeneutic philosophy of science, interpretation is not a recapitulation of ready-made results of inquiry, but a formative dimension of scientific research" (2008, p. 1140). Interpreting the world is an ongoing process and shapes how humans make meaning from their experiences. Interpretations of the study site were generated over the entire duration of the research. However, I did not formally develop any themes until after I had left the study site. This was an intentional decision that allowed me to attend more broadly to this integrated STEM model while present in the field.

Subjectivity

In studies such as this, the researcher assumes a critical role in the description and interpretation of the phenomena. Understandings exist only in a tentative form, with new information constantly gathered during the data collection process. The role of the researcher therefore, is to examine the phenomena from an outside perspective to present fresh interpretations. To fully explore the phenomena, I produced thick descriptive narratives that name the actions and interactions of participants as they engage with others as well as the contextual factors that situate the study.

I wanted to place the participant voice at the forefront and I purposefully repressed some inferential commentary early in the study, as evidenced in my memo from the field:

> Jeremy has provided so much personal commentary, while I've really tried to not insert my personal beliefs into our conversations. I think Jeremy wanted more of a two-sided interaction that is most familiar to the team in this professional environment. Jeremy is legitimately interested in improving his instruction but seems to maintain a belief that the purpose of my research is somehow evaluative. I try to offer him an outlet to express ideas and feelings embedded in the teaching context (Memo, 5/18/16).

Inferential statements are explicitly labeled and bracketed in an effort to acknowledge their interpretive value. In this study, I created a field note system that categorized my observations based on descriptions, inferences and interpretations. I structured field notes based on the work of Taylor, Bogdan and DeVault (2015) as well as that of Bodgan and Biklen (2011). Each note included a heading with basic information about the date, time and location. I provided each participant with a pseudonym that I used throughout the study; I also kept record of the names. I integrated the following four conventions to generate rich descriptions for each data set: observational notes (ON) included detailed observations of persons and places and constituted the greatest portion of the field notes; methodological notes (MN) highlighted aspects of the interview or observation that could be improved, such as lines of questioning or locations of interviews; I included observer comments (OC) with early interpretations as well as personal feelings regarding the participant or their responses; theoretical notes (TN) enabled me to work on the continuous development of recurring patterns found throughout the data sets. The OC and TN portions of the field notes comprise the bracketed portion of my work.

Positionality of the researcher

I grew up in a rural area in Upstate, New York in a white, middle class family. At one point my parents were both elementary teachers. The school system that I attended had a total enrollment of less than 1,000 students, only a handful of students (from only a few families) were students of Color. At Cornell, learning felt still very much segregated. I received a majority of my content area training at Cornell University, where I majored in environmental science. My science background, as well as my prior teaching experience, grounds my research interests. I gravitate towards innovative approaches to teaching and learning that promote conceptual understanding and real-world connections.

At the age of 22, I began my teaching career in Malawi, Africa, where I taught all academic subject areas, in an overcrowded and drastically underfunded classroom as a Peace Corps volunteer. Upon my return to the US, I pursued a teaching certificate in secondary biology and a Master's from an institution near my home. I taught for one year in an alternative education setting at the middle school level. I then gained employment at a career and technical high school as an integrated science teacher. As part of my position, I was responsible to developing science curriculum that connected directly to student occupational interests. For instance, I taught dendrology concepts to students seeking careers in natural resource management. Working at this facility exposed me to a variety of students with disabilities labels that had been isolated from their peers at their home districts. I found my time as an integrated science teacher extremely fulfilling and enjoyed my time working with students in this capacity. After four years, I left my position to pursue my doctoral degree. Since I maintained a love for the K-12 setting, I also enrolled in a certificate of advanced study (CAS) program in educational leadership to gain practical management and curriculum development skills. As a doctoral student I worked closely with secondary science education graduate students. I also was a data analyst for a NSF funded research project on integrated laboratory practices for first year undergraduates in chemistry and biology. I now act as a faculty member for a small liberal arts institution where I teach science and math methods and prepare pre-service teachers. As part of a cultural foundations department, I also teach an introductory course that centers on social justice theory in education. As part, I convey the need to confront various systems of oppressions enacted within current educational structures using a critical theoretical lens.

As a teacher, I maintain the belief that students needed a space to bring in their own conceptions of the world. I found that if I could engage students by creating an environment that was inquiry-based and rooted in real-world contexts that discipline problems would cease to exist. I was able to afford high school students the opportunity to earn solar panel installer certification and set up a system on campus. The hallmarks of my career were the moments when the content in the classroom became real for my students.

I believe that schools should act more like an organism than and organization and respond to the dynamic needs of the community. The schools I envision require true community partnerships and an investment in change. Theoharis (2008) profiled several administrators that championed social justice issues at their school. Although they had different personalities and approaches to implementation they all possessed the following traits: arrogant humility, passionate leadership, and a tenacious commitment to social justice. Having humility to ask a mentor for support is also critical when faced with potentially unpopular decisions. While I still am developing a racial consciousness, I do adopt a social justice stance that pervades the teaching and research that I conduct.

I definitely felt an affiliation with my teacher participants based on my past experiences with integrated STEM instruction. I was genuinely interested in the curriculum they developed as well as the instructional approaches they used. My identity as a white, cis-gendered, able-bodied women allowed me to smoothly build rapport with my white, cis-gendered, able-bodied teacher participants. I was able to gain a more intimate rapport with the women on the team based upon commonalities associated with gender. The teacher participants viewed me as a credible researcher because of my affiliations with a well-1known institution but also because of my prior public school teaching experience. The students also perceived me as an authority figure much like their teachers. When the teachers initially introduced me to the students they referred to me as Mrs. Gardner. I felt most distanced from the teachers during observations of didactic instruction. Also, there was very little discussion of social justice issues by participants during my study. Specifically, there was no mention of how structural oppressions are enacted within educational spaces.

I tried to maintain an awareness of my analytical thoughts and bracket my inferences when transcribing this work. Peshkin (1988) has compared the concept of subjectivity to a piece of clothing that cannot be removed. I purposefully collected as much data from my study site as possible for later analysis. I observed lessons and planning sessions and attended professional development sessions run by participants. I tried to record as much detail and as many diverse experiences as possible for subsequent retrospection. In alignment with hermeneutic analysis, I make my own position transparent using an autiobiographical reflection in the discussion chapter. By placing this information at the end of my work, I attempted to be transparent but prioritized in the document the participant view and experience.

The hermeneutic circle

Hermeneutics is a non-linear process used to derive interpretation from lived experience. I selected hermeneutics as an analytical tool to directly inform my research questions. I wanted to uncover how integrated STEM teaching and learning was implemented, as well as how participants interpreted this experience. The model used within this study has been in existence for multiple years. Teacher interpretations evolved over the years, as did students' experience with integrated STEM. Several of the focus students had participated in a similar approach in the seventh grade. Hermeneutics allows for multiple interpretations to be gathered simultaneously. Hermeneutics emphasizes the participant perspective and the model's contextual aspects that shape these views.

I confirmed my own interpretations through iterative engagement with the data. I obtained both descriptive and interpretative data. I further gathered observations, generated researcher memos and field notes, read and re-read data, wrote interpretations and rewrote these interpretations after completely reviewing the data set. Garza (2011) has suggested cyclically reading data to gain a more global sense of what it is like to experience the phenomenon central to the study. I consulted participants to clarify my assertions and used their descriptions of experience to guide my inquiry. I sought to understand the commonalities between participants when they both enacted and described this integrated STEM model.

Interpretation exists both inside and outside of our own experience. My position as a former middle school science teacher, field supervisor and doctoral candidate all contributed my interpretation of this integrated STEM work. I reflected honestly on my subjectivities and preconceived notions throughout the study using reflexive strategies. This iterative cycle, referred to in this study as the hermeneutic circle, was conducted over the span of one year (Figure 4).

I traveled back and forth in terms of scale to generate my findings, from individual experience to the whole model. I gathered a sense of the model from observing and interviewing participants. My understanding of this integrated STEM model guided my interactions with participants and framed the way in which I read my data. The information obtained from interviews and observations then, in turn, contributed to my overall understanding of the model. My process of hermeneutic interpretation oscillated from the individual to the system level (Figure 4).

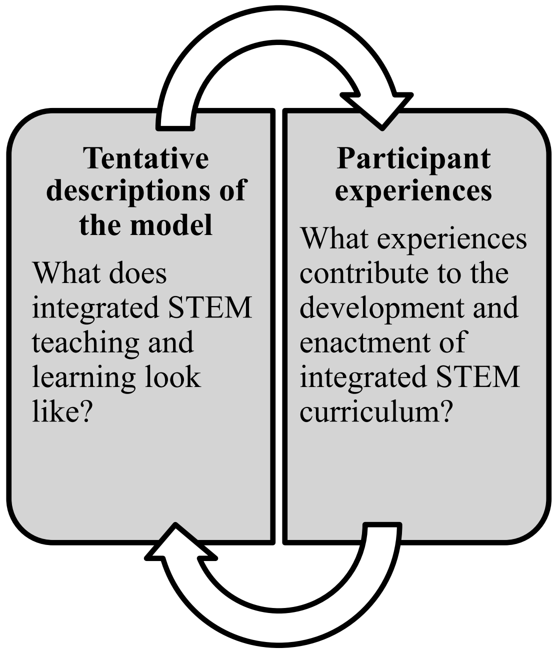

Figure 4: Hermeneutic circle

Event mapping

To gain a holistic view of integrated STEM instruction over the course of a ten-week marking period, I decided to organize my recorded observations using a technique referred to as event mapping. Event mapping offered a framework to systematically analyze classroom observations. Each lesson I observed I broke into various segments based on learning activity. I also documented the participating teachers as well as student group. The event map focused on a host of classroom activities including personal interactions, science content, and use of resources. In order to analyze this integrated STEM experience I opted to break up observation periods into smaller units of time. I could then locate more readily patterns of interaction over time.

The event mapping method allowed me to answer my second research question of the experiences that collectively represent this model of integrated STEM. I was also able to better understand how instruction was implemented in the classroom on a consistent basis using this analytical method.

When lesson activities changed (often discursively by the teacher) I made a note and recorded the time. I completed the event map for all classes observed from April 8th to June 21st during the 2015-2016 school year. I included a total of 30 lessons in the event mapping analysis. Jeremy advised that I observe a wide range of lessons to fully understand the range of teaching, so the event map represents an assortment of lessons. While on some days I observed a series of lessons to determine how they vary between groups of students, other days I observed lessons that featured integrated content or community building components. The event map allowed me to communicate these complexities as well as interpret their implications on teaching and learning (see Table 3).

I used transitional phrases to represent a change from one significant experience to another. Transitions are both verbal and physical in nature. Verbal transitional cues include words or phrases that signify an actionable change, as were used by both teachers and students. For instance, Annie provided directives to students during a whole group session in the following: "Then, um, after about, about ten minutes we will come back and then we will have some groups share what they've come up with" (Observation, 5/5/16).

Transitions can also be physical and these were observed based on student and teacher activity. I noted the time when a detectable change occurred between each learning task. I then bracketed each activity and noted its duration and significant details to further describe the experience. Event mapping makes it possible to analyze the triad of teacher, learner and content, while also accounting for contextual aspects. For instance, I recorded the number of students and teachers involved in each lesson as well as the space used (see Table 3).

Moment unit generation using event mapping in the classroom	
9:00	Jeremy (J) poses question of how many marbles can fit in the think tank

9:03	Annie (A) mentions the expectations for process and outcomes
9:08	Students find their work groups and prepare to present
9:18	Jeremy brings the class together as a whole group
9:20	Students groups present their findings (3 sets)
9:28	J, A, and Sam all explain their solutions and how they relate to student outcomes
9:35	Jeremy introduces the idea of displacement
9:40	Whole group lesson concludes

Table 3. Event map segment from May 5, 2016 whole group math and science lesson

Next, I converted the event map into a descriptive narrative form that included gestures and spatial positions of participants. I transcribed handwritten field notes into typed documents directly following periods of observations or interviews. I incorporated paralinguistic and nonverbal aspects of observations and interviews into typed data sets (Ryu, 2015). I found non-verbal utterances important to represent because they brought the human aspects of interaction to focus. Since anthropological phenomenology informed this study, the ways people engage with one another— important aspects of personhood— were crucial for me to pay attention to. To reveal presuppositions, I needed to gain a sense of how interactions took place within the setting and how I shaped those interactions, too. I used the event map to make sense of the integrated STEM instructional model during periods of classroom observation. The event map helped me isolate specific events that were considered significant within this model.

Similar to my study, Kelly (2014) and Johnson (2014) have explored engagement with learning based on social interactions. Furthermore, Kelly (2014) and Johnson (2014) also generated event maps to more clearly understand the temporal nature of instruction with attention to learning activities, time allocations, participant interactions, use of space and other resources. Kelly (2014) used event mapping to analyze how novice teachers respond to classroom situations, as informed by activity theory. Johnson (2014) also used event-mapping techniques to better understand experiences with failure within elementary school classrooms. Johnson's (2014) events focused on interactional units between teacher and student that reveal how the learner navigates design failure, as mediated by teacher support. Johnson's (2014) study also employed hermeneutic phenomenology informed by socio-cultural perspectives.

Thematic development

During the interviews, participants described their experiences as part of this integrated STEM model. Participants tended to order their experiences chronologically. For students, this meant first retelling experiences from the beginning of the school year and then working their way toward present experiences. For teachers, their experiences, and consequently their interpretations, spanned multiple years. I chose to code my data by locating moments of experience that informed my research questions and in alignment with the work of Giorgi (Garza, 2011). For the purposes of this study, I will refer to these coded segments of experience as "moment units". "The *moments* identified by the researcher present an "aspect" or "face" of the phenomenon under investigation — a sort of touchstone moment by which the rest of the data can be rendered sensible from a particular vantage point" (Garza 2011, p. 46; Garza 2004). I identified overlapping moments units reported by both teachers and students. As the researcher, the selection of moment units was a subjective process based on my own personal biases.

Participants signified moment units discursively through the use of transition phrases during interviews. Transitions could be numerical, such as phrases like: "in beginning" and "to start." Transitions also took the form of continuation phrases such as: "next" and "then." Changes in topics resulted in transitions that indicated digressions such as: "I might add" and "also."

Resumptions were also considered useful transitions that signified a shift in participant focus, for instance: “anyway.” Participants also used conclusion transitions, for instance: “finally,” “in the end” and “at last” (Transition words, www.msu.edu, retrieved 5/6/17). Summation transitions refer to the reflection on experience as a whole, such as: “all in all,” “overall” and “on the whole.” Transitional words or phrases bounded the participant experience into thematic segments that could be examined for patterns across interviews.

The final step in the data analysis process involved the collation of themes based on common moment units of experience. Similar to an ethnographer coding data using open coding methods, I clustered common experiences to identify aspects that recurred across interviews and participants (see Table 4). Starks and Trinidad (2007) found commonalities between grounded theory and phenomenology with regard to “coding, sorting, identifying themes and relationships, and drawing conclusions” (p. 1373).

Below is an excerpt from this study that highlights this process of coding using moment units. In this excerpt, Jeremy spoke to a group of educators about the creation of integrated STEM education at the studied school. He recounted his personal revelations regarding the need to coordinate with teachers. In bold are the portions from this passage that represent different periods of time. Discursively, Jeremy separated his thoughts using words and phrases that signify a change in place and time. For instance, the phrases “and then” and “I started” represent a transition in thinking for Jeremy. Each moment unit indicated a change in meaning of a particular situation by the participant. The entire sentence following a transitional phrase was incorporated into the analysis.

> As a teacher, (inaudible 5 secs) **[Moment unit 1] you <u>start</u> to realize that your teaching becomes a combination of your experiences…** I was just going to share an

experience of mine, um, that turned into one of those 'ah-ha' moments for me as a teacher (upward inflection in voice) because it takes some years to get comfortable and once you get comfortable you start creating stuff, ah and (inaudible) I thought I was approaching the expert teacher (smiles widely, the sides of his face wrinkle) area **[Moment unit 2] <u>about five or six years ago</u>, I thought, like, I was <u>starting</u> to get there, like this was getting good, and one ways that I could tell is that I had a parent letter that I gave out in the beginning of every year**. I'm going to be really honest with you my parent letter, in my opinion was awesome (places his right hand on his chest). I had everything you could imagine, the grading system, the colored tabs, the what to do with this mailbox, the grading for that, here was the system for that, it was tight (hands face outward, palm out, from waist). In fact, it was one of those pieces that got me kinda excited about teaching. I was planned enough ahead, I would send it out to (hands face outward, palm out, from waist level) before summer vacation and I would actually leave knowing that the next year was going to be a good year because it was printed and sitting on my desk. These were the types of things that got me excited as I was starting. And I was like, wait until these parents see me, imagine this well organized, well thought out syllabus with everything, we every possible rule and regulation. **[Moment unit 3] And <u>then</u> my kids started to go to school, by oldest is now a freshman in high school. <u>I started</u> to steal pieces of their teaching and putting into my letter.** I learned that what is better than open house as a teacher, is open house as a parent who is a teacher. Because you just sit there and scour the room (face turns from side to side, laughter from the audience). So like, I had amassed all these different strategies and all these different systems over the years of doing this that this letter was so thought out that my oldest got to seventh grade. And guess what? There are a lot of really good teachers out there with parent letters. With lots of different systems. So I thought, this is going to be awesome, I reached this great level where I'm a teacher, I've been teaching for twenty years. I've got a kid who is in the grade that I teach. I have it covered from all ends. So I was excited for the first day of school because I'd be like, 'Ok, bring out the parent letters.' I want to line all these eight or nine parent letters up and I got to signing and initialing. [Moment unit 4] **<u>I started</u> with science, not gonna lie, I got to signing and initialing and I was like, 'Oh, man, this is great stuff.' [Moment unit 5] <u>And then</u> flip it get to the next one, and I said, 'Oh, cool.'** I was actually writing stuff down. Sign here, initial here, yellow one, and all this and **[Moment unit 6] <u>[then] all of a sudden</u> you get like half way through and you get to realize, like, these are not coordinated in any way, shape or form with each other. [Moment unit 7] And <u>then</u> you get to thinking, 'Hey, is that three-ring binder (fingers from right hand tap on the table) all that they can you over here?' and 'These tabs are for this?'** And the school shopping list comes into play and they are all competing. **[Moment unit 8] <u>Then</u> all of a sudden, me, the most excited parent ever gets to the end of the list, I'm to the point where I am just signing and initially these epic pieces because I realize there's no, like, coordination** (hands come together, fingers clasp), they all sound like, gopplty gook, and then I go and imagine as a student what that must feel like to go to all these different systems, and expectations, (right hand moves in a circular rotation, three times) and tabs and all these things that we have all done individually, completely siloed. For me that is a moment where I said, wouldn't one letter suffice with all information? Better yet, wouldn't it be better yet if these teachers coordinated to come up with these systems, because any other industry really other than teaching, that's kinda called a lack of coordination there would be, kind of a failure of the system. And for me (left hand on chest), that was a huge eye opener (hands out, palms face the audience). For, how maybe we should approach the concept of teaching (Jeremy, Professional development event, 5/31/16).

Once I segmented transcribed data by moment units I then collated these moments into clusters that represented this experience as thematic threads (Garza, 2011). From the passage above the following thematic moments were grouped together using transitional words to signify a unit of analysis. I selected four moment units that contained pronounced significance to the participant. These moment units reveal Jeremy's inspiration for initial development of this integrated STEM model.

[Moment unit 2] about five or six years ago, I thought, like, I was starting to get there, like this was getting good, and one ways that I could tell is that I had a parent letter that I gave out in the beginning of every year.

[Moment unit 3] And then my kids started to go to school, by oldest is now a freshman in high school. I started to steal pieces of their teaching and putting into my letter.

[Moment unit 6] [then] all of a sudden you get like half way through and you get to realize, like, these are not coordinated in any way, shape or form with each other.

[Moment unit 8] Then all of a sudden, me, the most excited parent ever gets to the end of the list, I'm to the point where I am just signing and initially these epic pieces because I realize there's no, like, coordination

Clusters of moments units created themes that were translated into a narrative form. The following is one such example of my interpretations. One dimension of Jeremy's lived experience as a teacher is the desire to learn from others to enhance his own practice. This need to obtain ideas from the outside transcends the school day. As a father, he is positioned to view school from a different lens. Through the role of father, he engaged with teaching materials in a new way. He intended to leverage this experience to build his curricular and instructional repertoire. While Jeremy initially anticipated that this new engagement would yield many useful ideas, he soon identified a shortcoming of practice that signaled an impetus for change. Teachers at his son's school developed their own set of practices for each content area taught. When removed from the classroom setting, Jeremy found it tedious to comprehend each system. This experience revealed to him a need to innovate through integration. He noticed that co-teaching supported students by creating universal expectations. Jeremy also realized coordination potentially strengthens that relationships with parents and guardians by making school practices more streamlined.

After the outlined data was transformed into a narrative, I was able to better visualize interlocking experiences. These experiences gained thematic significance over time due to their replication across multiple contexts. Participant experiences directly informed my conceptions of this integrated STEM model. My understanding of this integrated STEM model subsequently grounded my ability to interpret these experiences. Hermeneutics took the form of a constant exchange between participant and context. Due to this formative process of meaning making, I routinely reflected on my interpretations to further improve my understanding. The themes I developed describe the elements of the experience and how it was perceived from a first-person perspective. After reading, writing and reviewing my field notes, I organized my findings around the main experiences recounted by participants and recorded during observations. The thematic conclusions from this study are a direct result of on-going engagement in the hermeneutic circle of meaning making.

Particular experiences surfaced over multiple interviews and observations. I noted the repetition of these concepts and focused my analysis on the concepts that reoccurred most frequently across the entire data set. For instance, I found that teachers and students mentioned their engagement with project-based learning approaches over 30 times on separate occasions. During every interview with a teacher participant, co-teaching experiences were mentioned. Moreover, teachers brought up the creation of instructional schedules 30 times during interviews and observations. Students also discussed class schedules on a consistent basis. Use of technology and space and social skill building were noted 20 times within the interviews. Project-based approaches, the scheduling of instruction, co-teaching/teacher collaboration, use of technology, use of space and the incorporation of social skills are the thematic concepts that occurred most frequently. Participants mentioned these concepts in two different capacities: they described their interaction with each experience and they also leveraged these experiences to describe the integrated STEM model. Together, these concepts represent the essential aspects of integrated STEM teaching and learning. From a hermeneutic perspective, interpretation is an ongoing and constant process. Once I gathered an initial understanding of the experiences that comprise this model, I remained open to refining these themes or generating new outcomes. Below is an example of the most commonly associated concepts based on the categories of teacher, student, content and contextual factors.

Participants	**Associated experiences**
Teacher	**Implementation of projects** **Scheduling instruction** **Team collaboration** **Promoting community**

	Using technology **Using space, space limitations** **Others**: Incorporating district initiatives, standardized testing, defining practice, risk taking, pushing up against constraints, struggle towards improvement, connection with subjects, differentiating instruction, identifying learning outcomes, curriculum design for student engagement, student grouping, state testing
Student	**Engaging in project-based learning** **Use of technology** **Flexible scheduling** **Interacting with peers,** Others: Hands-on learning, prior success/failure at school, speculating future

Table 4. Major thematic categories and related concepts

Verification strategies

Van Manen (1997) contended that the trustworthiness of the hermeneutic phenomenology as a qualitative approach is guided by orientation, strength, and richness. Direct involvement with the phenomenon grounded my interpretations of participant engagement with that phenomenon. Gaining access to my study site took upwards of three years after an initial relationship was forged when I supervised a student teacher in their team. Once the participants agreed to allow me to conduct observations and interviews, it took several interactions before team members became comfortable with my presence. The narrative generated by this investigation also directly contributed to its trustworthiness. During the analysis, I reflected upon my own personal subjectivities and how they informed my interpretations. I generated thick descriptions of the lessons that were observed, the planning episodes and the professional development sessions. Verbatim transcriptions of interviews also include a contextualization of space and place. The participants themselves provided the standard of authenticity. Participants were encouraged to provide feedback throughout the data analysis phase of the project. I also visited the study site once the interview transcriptions were complete (October 27, 2016) and explained the initial findings. Participants then received transcribed data sets and were asked to reflect on their accuracy. I also relied on my colleagues and peers to assist me in this process through regular accountability meetings to discuss initial findings and conversations with other qualitative and theoretical researchers in my department.

Cooney (2012) has stated that “there is no single way to carry out a phenomenological study” and has further highlighted its freedom from prescriptive techniques (p. 27). Since phenomenology can comprise a variety of approaches, I applied a methodology that could most clearly elucidate the experience of integrated STEM teaching and learning. Giorgi and Giorgi (2003) have argued that the validity of phenomenological data is best revealed in the researcher’s ability to convey the experience and not in the particular process taken to achieve this outcome.

Through phenomenology, I was able to investigate the experience of designing, enacting and sustaining integrated STEM instruction within one particular context. Findings gleaned from this study may inform other educators that may be in various phases of implementation. This study provided a glimpse into how integrated STEM teams engage with one another and their students, and how they function within a particular community.

CHAPTER 4: FINDINGS

Generally, integrated STEM education centers on building connections within and between subject areas through active and contextualized inquiry. The purpose of this analysis is to understand the lived experiences of a team of integrated STEM teachers collectively referred to as the “orange team”. To understand how integrated STEM models are developed and sustained over time, I focused my investigation on a single team of teachers who created and implemented integrated STEM instruction. This study centered on how one such integrated STEM model functions within a traditional public school setting. These findings featured a coupled relationship between experiences of participants and overall interpretation of the model at a system level. By understanding experience, I can better learn how this model functions as a whole. I consider experience and context to be inextricable and therefore analyzed both aspects to derive my themes.

Substantiated by member checks, my study answered the following research questions:

(1) Who is involved in the integrated STEM model and how do they perceive their participation?

a. In what ways do teacher participants characterize the integrated STEM model?

(2) What are the experiences that comprise the integrated STEM curriculum and instructional model?

(3) How does the integrated STEM teacher team collaborate to address student need in the context of both school and state standards?

a. How did the teacher team initially develop the integrated STEM model and how has it evolved since its inception?

(4) In what ways do contextual factors related to school and community shape participants' interpretation of integrated STEM education?

I organized my findings by research question and highlighted the themes that emerged to answer each.

Research question 1: Who is involved in the integrated STEM model and how do they perceive their participation?

Teacher roles and personalities

Jeremy, the science teacher, was a white male average in stature with a wiry build and dark hair. He often wore black-framed glasses and has tattoos on either side of his forearm. Jeremy walked rapidly and it was nearly impossible to keep pace. During our hallway conversations he continued to proceed, leaving others behind and not waiting for me to catch up. He also spoke swiftly and with confidence, professing that he "loves to talk." Jeremy's parents were also teachers who shared with him "tricks" that he used for classroom management.

With two teenage children at home, Jeremy felt comfortable engaging with adolescents and referred to his students as "cute" at one point during our conversations. When disruptions occurred in class Jeremy made light of situations and moved forward with his teaching goals. For instance, a student's phone rang during class. Jeremy danced to the ringtone and said, "That's my jam," and got a collective laugh by the class. He then within seconds he focused everyone back to the topic of sound waves. Jeremy smiled often during class and is described by student participants as likeable and funny.

During discussions of team roles, Jeremy explained first and foremost that he is the teacher responsible for ensuring that the science content area is sufficiently covered. Jeremy also brought up his secondary role as team scheduler. He explained, "It's kind of become my niche…I can make a schedule that makes them [other teachers on the team] feel more connected or allows them to do something else, take the pressure off of them, give them more time or less time depending on what they need" (Interview, 4/5/16).

Annie, the math teacher, was a white female with brown eyes and hair. She referred to herself as the "most set in her ways" when it came to pedagogical approach. During interviews, she also expressed anxiety associated with inviting other teachers into the classroom space. She recalled in years prior she had resources to pull from for curricular examples, but within the integrated STEM context, "there's not a lot to pull from…so I do struggle with that" (Interview, 5/19/16). Since her involvement in the orange team she believed her ability to modify instruction and collaborative interactions both improved:

> I think it's a struggle for all of us to go to somebody else's room and to, see what they're doing and see that somebody might be changing a little what your doing and the way that you do it. So, um, I think it's a good, it's a good struggle cuz it's creating growth in all of us (Annie, interview, 5/19/16).

Annie asked me many questions about my personal work. She was the first person on the team that I told about my new faculty position.

Calvin, the social studies teacher, was a white male, approximately six feet tall with a thin frame. His hair was graying, trimmed short to the sides of his head. Like Jeremy, he usually wore button up shirts, tucked into khakis and sneakers. Calvin admitted that team interactions don't come easy. While he hosted planning time sessions in his classroom he usually remained seated at his desk fixated to the computer screen. After an interview I noted, "Calvin is rather stoic and doesn't engage much without prompting." Jeremy mentioned that Calvin is the most willing to take pedagogical risks. Calvin envisioned integrated STEM instruction as "four or five general problems that the students all have to investigate throughout the year that we are ALL focused on" (interview, 5/31/16).

Noel, one of the ELA teachers, had mid-length, brown hair that was straight and shaped around her face. She was white and of medium build and height. She spoke quickly and gestures often, typically lifted her right hand and sweeping it around the table in a circular motion when she spoke. She will take on a different role next year as literacy specialist for the entire middle school. She showed the most disengagement during planning sessions. She listened to conversations and chimed in periodically while she simultaneously snacked on popcorn and viewed her electronic device.

Terri, the other ELA teacher, was a white with short with bright green eyes. Since there was not a dedicated space for teachers to store their personal items, Terri brought with her a large cloth tote bag with a laptop and a multitude of papers. Noel and Terri often spent free periods together. They enjoyed similar interests such as horseback riding outside of school. Terri tended to assume to role of rule enforcer on many occasions, especially during whole group lessons. For instance, on the last day of classes she chided the entire student group:

> Can I address something real quick? I few of you switched places from where you were supposed to be sitting and we didn't say anything about that and now you are being loud which I find doubly rude. If we didn't say something the first time (right pointer extends) for something you were supposed to do please don't be rude by being noisy while Mrs. Oldfield is trying to speak. The expectations are while an adult is talking, you are listening (Observation, 6/21/16).

Sam, the special education teacher, enjoyed teaching math out of all the subjects and had a previous career in carpentry. He spent the majority of the day in the math classroom. Sam was a white male over six feet in height, wore carpenter jeans and sunglasses on top of his head on most days. He mentioned his ability to view the team as both an insider and outsider. His roles changed multiple times since he began his career at VCM. Sam started out as a part-time teacher on the team when special education student numbers peaked. He then was moved to the high school based on the district need. He described himself as "sort of the utility man for the district and this is the first year I've done the same thing two years in a row" (Interview, 6/8/16). Administration frequently requested that Sam attend special education meetings throughout the day.

Deb, the paraprofessional dedicated for the team, was white, short in stature, around 5' with rounded features. Deb attended a teacher preparatory program and was certified in ELA before she determined that the paraprofessional role "was the better fit" (Interview, 4/6/16). She spent most of her time during this study in Jeremy's classroom to assist during hands-on activities.

She formulated close bonds with students through her role as advisor of several clubs. She recalled an interaction that highlights her strong student connection:

> Year after year, it's yah know, they'll either find me, I had a kid yesterday, no not yesterday, last Friday. He was like, 'I'm all done, my last day'. Yah know, it didn't really occur to me at the time, I was like, 'Ah (nose scrunches, eyebrows knit) yeah, have a great summer, see ya in the fall, like, 'I'm done, I graduate next week'. Then I was like, I got all upset. 'Oh, no' (eye widen, nose scrunches). It was like forever, I'm not going to see you, I was, we were in the parking lot, I had to make sure to find you before I was leaving because I was on my way to my car,
>
> Meg: Wwwooow.

Deb: He came running out of the building, I was like, 'It was so good to see you, thank you so much,' (this last statement was all spoken in a high pitch).

Meg: Right.

Deb: Yah know. [3 second pause] It felt good to be remembered (Interview, 6/15/16).

Deb gained full access to all classrooms on a consistent basis and therefore possessed a full awareness of the daily operation. She told me she loved science and learned a great deal from partnering with Jeremy on a regular basis.

Each teacher participant brought a unique perspective to the model based on years of prior experience and interests outside of school. Calvin's view of integrated STEM instruction was balanced by Annie's more traditional stance on pedagogy. Jeremy explained that competing educational philosophies with regard to pedagogical decision-making actually benefits the team. Jeremy identified himself as in the middle of the continuum with Annie swaying toward tradition and Calvin leaning on the side of innovation. Jeremy interpreted the differences in pedagogical approach as rooted in individual preference rather than the demands of a particular subject area. Jeremy believed he should expose students to traditional learning environments where lecture is the norm to prepare them for high school. Jeremy described himself as the group facilitator, but like Calvin acknowledged the struggles involved in collaborative interactions. He struggled to let others be heard and not dominate conversations. Noel and Terri often functioned as a single unit, traveling together and offering like-minded opinions on collaboration. They requested to be interviewed together.

Focus student perspectives

There were 101 students that participated in this integrated STEM model the year this study was conducted. This number fluctuated from year to year based on district enrollments. Jeremy told me that each year the students were randomly selected to be part of this integrated STEM model. Jeremy explained that the students have a range of abilities and interest levels in science. The middle school has another eighth grade teacher team with similar numbers of students that was referred to as the "blue" team. The students reported that the blue team tended to spend more time on seatwork and independent projects. Many of the students interviewed also took part in a similar model in the seventh grade. It was unclear whether students could opt in or out of each team. Students did mention that parental feedback was taken in consideration when placing students.

Aaron

Aaron was one of the tallest students in his class, around six feet tall with a medium to heavy build. He had white skin and dirty blonde hair parted to the right hand side and wore thick-rimmed black glasses that contrasted from his complexion. He spoke with a slight Eastern European accent. Aaron described himself as "a really quick learner."

During interviews Aaron talked about his challenges as a very young student:

> Well, in kindergarten, first grade, second grade, I wasn't the smartest kid. I mean, ah, I didn't know how to read and write. I needed help so I took ESL and in second grade I graduated from ESL and then in third grade I started slowly progressing (Interview, 5/5/16).

Aaron admitted, "I learn way more outside of school." He added "my father, he works for National Grid so I already know some of the stuff" (Interview, 5/5/16). This student seemed engaged throughout the lessons I observed and Jeremy considered him a high achiever. Jeremy stated that Aaron was "smarter than him". Aaron offered many contributions during the unit on electricity based on his prior knowledge from home.

Aaron participated in the seventh grade version of integrated STEM as well that developed two years after the initial orange team. The seventh grade team also involved an “R” component defined as research. Aaron compared the projects from the two years, “We do more sophisticated projects in eighth grade than in seventh grade.” He also found this year’s integrated STEM model “really organized and very advanced” (Interview, 5/5/16). His use of the term advanced signaled that he felt the curriculum was more cognitively demanding. He planned on pursuing a degree in engineering but remained undecided on the particular type.

Zara

Zara was a student of Color with green eyes and curly hair, a little shorter than her shoulder. Zara seemed consistently engaged during science lessons. At one point during an observation she rigorously raised her hand and stood up in excitement. “And I’m like a really energetic person, so sitting in a chair for forty minutes is not, what I like to do, I have like ADHD” (Interview, 5/13/16). She typically sat in front of the classroom on the right hand side. Zara said she liked being interviewed and that she felt like she was on a talk show.

Zara described the integrated STEM approach in the following manner: “It’s very different than what is was last year. Like, the setup from other schools, because I like moved a lot” (Interview, 5/13/16). She added, “And this team, I really like how, they just make you feel as though you can know what you are doing and it’s, I probably would not want to switch teams” (Interview, 5/13/16). She brought up how the team curriculum contained practical applications: “We’ll be learning about something that will connect to life, you know, outside of school” (Interview, 5/13/16).

Zara elaborated on challenges she faced as a student with ADHD, “it gets overwhelming, you’re super hyper, you can’t sit in your chair for forty minutes. You know, sometimes, you get like, really bored and you are not even paying attention…but I don't think it's really the orange team or the blue team, I think it's the setup in general" (Interview, 5/13/16).

Lee

Lee was medium build, white with bright red hair and a light, shaggy facial hair. During the interview he crossed his arms and hugged his sides. He paused between responses for several seconds at a time. Lee pronounced "r" as "w," which was most detectable in the second portions of words.

Jeremy's homeroom (which Lee was a part of) competed against the other homerooms as part of a penny boat float challenge. The activity centered on the construction of a small vessel made from Aluminum foil as an application of the concepts of buoyancy and density. The students dropped pennies on the boat until it sunk. The team with the boat holding the most pennies won the challenge. On the day of the interview, Lee's aluminum boat held the most pennies during experimental trials in Jeremy's homeroom. He stood in front of his peers as they all counted aloud each time he dropped a penny in the aluminum foil boat. When the boat held around ninety pennies, Jeremy's homeroom started to chant, "Lee, Lee." His boat beat out the other students' groups. When Lee won he yelled loudly and beat his chest multiple times with close-fisted hands.

Following the penny boat float challenge, Jeremy informed me that Lee spent some of his study hall periods in the resource room and led me there. Jeremy remarked that I should interview him while his "emotions are high." Jeremy led me down the Atrium and towards the gym locker room. We passed a display case with trophies. On the right hand was the resource room where a large floor fan ran on high. Sam Perry sat at a desk to the right of the entrance. There were at most fifteen desks in the room, which was not much bigger than a bedroom, maybe fifteen feet by fifteen feet. There were only boys in the room. I found Aaron also present. All students worked independently and quietly when I entered.

Lee also pointed out that he was also a member of the seventh grade integrated STEM team. He explained the “the respect that was demonstrated on this team is unparalleled to what I experienced in sixth grade” (Interview, 6/15/16). He developed a strong bond with special education teacher, Sam Perry over the course of the school year. Mr. Perry propositioned Lee that if he received a one hundred on a unit test he would give him ten dollars. Lee scored one hundred on five out of the six consecutive tests and proudly reported a math average of 100.2. He described this bet as a “catalyst” to pursue future aspirations. He planned on taking AP courses in high school and attending John Hopkins upon graduation.

Hank

Hank’s hair was short, almost a buzz cut. He was white with dark eyes and dark hair. When Annie noticed I interviewed Hank she remarked, “Oh, good. He’s a good kid.” In the exchange below, Hank recounted his experience on the orange team.

> Meg: How do you feel about the year so far?
>
> Hank: Um, it’s been a lot funner, I don’t care that funner is not a word (smiles).
>
> Meg: (Laughs)
>
> Hank: (smiles) It’s been a lot funner than um, than previous years in school.

Hank explained science instruction as compared to prior years:

> It’s definitely different. But I like it different because the way he um, Mr. Ford teaches, it’s just so hands-on. He wants to make sure we are paying attention so that’s why he does the little gags and all that so that it keeps us, it keeps us, fully aware of what’s happening (Interview, 5/5/16).

Sarah

Sarah was white with dirty blonde hair cut to her shoulders. Her nails appeared to be acrylic with white tips. Jeremy believed she would be interesting to interview and thought she would provide honest feedback. He mentioned afterwards that Sarah is not the strongest student academically. However, Sarah viewed her academic ability differently than Jeremy. She recounted an interaction with her mother where she mentioned an interest in becoming a cosmetologist. “My mom was like, ‘you’re a little bit too smart to be doing those kinds of things,’ and I was like, ‘Yeah.’ I might want to be a researcher, it all depends” (Interview, 4/15/16).

She also was part of the seventh grade version of integrated STEM and reflected on the experience in the following way:

> Sarah: I was feel like people learn better too, with the STEAM thing. Cuz it’s more hands-on. And, yes, there still is, like, sitting down work, but it’s better. I’ve gone to seven different schools, so, I think this one’s the best.
>
> Meg: What does that mean? The STEAM team?
>
> Sarah: Science, engineering, science, technology, engineering and mathematics. So mostly it’s we do a lot of projects, it’s pretty, you just learn better that way, you’re just doing more stuff. Instead of just sitting there reading a textbook (Interview, 4/15/16).

Frannie

Frannie had pale skin, brown eyes, and a metal band around her top teeth. During a web-based game in science to review physical and chemical properties, she scored the highest in her class. Her team, along with Caiden, also won the class vote for best energy project on the last day of classes. I had no real knowledge of her actual grades, but believed she performed well in school. Frannie found it impressive that some content for the year was advanced, “He [Mr. Ford] says we learn at college level, which is really cool” (Interview, 6/15/16). She described this integrated STEM model as, “unorganized but in a GOOD way. Because you never know what class you have” (Interview, 6/15/16).

Frannie articulated clear academic goals for herself: “I want to be like tenth in my class, or in the top ten.” In order to achieve these goals she explained, “I try to just work on my own stuff and do, like, I have my own goals, I do me (smiles), nobody else (Interview, 6/15/16). She adapted to the orange team to the point where it felt normal to her: “I don’t know, now that you say that, it’s just like, ‘the orange team’, I’ve just been used to it, so I haven’t thought about it” (Interview, 6/15/16).

Caiden

Caiden was also white and had brown hair parted to the right several inches in length, just covering his ears. I noticed Caiden on the first day of my entry into the study site as he threw a small orange ball with a friend in Calvin’s room during a free period. He frequently offered to present in the large group setting and tapped Hank’s head during our interview. Both Annie and Jeremy showed hesitance with my decision to interview Caiden because they said he often had responses that were “off base.” During special orange team events, media for interviews often approached Caiden. When I asked him to speak with me he expressed the desire to miss some of his next period ELA class. He explained the orange team as, “basically like group stuff, based on like group work and project based learning versus independent projects, labs, stuff like that” (Interview, 5/5/16). Caiden also enjoyed STEM subjects and envisioned a career in this field: “Oh yeah, one hundred percent. Science, math. Definitely somethin’ in the medical field, that I want to go into” (Interview, 5/5/16).

A majority of the randomly selected students interviewed as part of this study previously participated in the seventh grade version of integrated STEM. It is most likely that a parent or guardian advocated for their participation in their eighth grade year. “My mom recommended it this year because she liked how it was last year,” said Zara. The focal students overall spoke positively about the integrated STEM model. In particular they enjoyed the project based learning aspects and use of technology. Almost all of the students interviewed mentioned that they considered pursuing a STEM focused career. One aspect that all student participants cited as a challenging was peer interaction, especially engagement with students they did not know well. Jeremy commented on his students during the professional development session in the following manner: “What do you think our kids are? Some random kids that are just awesome, no. There are good kids and bad kids, there are no bad kids (hunches and says quietly). Ah, we make it work (PD event, 5/10/16).

Overall, students felt that the integrated STEM model presented content with sufficient level of cognitive challenge. Zara believed that the content covered seemed easier because of the amount of teacher supports in place. Lee also identified caring attitudes of teachers as contributing to his success. The students considered topics like nanotechnology to be high interest. Student frequently referred to this model as “hands-on” and enjoyed participation in projects that created some form of final product such as an insulated ice-box or rubber band powered car.

In order for students to identify as STEM learners they need “positive self-efficacy and attitudes toward math and science” (Rice, Barth, Guadagno, Smith & McCallum, 2013, p. 1037). Stevens, Olivarez, Lan, and Tallent-Runnels (2004) describe self-efficacy as follows, “When confronted with specific tasks, individuals use a self-referent process to judge their ability to self-regulate and succeed in the activity" (p. 209). Self-efficacy is connected to other affective factors such as confidence and motivation that also impact learning. Cribbs, Hazari, Sonnert, & Sadleret (2015) claim "the more strongly students believe in their ability to understand and do mathematics, the more likely they are to be interested in mathematics" (p. 1058). STEM interest and perceptions of ability are intermingled. While some focus students struggled in prior years, they all reported positive attitudes towards learning within this context. A majority of the focus students mentioned personal academic success through participation in the orange team. From the student perspective, the instructional practices encouraged the development of STEM identities.

Research Question 1a: In what ways do teacher participants characterize the integrated STEM model?

Characterization of the model

Instruction involved both multi-subject areas lessons as well as episodes of stand-alone instruction where one subject area was the focus. The team constantly maintained communication to align instructional goals and offer complementary instruction. Instructional periods varied from day to day. This model included a professional support network comprised of subject-area teachers, one special education teacher, and one assistant.

The district website posted the following description of this team. Jeremy informed me that the team resisted this "STEAM team" label.

What is S.T.E.A.M Education?

An Integrated Approach to Teaching:

S	Physical and Social **SCIENCES**
T	Incorporation of **TECHNOLOGY**
E	Principles of **ENGINEERING** and Design
A	English Language and Fine **ARTS**
M	Application of **MATHEMATICS**

Figure 5: STEAM components

Jeremy conveyed from our first interactions that the team now identified as “orange.” The team cited two reasons for the new distinction. The first is that the team found that labels felt limiting. “People think we are one hundred percent project based and we’re NOT” (Annie, Interview, 5/4/16). The team relied on a variety of approaches and believed that one label was insufficient to describe their teaching. The second reason that prompted the change related to feelings of division within the school community.

> We never wanted to be called STEAM. We knew that the name had the potential to polarize and we never wanted to polarize people. What we set out to do was have a team and plan together. That is all the model really is, just, planning together. Take advantage of the flexibilities you have together as opposed to doing it separately (Jeremy, interview, 6/21/16).

“We use a flexible dynamic six grouping model,” he explained. “This is an essential piece of our model. It allows us to use time really efficiently. Ideally, the number of minutes is maximized” (PD event, 5/10/16). Jeremy emphasized the efficiency of whole group instruction to transfer information such as project guidelines, group presentations, or laboratory demonstrations. For instance, Jeremy organized a Skype session with partners from NASA each year as part of a Mars rover project. The team found it easier to organize special sessions with outside presenters by gathering the entire group of teachers and students. Teacher participants mentioned on multiple occasions that they valued time efficiency. Adapting a forty-minute bell schedule to a new flexible scheduling system resounded as a critical shift in practice. It was brought up thirty different times during interviews, second only to the topic of project based learning approaches. The teachers refused to name this integrated STEM model after any particular approach: “I think a lot of people have the perception that we are just one hundred percent, problem based, and, we’re NOT” (Annie, interview, 5/19/16). The team resisted any formal label of their work, deeming them not a true reflection of their practice. Their explanations of the model varied in focus. Jeremy tended to explain this model as a collaborative endeavor that actively restructures time.

Jeremy and Annie identified several major challenges associated with implementation of the model. Jeremy mentioned the following potential constraints on a power point slide during a professional development (PD) he facilitated: (1) Traditional school day and time, (2) State standards /local curriculum, (3) Departmental benchmarks, (4) Limited space/staffing/class size, (5) School culture and (6) There are 1,000 reasons why this won’t work! “We don’t live in some utopia where we just sit on the floor and are like, ‘Om’, it works, it’s wonderful, we have culture” (PD event, 5/10/16).

In order to resist traditional teaching, Jeremy named status quo school norms during professional development sessions. His notions of traditional were divided into physical spaces, schooling practices, and schooling organization. Physical space was referred to four-walled classrooms and hallways. He noted that each space had a clearly demarcated purpose associated with it. For instance, teaching only occurred in classroom spaces. Schooling practices that were considered traditional emphasized test preparation for local, state, and national assessments. Jeremy perceived the organization of a 180-day, ten periods, and forty-minute lesson school schedule as another notable aspect of traditional schooling.

Jeremy discussed how their team has circumvented these barriers. Teachers modified instruction and environmental parameters to most closely meet the needs of students. While the school day still contained hard start and stop times, the time allocated to core content area classes was be altered to best fit the needs of learning goals. The teachers negotiated time by the group on an ongoing basis so that the teaching time fits the need for the activity. Teachers adhered closely to state learning standards. Jeremy posted a piece of paper near his desk that has every content-area learning objective, nearly sixty in total. He kept track of his progress making to ensure that students felt prepared for the state test in the spring. Departmental benchmarks do not seem as stringent for science and social studies but are areas of concern for ELA and math. Jeremy asked Annie explicitly during the PD event presentation whether she adhered to department objectives. She nodded her head to affirm that she did in fact strictly follow national, state, and departmental expectations. Jeremy and the team definitely elaborated on the limitations of space but seem relatively satisfied with the staff supports in place. This included a full-time teaching assistant and special education teacher that worked only with the team. Staffing only seemed problematic when it came to providing special education services. Sam explained, "it was frustrating cuz I wanted to be there the whole time" (Interview, 4/8/16). Depending on the number of students with disability labels assigned to the team, staffing supports fluctuated. Sam stated that there was a "mixture" of students with special needs labels currently on the team. The district initially hired Sam to provide additional services because one special education teacher did not sufficiently serve this population. The team also articulated the creative uses of space. The auditorium was viewed as a whole group instruction venue. Hallways were transformed into break out spaces for student groups. The elements of this integrated STEM model mentioned directly by teacher participants will be further detailed to address research question two. Diverse arrays of pedagogies were combined during science teaching in a purposeful way. Jeremy added that the team only combined disciplines at intersections that prove beneficial for student understanding.

On the last day of school, Deb created a slide show presentation that represented experiences from the year. The slide show projected 17 different images, viewing each for a total of three seconds before moving on to the next. In the background was contemporary music, like the kind you would hear on a latest hits radio station. Seven of these slides contained students engaging in some form of science instruction. The first image contained students working on a kite-making project. A group of students are standing in the Flex classroom. There are three brown triangles suspended from the ceiling. 11 students are standing in a row in the center of the classroom with their hands out, holding each other's hand. Jeremy is standing in the middle of the classroom, facing the students. His left arm is extended outward to the left. Two of the slides depicted students using technology, specifically Chromebooks. Three female students are standing in the pit in the auditorium facing the other students. They all have their Chromebooks out and are looking at the screens expressionless. Noel is in the background. Two slides referred to school community events such as "spirit week". On the top of the picture it says, "spirit week orange and blue". There are eight students in total, three boys, one student of Color. All wear their uniforms or orange/blue athletic clothes. They are posed in the picture in two lines, most of them are smiling and looking toward the camera. Evidence of science as valued subject area is noted in these visual displays. In all the images of science learning, students are engaged in some form of hands-on task. Also, of the images captured, students are working with other students. The role of technology, specifically, the use of laptop computer devices is also emphasized in this slide show. The community aspects of the team are also illuminated as part of this presentation. Student affiliations with school organizations are given importance. Many students express their team identity by wearing school shirts or the color orange. After the slide show, students loudly cheered from their auditorium seats. There response seemed to affirm Deb's interpretation of the year while also acting as an expression of appreciation.

From a system perspective, I developed a visual to help illuminate the interactions between disciplines and teachers. From interviews and observations, I found that science seemed to anchor many of the multidisciplinary projects. Annie believed this was the case because students viewed science topics as high interest. Students and teachers often characterized Jeremy's personality as outgoing and he expressed willingness to speak on behalf of the team. Due to Jeremy's personality and team roles, science acted as a predominate part of this model. The technology integration component of the model pervaded all classrooms through the use of Chromebooks and a wide array of digital sources and software. However, there was no single teacher that explicitly taught this form of technology. It was visually depicted as a series of dots that connect with all subject areas. Engineering is represented by a lower case e because of inconsistent integration. The orange team typically combined engineering design science instruction once a month often in the form of multiple day project-based learning challenges. These design challenges served to connect teachers and students and generate interest in science topics through hands-on application. The A of the model refers to the "arts" and both English language arts (ELA) and social studies are housed under this label. It is represented above as a capital because of the amount of time committed as well as its strong bond with science teaching. For instance, Jeremy was covering the idea of elements versus compounds. Students were talking about Hydrogen as a pure element. Jeremy said, “Do you remember the Hindenburg?” and many students nodded their heads in recognition. Calvin situated science content within historical and socio-cultural contexts, “When in history and when in our community were those things are used” (Calvin, interview, 4/5/16). Reading and writing were considered by the teachers to be foundational skills to be able to inquire about the world and communicate ideas to others. Math is also represented with a capital “M” because of the amount of attention it demanded. Annie expressed feelings of isolation from the other team members.

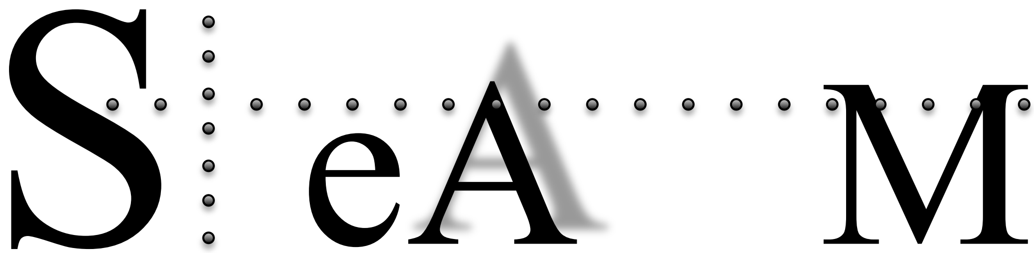

Figure 6: Integrated STEM model representation

Research Question 2: What are the experiences that comprise the integrated STEM curriculum and instructional model?

Element of experience 1: Project based learning

"I REALLY, really, liked the rover project." (Sarah, 4/15/16).

During interviews, teachers and students alike frequently mentioned project-based learning experiences. Participants found projects to be the most memorable aspects of the orange team, especially those that included all content areas. Teacher participants all mentioned the Mars rover project when prompted to describe project-based learning and offer examples. This project involved the manipulation of Lego robotics to create a structure with a parachute to drop a model rover. The team website depicted the project in the following passage: 'Students work in teams to design, construct and deploy ROVERS that land on a simulated Martian surface, navigate to an area of interest and collect a variety of data on a rock specimen. Once deployed, the only interaction between the ROVER and Mission Control is data sent back via live feeds from on-board cameras and instruments" (retrieved from the team website, 3/21/17).

Sarah, John, and Hank all cited this project as a favorite of the entire year: "We had to a make ah, computer program, we made like a whole Lego thing move" (Sarah, 4/15/16). While the project presented obvious connections with science and technology, social studies supported design efforts through historical contextualization. Calvin taught concurrent lessons on imperialism and US expansion. He asked, "Well why are we going to Mars? For the same reasons that we went to the Spanish American War" (Interview, 5/31/16). Teachers found projects to be enjoyable but also a challenge to execute with appropriate level of rigor and a balance of student accountability and evaluation. Annie reflected on this challenge, "We had some good projects in the beginning, some fun projects, but not necessarily really hitting on the priority standards in the curriculum, and focusing on the things that were taught in the curriculum, our goal, and our shift right now is now to align our projects with our curriculum and making it meaningful and rigorous for everybody" (Interview, 4/5/16).

Team-maintained Twitter feeds provided glimpse into project roll-out, progress, accountability, and final outcomes. Below is an example of Jeremy's Tweets related to the Mars rover project spanning from February 9 to March 1. February 9th marked the project roll-out event where students gained familiarity with the materials and programming software necessary to complete learning tasks.

Figure 7: Mars Rover project

Jeremy then tweeted a video on February 10, 2016 that showed how the project is launched and the background information provided for students in order for them to work independently.

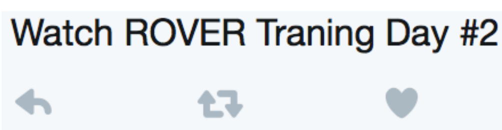

Figure 8: Tweet

On February 25th and 26th Jeremy offered public updates on phase II and III of the project.

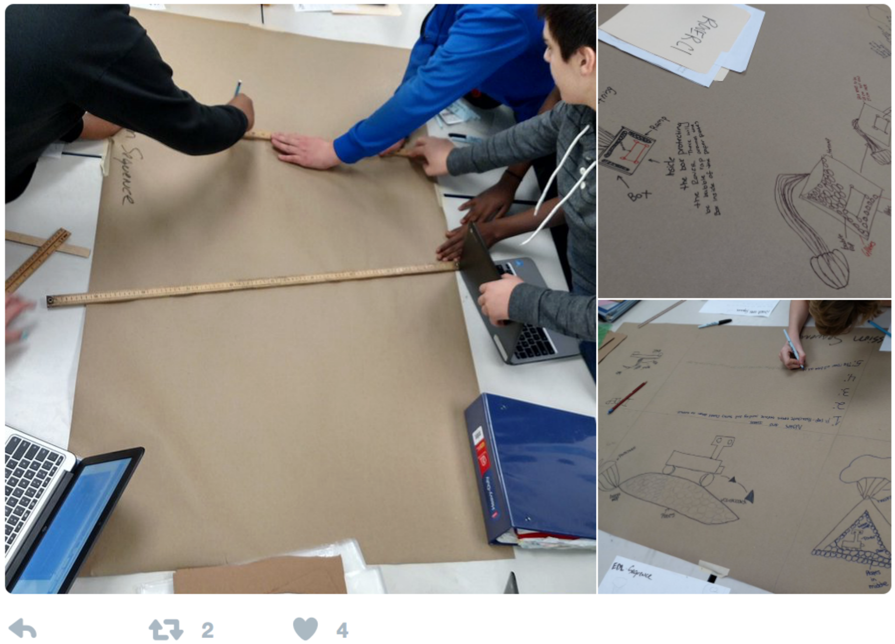

Figure 9: Twitter post of phase II and III of the Mars rover project

Figure 10: Twitter post of phase II and III of the Mars rover project

Jeremy also posted a link to the working document that framed the learning tasks, differentiates roles, and provided a record of accountability.

Mission to Mars: ROV Status

STUDENT ROLES:

1. ROV Programmer - Creates, develops, stores, uploads, manages files on ROV-CPU
2. Drive Engineer - Designs and builds structures that support LAS, MFO and CorNav operations.
3. Payload Specialist - Develops and builds structures that secure and deploy HabMods on Martian surface.

ROV	Landing Apparatus Separation (LAS)			Magnetic Field Orientation (MFO)			Course Navigation		Habitation Module Deployment			*ALL SYSTEMS
	Built	Program	Tested	Built	Program	Tested	Program	Tested	Built	Program	Tested	TEST
1				X	x	x	x		X	x		
2				x	x	x	x		x	x		
3	x			x	x	x	x		x	x		
4				X	x	x	x		X	x		
5	x			x	x	x			x			
6				x	x	x	X	X	x	x	X	
7	x			x	x	x	x		X	X		
8	x			X	x	x	x		x	x	X	

***Once ALL systems are running in sequences, ROV Team can integrate testing with Entry, Descent and Landing (ELD).**

Table 5: Mission to Mars

Beginning on March 1, 2016 students started the process of testing their rover creation based on the simulated mission crafted by the teachers.

Mission to Mars Project Construction Day 2: Test and Improve! #pbl #stem

Figure 11: Twitter post from Mars rover project

Finally, student projects were ready for the final round of testing.

Figure 12: Twitter post of final Mars rover products

Students also video conferenced with NASA representatives and interviewed professional engineers.

While the Mars rover project launched in the beginning of the school year, the team closed with a culminating energy project that also incorporated hands-on instructional elements and cross-content connections. Jeremy thought of the energy project as the end of the year "swan song". Jeremy described the project in the following passage:

> Our final large project is the interaction between the [Elm Tree 8th grade] Laboratories and We Built This City. That's where it's no longer viable to purchase electricity from neighboring municipalities, so Elm Tree Laboratories creates action teams that look at hydroelectricity, solar, nuclear power and then brings that to a vote for We Built This City. We have a division of the team focused on We Built This City media. They're constantly reporting on the dynamics of this as it plays out and as the government starts looking at codes and regulations. We have an elected government and it's really the play

> between those different entities that gives rise to a final vote, which is the town hall meeting (newspaper article, 3/24/13).

The energy project created hypothetical tension between business demands such as profits and personal needs at home like a clean drinking water.

Annie mentioned that whole-team projects that featured science content tended to be better received by students. Integrated STEM projects involved all teachers and students to design and create a product or solution to a real-world scenario. The team covered content from all major content areas, infused technology, and used a variety of school spaces during episodes of project-based learning.

> Annie: We had some strong ones (projects), that, the rover project and the a, the a science energy project at the end of the year those two projects have been solid straight from the beginning, we modify them every year but they have been pretty solid. Um, we are finding that the science based ideas, are really, are carrying us to better quality.
>
> Meg: Good, can you tell me more about why the science projects are considered higher quality? Compared to that first (project)?
>
> Annie: I think we have, um, better buy-in by the kids (Interview, 4/5/16).

Engineering design-based science has no single prescribed method of instruction. Often project based learning is incorporated to address science and its engineering applications. The orange team used project based learning approaches on a consistent basis to build real world relevance and heighten student interest. Dewey (1913) defined the concept of interest as “a name for the fact that a course of action, an occupation, or pursuit absorbs the powers of an individual thorough going way” (p. 65). Dewey categorized interest using the following indicators: dynamic nature, personal meaning, and object related (Guzey, Moore, & Morse, 2016). Each orange team design challenge offered students a different way to engage with engineering content. Each student attached personal meaning through responsibility to a specific project role. Students also were expected to present their products and publicly evaluate its performance. Dewey theorized that interest stemmed from the assignment of worth to a particular object. The design challenges associated with this integrated STEM model centered on the development of a particular product. Products ranged from an insulated icebox to a Lego robot programmed to perform a particular task. As supported by Dewey's early assertions, students felt a strong investment in the project because of the creation of tangible objects.

Prior research, while still scant in this field, also reveals a connection between engineering based instructional strategies and student interest. Bolte, Streller, and Hofstein (2013) investigated connections between student interest and chemistry. Bolte et al. (2013) offered three key recommendations for science teachers striving to enhance student interest in the classroom. First, teachers should leverage socio-scientific issues, or areas of current debate among scientists, when presenting content. Second, teachers need to combine a wide array of pedagogical approaches to address scientific topics. Third, individual creativity should be encouraged as part of the learning process. The project based learning tasks conducted by the orange team exemplified high interest teaching. Students were challenged to think about open-ended and controversial topics. For instance, classroom discussions talked about the potential negative consequences of space exploration. Students were challenged to think about how scientific knowledge could be capitalized for the benefit of the private sector. They also discussed the potentially harmful effects of the introduction of Earth pathogens to other planets. Pedagogical approaches varied greatly depending on the particular learning task. Student grouping was dynamic in nature, tasks included manipulating physical objects as well as software, and content was conveyed through a mix of media, lecture, and discussion. Creativity and ingenuity was openly celebrated during weekly class meetings. Students were encouraged to explore multiple pathways to solve problems.

Research also suggests that design challenges are best integrated in direct connection with science principles. Jeremy taught heat transfer principles in tandem with the construction of insulating ice-boxes. Guzey et al. (2016) also found that integration of science and engineering was most effective when explicit connections where drawn between the two. “Instead of the engineering just being an add-on to the science, the two subjects were necessary to each other for this activity” (Guzey et al., 2016, p. 417). The orange team project based approach used both engineering and science concept to enhance student understanding. Dewey (1913) cautioned that if adding interest could potentially distract from the content being taught. The orange team did admit they initially struggled to balance academic rigor with incorporation of high interest activities. By reflecting on their practice as a team they refined their curriculum to meet academic goals while also “catching and holding” student interest (Mitchell, 1993).

The use of engineering based science instruction is gaining popularity and legitimatization under the NGSS. Project based learning tasks help to unify science knowledge and engineering practices. During project time, students were presented with a problem that leveraged multiple content area disciplines simultaneously. Content bundled together in an integrative package that is more indicative of the real world. When we engage in the world we do not separate knowledge based on subject area. We synthesize science, math, engineering, and a host of other contents to solve authentic problems and communicate our solution to others. Project-based learning allows students to more readily assimilate science knowledge. Socially constructed disciplines are blurred during these projects that offer space and time for diversity in thought and problem solving approach.

Element of experience 2: Flexible scheduling

"Every day is different, of course" (Deb, interview, 4/6/16).

The team developed their own adaptation of a standard nine period schedule by combining the instructional minutes for all content areas. Below contrasts the traditional bell schedule at the school and the schedule that the team created. The two large blocks of time, one in the morning and one in the afternoon, represented the common instructional minutes that the team shared. The available spaces are also noted. The team distributed instruction minutes and spaces in unique formations on a daily basis to address specific learning goals: "When you own those rosters and own those times you can again start playing with these rosters and time. So we chose a place where we have control and could lift those constraints very easily" (Jeremy, PD event, 5/10/16).

Traditional Schedule		**Dynamic Schedule**
1	Physical education	
2	Social Studies	83 minute period, 101 students 4 rooms, 7 teachers, auditorium and atrium
3	Writing	
4	Art	
5	Lunch	
6	Foreign Language	
7	Science	128 minutes, 101 students 4 rooms, 7 teachers, auditorium and atrium
8	Math	
9	Literature	

Table 6: Comparisons of traditional instructional periods with a flexible schedule

Teachers viewed flexible scheduling as a means to facilitate dynamic instruction. Sam said, "I think, in my mind it all goes back to the flexible scheduling" (Sam, interview, 6/8/16). Annie explained, "It's the flexible scheduling that allows us to work within the classroom and work with other content areas across the curriculum."

During the professional development session Jeremy explicitly named the model as being "a flexible dynamic six grouping model." He explained how the model operates in the following passage:

> So we chose a place where we have control and could lift those constraints very easily. So, in a nutshell, for our implementation. We have all of our kids, all of our teachers and all of our spaces. So what can we do? First thing we can do is arrange the kids anyway we want. I have one period [in the morning], it's eighty minutes long. I have a class in the afternoon that is one hundred and twenty six minutes long. Ah, how do we schedule it? Any way we want (Jeremy, PD event, 5/10/16).

This component of the integrated STEM model is "completely homegrown" and therefore "gets a lot of attention from the outside," according the Jeremy (Interview, 6/21/16). Since the team internally created flexible schedules there is a particular sense of pride associated with that aspect of the model. The leadership allowed the orange team teachers to reformulate the traditional bell schedule as long as the team met state guidelines for instructional contact. Jeremy referred to this freedom to adjust the schedule as "peeling away the constraints," meaning that the district provided a supportive climate allowed for innovation. The superintendent affirmed this stance in the following comment made during a PD session, "We stay focused on student learning, we [provide] permission, support, and protection" (Dina, 5/10/16).

The team devised multiple schedule variations that were difficult for an outsider to fully comprehend. The teachers referred to each schedule with a term they created such as "B-52s" or "Oldfield on the block." During my time at the study site, I noted nine different schedule variations put into practice. The orange team of teachers developed a set of terms that are specific to the flexible scheduling process that they use adeptly to describe versions of time allotments. The classroom logos are depicted at the top while the grouping configuration is listed using letters. Teachers grouped students either homogenously or heterogeneously based on their perceived ability. Four sections (A, B, C, D) indicated homogeneous grouping and three sections (A, B, C) signaled heterogeneously grouping. Jeremy said, "No matter how heterogeneous we try to be we're still driven by services, B in ELA and math. So that's gonna skew it" (Jeremy, observation, 4/15/16). Jeremy referred to the need for special education services for some students in the areas of ELA and math. These services dictated the composition of groups and teachers involved. The groups changed at least once every ten-week period. The X in the schedule was an opening for that teacher to co-teach with the others. The thick black bars connoted periods of common plan time or lunch. "Morning meeting plus five" referred to a whole group morning session followed by traditional 35 minute content area courses (see Figure 13). Jeremy described the current scheduling practices in place:

> Flexing our schedule pretty regularly, not as creatively as we'd like but we've allowed for um, morning meetings to take place every Monday. We have, um, opportunities for large group instruction that we take advantage of, I say, (2 second pause) honestly, once or twice a week we are able to do those types of things, um, we've done, it's kind of ebbed and flowed (Interview, 4/5/16).

Morning Meeting

(Matrix 5A)

	L	ARCHIVES	Think Tank	FLEX	HUB
8:55	Morning Meeting				
9:30	X	D	C	A	B
10:05	B	X	D	C	A
12:23	B	X	D	C	A
12:48	A	B	X	D	C
1:22	C	A	B	X	D
1:56	D	C	A	B	X

Figure 13: Schedule the features all-team meeting

Another common schedule used by the group was referred to as “co-slide.” This is the most traditional iteration where students attended separate content area classes. Again, the X is a period the teachers used as a collaborative opportunity rather than a free period. Teachers did not take advantage of “free” periods during instructional periods. Instead they observed each other’s practice— Jeremy stressed that teachers visit each other’s classrooms on a daily basis. Jeremy noted the benefits of supporting each other’s teaching. He used Noel’s support of the electromagnetic spectrum project as an example, “It’s still pretty cool nonetheless because even if she’s not here she knows what’s going on so she becomes another resource …now she is embedded in the project” (Observation, 4/15/16).

The drop-in visits by other team members ranged from formal co-teaching sessions, deliberate in nature, to brief check-ins. Out of thirty lessons extensively analyzed, 18 of these instructional periods involved the presence of two or more teachers in the classroom. Jeremy described the interactions between teachers during “free” periods as follows:

And it's not a big spectacle, but if you go to another, that's different. The fact that a math teacher is there. It's funny we do big things and have people in for learning tours. They are more interested with these interactions then, like, the big projects. We'll just go into each other's classes cuz we flipped and brought her out. She was doing something else but now she's free, so, its the common expectation when your free, so what's everybody doing? So when your free then you kind of just slide in, so..It's very informal a lot of the times (Observation, 4/15/16).

CoSlide A

(Matrix 5A)

	I L	ARCHIVES	Think Tank	FLEX	HUB
Period 2	X	D	C	A	B
Period 3	B	X	D	C	A
Period 7	A	B	X	D	C
Period 8	C	A	B	X	D
Period 9	D	C	A	B	X

Figure 14: Most common schedule variation

Another version of the schedule that appeared with some frequency was the project-based schedule. During projects or design challenges, time was allotted for group activities at the very end of the day. In the figure below project time is referred to as homeroom. In the figure above, teachers staggered the free period X to increase the amount of teacher interaction in each other's classrooms. In the schedule below the X is located in one column. Jeremy used this opportunity to spend the entire day in other classrooms to support the roll out of the project. (see Figure 14).

8:08-8:12	HOMEROOM				
Period 1	OFF TEAM				
Period 2	B KEEP IT COOL	A KEEP IT COOL	C KEEP IT COOL	D KEEP IT COOL	X
Period 3	B	X	C	A	D
Period 4	LUNCH				
Period 5	OFF TEAM				
Period 6	OFF TEAM				
Period 7	C	X	D	B	A
Period 8	D	X	A	C	B
Period 9	A	X	B	D	C
2:30-2:34	HOMEROOM				

Figure 15: Schedule with built in project time

Once Jeremy broke down the structure of the scheduling during the professional development session, he then mentioned the benefits of such instruction on student learning. He emphasized the instructional freedom experienced through the use of schedule variations.

> It allows you teach really efficiently… It can set the stage for co-teaching, transdisciplinary teaching and stuff like that…It just unlocked a ton of possibilities as to how we group kids" (PD event, 5/10/16).

Students found aspects of the flexible schedule model frustrating. Lee described the schedule structure in the following manner: "Not knowing what class you are going to and walking into that door, it's frightening" (Interview, 6/15/16). Hank found the completion of homework to be confusing due to the frequent changes in schedule, "I never know, like, what I have to prepare for" (Interview, 6/5/16). Frannie notified me that she would change "the ten-minute classes." She elaborated, "I understand that it can tie up loose ends and all, but to me it just seems pointless to sit in a class for five minutes when you could be learning something else, like, do twenty minute classes. Or fifteen minutes" (6/15/16).

Jeremy represented the process of schedule creation in the following passage:

> … I've spent a lot of, a lot of my planning time, ah, talking with, either the group or individuals on the team with what they need to happen from a time standpoint, because I kind of get a say in the sense I'm the one that puts it on paper, my opinion doesn't need to get voiced because it's by design. I constantly have to have that barometer out of what people need, where people are and then make suggestions and accommodate all those needs. And address people's frustrations you can do a lot with the scheduling. You can tell when people are overwhelmed or feel like something isn't fair. Or they are doing, or if they are feeling disconnected. I can make a schedule that makes them feel more connected or allows them to do something else, take the pressure off of them, give them more time or less time depending on what they need (Interview, 4/5/16).

There were many taken for granted aspects of scheduling as part of this model. The teachers used insider terms to refer to the various types of schedules. Jeremy would ask nonchalantly ask the others, "So do you want a co-slide for tomorrow?" Others responded accordingly with full recognition. The flexible scheduling theme was prevalent through all interview data sets. While the team openly denounced the project-based label, they seemed to invite descriptors that related to flexible scheduling. The team created this scheduling approach independently and expressed pride with regard to its creation.

Element of experience 3: Co-teaching

"We just take a look at what part of this experience is gonna be connected to my class. Then we all look at that" (Calvin, Interview, 5/31/16).

To better understand how the team created co-teaching experiences, I recorded and analyzed over 1,300 minutes of recorded observations as part of an event map of classroom activity. I gained a more global understanding of content area covered, teacher participation, learning activities as well. Below is an example of one science focused lesson.

Topic	**Group**	**Collaborators**	**Time**	**Activities**
Doppler effect	B	Jeremy, Deb	1:00	Review of wave frequencies on EMS, J asks student to connect this material with concepts from a unit on sound
	B	Jeremy, Deb	1:10	Students ask a number of questions related to pitch and volume
	B	Jeremy, Deb	1:15	Deb plays a pitch oscillator on her phone to compare various levels.
	B	Jeremy, Deb	1:20	Students make a representation of Doppler effect in an online journal.
	B	Jeremy, Deb	1:25	Students are able to ask a number of questions related to pitch and volume.
	B	Jeremy, Deb	1:28	J challenges students to think about what happens if a car travels the same speed of sound

Table 7: Event map example

I found that whole group instruction with all content area teachers present represented 30% of the total recorded classroom footage. Science instruction with only Jeremy and Deb present totaled 35% of these observations. The remaining time divided among an array of teacher groupings.

Co-teaching combinations	**Number of times the combination appeared**
Science, TA	93
Science, TA, Math	10
ELA, Special Education	6
Social Studies, TA	8
Social Studies, TA, Science	13
Science	4
Science, ELA	31
Science, ELA, Math	20
Science, Math	1
Science, Math, Social Studies, TA, ELA, Special Education, ELA	69

Co-teaching combinations	**Number of instructional minutes**
Science, TA	483
Science, TA, Math	83
ELA, Special Education	20
Social Studies, TA	28
Social Studies, TA, Science	63
Science	14
Science, ELA	144
Science, ELA, Math	45
Science, Math	83
Science, Math, Social Studies, TA, ELA, Special Education, ELA	420

Table 8: Co-teaching combinations and time dedicated for instruction

Based on observations, this integrated STEM approach balanced content area instruction with integration of other disciplines. The team incorporated significant opportunities to engage with one another. Whole group instruction was a normal practice carried out on a consistent basis.

Zara explained teacher collaboration from the student perspective in the following passage:

> Sometimes the teachers will teach together, like Mr. Ford and Mr. Mitchell teach, ah, science and social studies. We did something where we worked on little Lego robots and programed them, they worked on that together. The ELA teachers work on stuff together. Mr. Ford and Mrs. Oldfield sometimes they work on stuff together because science and math are kind of related. Um, when we did our Isaac Newton unit we kind of learned about it in every, you know, in like, in history, because you know we learned about it, science you know. We learned about it in like, every class (Interview, 5/13/16).

During the month of May in 2016, the science and math teachers collaborated to develop an open-ended learning task that addressed both content-area standards. I used this co-teaching occasion as an example of how teachers collectively conveyed curriculum. Teachers posed the question to students, how many standard sized marbles will fit in the Think Tank classroom? This lesson served as one example of how the team attempted to bring in real-world scenarios. The team provided students with simple instruments such as a ruler, a marble, and a calculator, and directed them to collaborate in groups of three to five to solve the question. To scaffold thinking in prior lessons, Jeremy took students on a scavenger hunt around the school to attempt to measure things that they could not touch, such as the school ceiling. Student groups wrote out their steps and submitted this information on the Google classroom platform for credit. To gain a total of two points, students outlined a series of logical steps used to solve the problem. The math teacher expressed to students that they gained partial credit for all attempted answers. Annie, Sam, and Jeremy worked independently to derive their own solutions.

Jeremy explained the math connections:

> The volume of more complex shapes happens in math and we never overlapped when we taught it. This year were kind of like, let's hop on it to co-teach it. So, um we kind of

divvyed up the task where Annie is talking about substitutions and process and then I'm talking about the ideas behind volume (Interview, 5/4/16).

On day two of the lesson, all students and staff assembled in the auditorium to discuss their results. Students were given fifteen minutes to meet with their groups to solidify their methods and polish their responses before a whole-group sharing opportunity. Jeremy addressed the entire study group.

> If you are finding it challenging, that's appropriate, because the three of us have been trying to solve the problem right along with you. The three of us [Annie, Sam, and Jeremy] are challenged by this problem and had to develop new methods to try to solve it. We didn't even know we're there (Observation, 5/5/16).

Once students completed the task, they volunteered to present their results to the entire group. Four white, male students walked up to the orchestra pit area of the stage to address the whole group. Caiden was first in line with a Chromebook in hand. The remaining students stood to his right in a straight line with their heads down. Caiden had on a black hooded sweatshirt and a white t-shirt on underneath. Hank was also in queue with an orange school T-shirt and a yellow plastic wristband.

> Student: So basically what we did first is we took the measurements of the room, um, to find volume (his hands are placed in the pockets of his sweatshirt and he looks downward).
>
> Caiden: Then we measured the ah, radius of the marble...There were tiles on the floor so, we were thinking, if you measured the tiles on the floor which are twelve inches, how many marbles can be in a room which is twelve inches, then we figured, we pulled, if we make a box, like this (touches the cube on the demonstration table), we fill it with

> marbles, we'd have eight thousand marbles in the box. Then, we figured the volume of the room is seven million, seven hundred and ninety seven inches or square feet and then you multiply that by the number of boxes and you get 62 million three hundred and eight two thousand marbles.

Only after students offered their solutions did the orange team teachers give their final answers. The teachers did, however, model their thinking throughout the multi-day learning event.

> We specifically (looks over at Annie and Sam) all had answers that were in the MILLIONS of marbles. So as you look at your answers. The responses that YOU have. Look at it, and look at the numbers that you see and say, 'Is our answer in the millions?' (Observation, 5/5/16).

Seven of nearly 100 students in the room raised their hands to signal that their answer was also in the millions of marbles range. Jeremy then asked of the seven students with raised hands how many of them calculated a result in the tens of thousands range. The seven students continued to extend their arms in agreement. These students were encouraged to come to the front of the group and share their results.

With Calvin, Noel, Terri, and Deb looking on, Jeremy, Annie, and Sam then shared their approaches and outcomes with the students.

> Jeremy: We got sixty three million. Doing it a completely different way, ah, we came up with an answer that is pretty much identical to yours [Caiden's group]. Ah, which I thought was pretty cool.

Jeremy demonstrated a way to measure the space between the marbles by pouring water into the clear 1000mL cube. Annie applauded the groups for obtaining similar results despite the use of different units. Caiden's group measured in feet while the second team that presented used centimeters as their primary unit of measurement. After 45 minutes the whole group portion of the lesson concluded and students were divided into four groups. One group headed back to the Think Tank to work with Jeremy and Annie. In the classroom, the two teachers organized a series of four stations set up for students to rotate through. Jeremy facilitated a lesson on density that involved the comparison of several cubes of different dimensions composed of various materials.

I interviewed two members of the first student group to present, Caiden and Hank, directly following the lesson to better understand the experience through the lens of the learner. Hank mentioned that the group made multiple attempts to achieve their final solution: "We took like three different approaches to it. But only one came out to give us, like the most reasonable answer" (interview, 5/5/16). He described the iterative process the group took in order to generate the most accurate answer:

> Hank: And um, apparently we were wrong, again.
>
> Meg: Ok, what went wrong at that point?
>
> Hank: Um, we didn't take into consideration, um, we used a tape measure to measure the length of the room, we laid it on the floor to keep it straight, we didn't take into consideration that the vent wasn't like completely flat to the wall (smiles).

Caiden's recollection of the experience focused mainly on the presentation stage of the lesson. He said, "I like presenting. Everyone likes me so I just kind of talk." A drawback that he sees from group work involves distribution of labor: "One person usually does ninety nine percent of the work and everybody else sits and watches and then takes credit for the work." This sentiment was incongruent with Hank's view: "We split up the jobs evenly and then we brought each other together and then distribute the information." However, Hank mentioned that Caiden was selected to present because he understood the solution best. "Caiden, he did most of the work" (interviews, 5/5/16). Caiden demonstrated leadership skills due to his ability to articulate to others a viable solution to the problem. For that reason, Caiden felt as though he takes on the majority of the work during group activities. As part of this integrated STEM model, students frequently engaged with others in group related learning activities. During student interviews, Caiden is the only participant that openly voiced his discontent with participation during group activities.

During this co-teaching episode, teachers expected that student methods and responses would vary. Measurement is a module that typically is taught in isolation with a focus on repetition of skills. The co-teach lesson completed by Annie and Jeremy served as a deviation from this traditional format. Jeremy acknowledged an internal struggle when the traditional measurement unit was not taught in the beginning of the year. Jeremy scaffolded instruction throughout the month of May so that students can first gain awareness on how to calculate volume and then mass. Students are then prepared to make density calculations. Jeremy did not focus purely on summations however. He attempted to improve student understanding of these concepts as well by representing them in multiple ways. When Annie solved the marble question she went "all math" while Jeremy applied principles such as displacement as part of his solution. The transparency in which this was conducted gave students an opportunity to see multiple pathways for solving mathematical computations reinforcing the value of creative thinking.

Math and science integration is most studied out of all permutations of STEM. Hurley (2001) conducted a meta-analysis of integrated science and math teaching. Hurley (2001) discovered three primary levels of integration: partial, enhanced, and total. Total integration involves a commitment by both science and math teachers to collaborate on every aspect of the lesson from planning to execution. The lesson segment from above exemplifies total integration because Jeremy and Annie designed and enacted instruction as a unified team. Hurley (2001) found that the benefits of total integration disproportionately favors science. According to Hurley (2001), math achievement tended to be optimized using the sequenced level of integration. Sequenced science and math instruction involves complimentary lesson planning and alternating instruction. This finding suggests that science and math co-teaching requires a balance between sequenced and total integration. Annie expressed difficulty in finding appropriate math connections during integrated activities. In this co-teaching instance, she refers to her solution as “all math” carving out a space to address her content in its pure form. Annie’s frustrations have been echoed in past studies of integrated STEM. Wang et al. (2011) also reported similar outcomes in research conducted on teacher perceptions of STEM integration. Math teacher participant, Nate, disclosed that he struggled to find places of mathematical connection with project-based approaches. He viewed mathematics only as a tool for application within other STEM contexts. He struggled to cover curriculum and fully participate in STEM integrated projects. Annie and Sam echoed this sentiment, concerned over the amount of content to cover in math. Legislation, such as NCLB, created an era within education that is fixated on standardized testing outcomes (NRC, 2014). Math took the brunt of the attention because of its quantifiable nature and perceived importance in future national economic security. National and state evaluations hamper the incentive for math teachers to reimagine their curriculum. Sadly, in many cases, mathematics has become distilled to procedural fluency disregarding the art and beauty of the discipline.

Co-teaching in its various forms can offer a means to learn and support one another. In this way teachers gain capacity to navigate top-down demands. Content and pedagogical approaches are more readily exchanged. Co-teaching need not take a single form but perhaps a mix of sequential and total integration to better enhance student learning.

Element of experience 4: Social skill building

"It's more, team interactive than it is individual," (Hank, Interview, 5/5/16)

I asked Hank to elaborate on his description of the orange team model in the following passage:

Meg: Ok, what do you mean?

Hank: Um, so like, every marking period we've switched up groups, we get to talk to everyone, we get to talk to everyone in the whole orange team. So, then after that, he gives us different projects and we are in different groups so we find a way to work with other people and it gives us more social skills I would say, and like, more focus, cause you don't always work with your friends (Interview, 5/5/16).

All students were expected to speak in whole group settings and evaluate each other's work. Teachers conveyed collaboration as a philosophy to students as early as week one. The teacher team modeled respectful interactions and gave opportunities to practice these skills explicitly during weekly morning meetings. Annie recalled, "We had the goal of building that sense of community and culture within the team, we did that through morning meeting" (Interview, 4/5/16). She mentioned that the purpose of the morning meeting is to preview the content for the week as well as share student accomplishments. She emphasized that the time revolves around activities perceived by students as "non-threatening" and "fun." Valle and Connor (2011) support the importance of building a classroom community as part of an inclusive environment. One suggestion that they offer, "discussion is deliberately fostered among students" (Valle &

Connor, 2011, p. 79). They also emphasize that students know each others' names and that individual talents are recognized among all.

Sam, special education teacher, commented on building collaborative skills prior to the roll out of design challenges (Interview, 4/5/16).

> [The] first couple weeks of school and they are for the most part, we are teaching the kids how to learn…We do a lot of modeling, I know the first year we actually filmed ourselves having a conversation. So it was like, a tripod, a camera, and teachers sitting around a table (Interview, 6/8/16).

Panitz (1999) posited that during collaboration "individuals are responsible for their actions, including learning and respect the abilities and contributions of their peers" (p. 3). During group projects, orange team students are provided with structures that facilitate cooperation. Sam noted that many students with special education labels are "extremely engaged" during group project time. In order to keep students on task during hands-on activities, the teachers often provided a series of guidelines to clarify individual roles and responsibilities. Below is a chart used during the Mars rover project to outline specific roles and steps to accomplish a particular task.

Mission to Mars Job and Department Descriptions

Job Descriptions

1. **Programmer**
    a. Writes and modifies programs.
    b. Explain how program works to large group.

2. **Engineer**
    a. Builds structures.
    b. Explain how structures are put together.

3. **Scientist**
    a. Actively researches mission constraints.
    b. Actively researches how structures work. (Parachutes, Air-Bags, Senses, etc.)

ABBR	Department Name	Department Responsibilities
P-DEP	Parachute Deployment 1. Scientist 2. Engineer	Research, develop, construct and test various structures that will use air resistance to reduce terminal velocity of iROV Lander when entering planetary atmosphere.
IM	Impact Management 1. Scientist 2. Engineer	Research, develop, construct and test various structures that will minimize the forces transferred to the iROV Lander when making contact with planetary surface.
LAS	Landing Apparatus Separation 1. Programmer 2. Lander Engineer 3. iROV Engineer 4. Scientist	Research, develop, construct and test various structures that will allow iROV to leave Lander once safely deposited on planetary surface. Program iROV to move at least 25cm away from landing apparatus in a variety of scenarios.
AOA	Autonomous Obstacle Avoidance 1. Programmer 2. Engineer 3. Scientist	Install Touch or Distance Sensor iROV Program iROV to search for land area a minimum of 25 cm from any that could cast a shadow.
I-DEP	Instrument Deployment 1. Programmer 2. Engineer 3. Scientist	Install additional motor and instrument on iROV. Program iROV to deploy instrument and collect data on iROV CPU.

Table 9: Student roles and responsibilities as part of the Mars rover project

Mission to Mars: ROV Status

STUDENT ROLES:

1. ROV Programmer - Creates, develops, stores, uploads, manages files on ROV-CPU
2. Drive Engineer - Designs and builds structures that support LAS, MFO and CorNav operations.
3. Payload Specialist - Develops and builds structures that secure and deploy HabMods on Martian surface.

ROV	Landing Apparatus Separation (LAS)			Magnetic Field Orientation (MFO)			Course Navigation		Habitation Module Deployment			*ALL SYSTEMS
	Built	Program	Tested	Built	Program	Tested	Program	Tested	Built	Program	Tested	TEST
1				X	x	x	x		X	x		
2				x	x	x	x		x	x		
3	x			x	x	x	x		x	x		
4				X	x	x	x		X	x		
5	x			x	x	x			x			
6				x	x	x	X	X	x	x	X	
7	x			x	x	x	x		X	X		
8	x			X	x	x	x		x	x	X	

***Once ALL systems are running in sequences, ROV Team can integrate testing with Entry, Descent and Landing (ELD).**

Table 10: Accountability guidelines for students as part of the Mars rover project

While students appreciated the hands-on elements of the group projects, the cooperative aspects of learning directly challenged many of the students interviewed.

> Aaron: We usually work with a group.
>
> Meg: Ok, and how is that?
>
> Aaron: It's sometimes good, but sometimes bad. I'm a, sometimes a very independent person, um. That's something that I, I might be good at all of the stuff that we are doing. So say, there is a part A, part B, part C in a small project. So I might be good doing all of it, so sometimes I wish, it was an independent project (Interview, 5/5/16).

Lee, Hank, and Sarah all explicitly echoed this sentiment. They preferred to work independently on projects because they perceive their teammates as less competent. Sarah described herself as a “faster pace person” than the rest of her teammates (Interview, 4/15/16). Hank noted, “as long as there is not like completely dumbfounded people in the group, they have some sense of what’s going on then it usually works out pretty well” (Interview, 5/5/16). Lee described the orange team as comprised of a lot of “ashy representatives.” Whenever possible he chose to work with his friend, Nate, because “We’ve been winning projects as humbly as I could say, it’s just sort of natural” (Lee, interview, 6/15/16).

Engaging productively in a cooperative instructional task presented challenges for students. I interviewed Zara following an incident where the group had internal conflict. She worked on a group project, Chromebook policy development, with Aaron and Jennifer and faced some dissention among the partners. When Jeremy went over to check in with this group, seated in the far back left of the middle section of the auditorium, Zara appeared frustrated that Aaron erased the notes she put up on the Google doc site. Jeremy counseled them through this conflict and advised that they focus on developing a few bullets so that they would have something to contribute if their group was called on. Jeremy explained, “It’s like that, cross-curricular, soft skills, or twenty-first century skills piece that is underlying everything” (Interview, 5/4/16). Later, I checked in with Zara to better understand this experience from her perspective.

> Meg: Ok, so how did it go today with the project you were working on with the two other team members? What was going on today? (haha)
>
> Zara: That was, that, oh yeah (her voice is light and airy). About that (a conservative chuckle). The two that I was working with, they, do not like each other (upwards inflection), and every time I would type something, one of my group members would delete it, he didn’t think it was good enough or something, I don’t know. There are some things you don’t really want to work on (voice is strained) with people because everyone

> has opinions. Like, one thing I don't like about the team is, when they do pick our groups they don't really let us pick our groups because we want to work with people,
>
> Meg: Hmm. Hmm.
>
> Zara: that we work well with, and I think it's easier to work with people you are friends with because you can, you know, like understand like their aspects of things, and they understand what your thinking, you know (Interview, 5/13/16).

Social structures are needed in order for students to make sense of project parameters and talk through the nuanced relationships between content areas. During group challenges, the orange team teachers configured students so that they are able to work with one another with minimal intervention. Teachers also expected students not only to work cooperatively on group tasks but also to access digital resources and use online software appropriately. By removing subject silos, the teacher team opened up new areas for social interaction and active collaboration by both adults and students. The team embraced the presupposition that social interaction is a critical component of learning. The teacher team looked at learning as an iterative process that involves personal growth and self-reflection.

Vygotsky's (1978) notion of the zone of proximal development (ZPD) supports meaning making as a collaborative classroom process. Internalization of knowledge begins with the interpsychological plane and then transfers to the intrapsychological plane (Vygotsky, 1978). Through social exposure to both teachers and peers, students are able to construct meaning at a personally optimal level.

Element of experience 5: Use of technology

"It's a luxury, I'd say," (Aaron, Interview, 5/5/16)

A student, Aaron, described his experience related to laptop access:

> …You don't have to look up all these things in a dictionary or look at books not too much. Not too many activities on paper and it's digital on the cloud, so you don't have to worry about losing anything (Interview 5/5/16).

The team used Google classroom to house all curricular materials. Students referenced their laptop devises rather than textbooks. Teachers created folders with content and other resources that they stored digitally on the Google classroom site. The teachers all developed Google classrooms, with the exception of Annie, to house pertinent resources and student journals. The digital platform allowed students the flexibility to work at their own pace and access school materials any period in the day. All team teachers viewed student documents and provided instantaneous feedback. Students are responsible for turning in weekly assignments electronically that are designed to reinforce vocabulary and content from physical lessons. The teachers drafted a parent letter that outlined the use of Google classroom and laptops. The letter stated:

> We are excited about continuing with the VCW initiative of using the Google Classroom and student use of a Chromebook. This will allow for more efficient communication about assignments and student progress. This tool works on any device and allows students to continue learning beyond the classroom with the ability to access their work at any time. We encourage you to explore classroom.google.com with your student. We will train students on this tool the first week of school (Retrieved from website, 3/20/16).

The Google classroom platform allowed for differentiation of instruction. Additional assignments can be posted to challenge high performing students or help struggling learners through further practice. The digital platform enhanced the team's efficiency creating more instructional time to focus on hands-on learning activities.

The team dedicated little time to explicitly teach how to use software applications. Instead, the teachers encouraged students to leverage classroom time to explore software independently. They also selected particular applications that they designated as intuitive such as iMovie. Students seemed to easily navigate these, on rare occasions, students signaled some confusion carrying out a task. For instance, students during a lesson on chemical change, lacked awareness of how to make a subscript. Other students quickly assisted the others and the problem remediated quickly. Peers actively taught other peers how to properly access software programming. At times, students assigned the role of informational technologist and floated from group to group to provide assistance. Deb also scanned the laptops to see if everyone is on the same page before proceeding. Deb mentioned that students with special needs such as those with ADHD designations prefer using the computer for note taking and lesson activities.

> The Chromebooks are helpful in that because at least you are physically (hands move outward, palm out) doing something, yah know? Moving the keys, typing or yah know, back and forth between different websites or whatever, it's something more stimulating for them, you know, visually on their Chromebook or physically. Those kids do really well with it (Deb, interview, 6/15/16).

The district placed no restrictions on Internet access or website usage. Even as a guest, I was easily able to gain Internet access through the devises I brought to the study site. Jeremy mentioned that it is an orange team expectation that students will appropriately use technologies. Students are responsible for generating policies associated with their Chromebook use. The team organized a morning whole group session to create recommendations for the district on proper use protocols.

"We almost have our own parallel technology piece going on where it's really about engineering" (Jeremy, interview, 6/21/16). Technology class is offered for all eighth grade students but it is held in a physical classroom and involves building materials. The interpretation of technology as an industrial arts class is not a part of the orange team.

> Technology class is still pretty traditional. We build stuff we don't solve problems. I think we are doing a good job as a team but I think there is a breakdown with our technology department with some staffing (Jeremy, interview, 6/21/16).

As part of the end of the year energy project students designed a power facility to fulfill the role of group engineer. Students were not formally trained on how to use the software package. Below is an example of an hydroelectric power facility schematic created in TinkerCad that was uploaded on Twitter by a student group.

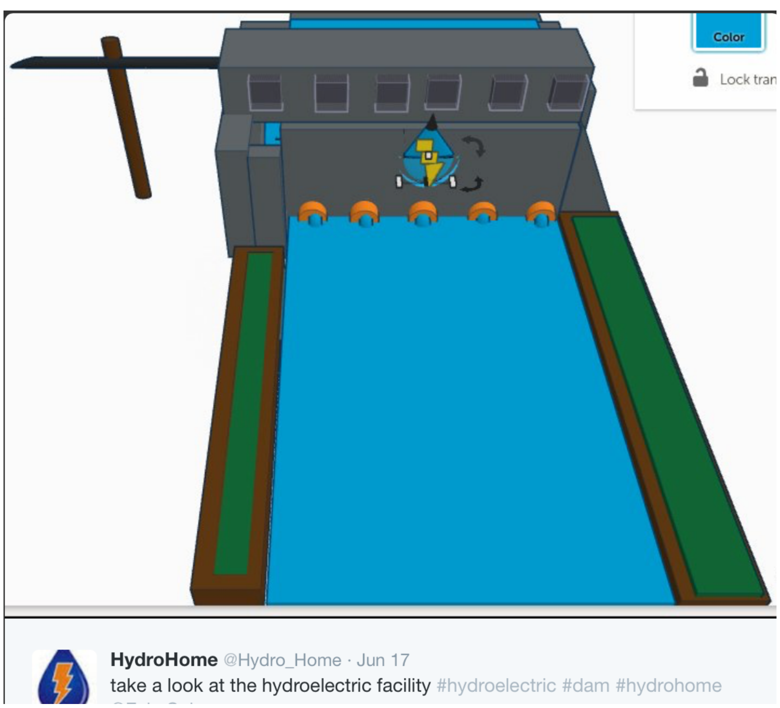

Figure 16: HydroHome

Jeremy noted a major shift in his teaching as a result of technology. Ten years ago, Jeremy focused on fact memorization during lessons. For instance, he would "wow" the class by memorizing the distance of Earth from the planet Mars. Now, students are able to access this information readily through the use of Chromebooks provided by the district as well as personal devices.

> [Technology is]Another tool in the arsenal to enable you to teach. That has recently shifted for me. I used to really ascribe to that belief system…I think a fundamental shift happened once the kids went one to one with like online devices where I was not the source of information anymore and the information could be delivered to the student in more efficient ways than I was able to deliver it…I can't wow them with facts anymore. But I can set the stage for cool inferences.

Technological innovation opened a wider array of assessment opportunities. For instance, Jeremy used to have students create poster projects as part of alternative assessments. Now they use various software packages to make student projects come to life with pictures and videos. He recalled, "Now that the digital media has come around it's kind of become something more interactive" (Observation, 4/12/16).

Technology class is offered for all eighth grade students but is held in a physical classroom and involves building materials. The interpretation of technology as an industrial arts class is not a part of the orange team. The orange team interpreted technology to mean computer technology. As part of science teaching, digital technologies are integrated as part of almost every lesson. With the Chromebooks, students are provided with all day access to the Internet and other classroom online resources. There are some mixed messages by the team, to face each other while speaking but also to almost exclusively use Chromebooks to upload work. If you look at the last day's photo montage many of the pictures are of students looking at computer screens.

Technology also increased accessibility of lesson materials. "The primary neurological channels that the brain employs for learning are visual and auditory" (Danforth, 2014, p. 149). Computer access allowed students to view websites and interactive simulations that incorporated both video and audio information. For instance, students referenced an online periodic table that offered 3-D views of atomic structures and audio pronunciations of elements.

Element of experience 6: Rethinking space

"We use whatever we have access to," (Jeremy, PD event, 5/10/16).

The orange team reimaged spaces throughout the school to maximize learning opportunities. Jeremy explained during a professional development session:

> How can we use our limited space differently? I was talking to some of you guys out in the hall out there, in the atrium, um, to our team that is a priceless space when we first look at it. Do you realize that is a hall that is beautifully lit and that is just sitting there, it is a whole break out space... We have students sitting on the stairs, to address the whole group… (Jeremy, PD event, 5/10/16).

However, the school setting presented limitations to the creative use of space. Since the orange team is located this year in the high school, the only suitable whole group space is the auditorium. The auditorium has a capacity rating of 500 and is a cavernous space. The team is only able to access the auditorium in the morning hours since in the afternoon the music teachers in the high school practice. Each time the team entered with their classes they scramble to operate the lights at the station in the back of the room. Usually it is only lit in the orchestra pit and the remaining spaces are cast in shadows. The team conducted morning meetings, group presentations, and science demonstrations in the auditorium space. The orange team experienced difficulty practicing appropriate social interactions in this setting. Sam commented on the issue of space:

> …facing each other, that's why our large group space is pretty important to a lot of the stuff that we do, and our auditorium, whether it's a great for lecture style stuff and for kids to present back, it doesn't facilitate group work. Cuz kids are shoulder to shoulder. Our expectation is that we look at each other. We sit in a circle or a half-moon or something like that so that the kids can visually see the speaker. And it doesn't, it doesn't, work in that setting. So in order to have those, we have to break out back into the classrooms…It is way more conducive for that, for what we want them to do (Interview, 6/8/16).

In the following picture shows students at a morning meeting session where each teacher gives a complement to one student. The rigid seating structure presented difficulties engaging in team learning activities.

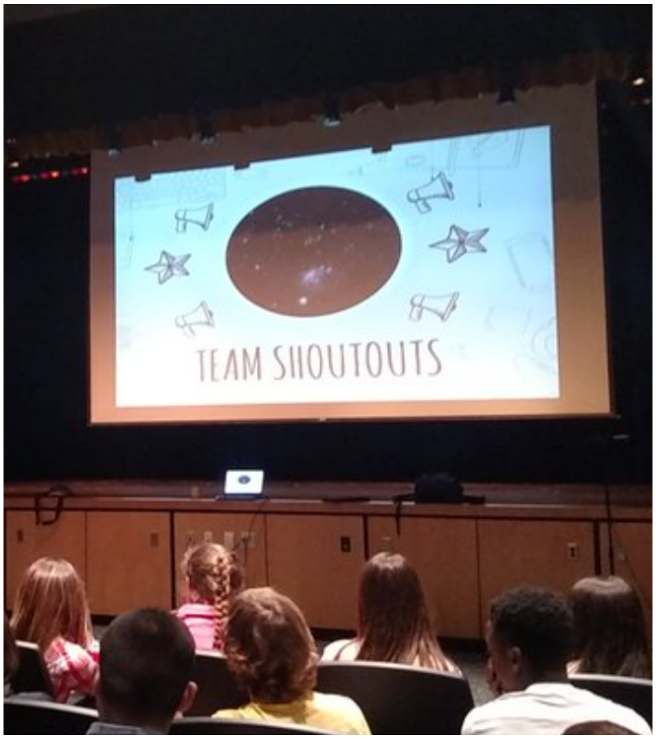

Figure 17: Team shoutouts

In prior years, the team opened the door between classrooms to generate a whole group space. Noel and Terri described this experience and how it shaped conversations between teachers and students:

> Noel: We would just open up the door. We would kind of ran it. She had a study hall roster, I had a study hall roster but we kind of ran it with our individual attendants but you know you could,
>
> Terri: It was a team, if they were working on something and they want out, cuz that was their home base.
>
> Noel: Yep, if her and I were having a conversation about, you know, whatever was coming up, or maybe if Calvin was next door, we could have those ALL day conversations…That was nice, or like a kid was like, 'Hey, I want to go here.' It wasn't a concern. They weren't going far, it was like, RIGHT there (Interview, 5/20/16).

Sam emphasized the need for dedicated spaces to conduct break-out activities during hands-on activities or projects. He expounded on this frustration in the following passage:

> It's just not IDEAL, in terms of sharing space. Where we depend on, especially with projects. You've got a project in full swing, you can't, PHYSICALLY, you can't tear it down so that another teacher can use the class and then tear it back up. And we spun our wheels a lot last year, trying to battle, trying to figure out how to do these, and finally we were just like, 'We're not getting anywhere cuz we're trying to fit a square peg in a round hole' (Interview, 6/8/16).

Another teacher came in at that point to use the room. Sam looked at me and noted, "We're gonna have to move, cuz we have another class in here" (Interview, 4/8/16). When I interviewed Noel and Terri students we had to talk in the atrium where students and teachers constantly passed. Nine different students approached the teachers during the interview. Disruptions by teachers and students became a regular occurrence. The renovated middle school facility held great promise for the team. The team hoped that their work could be implemented with greater ease in the new building.

Valle and Connor (2011) offered suggestions for classroom organization to foster inclusion. Furniture and chairs should be moveable based on the specific goals of the lesson. Students should be able to easily move within instructional spaces. Space should accommodate opportunities to work independently, in small groups, or with the whole class.

The model: A system view

Using hermeneutics as a tool for analysis, I was able to better understand this integrated STEM model as a function of experiences. Teachers and students engaged in and with this model. Those experiences that surfaced again and again included the following: (1) project based learning, (2) flexible scheduling, (3) co-teaching, (4) social skill building, (5) use of technology, and (6) creative use of space. These aspects of experience were used to create a characterization of this integrated STEM model. These signature experiences were used to generate a descriptive framework to understand this model from a system level. The model created a set of circumstances that necessitated participant reaction. Conversely, the participants themselves added a dynamic element that caused the model to be subject to constant change. Understanding integrated STEM as a context meant simultaneously understanding the teacher and learners involved.

This integrated STEM model draws from inclusive instructional practices. “Differentiated instruction is an approach to teaching that fully accepts and attends to the diversity of talents, skills, interests, and desires of students” (Danforth, 2014, p. 148). To create inclusive classrooms, Danforth (2014) suggests multiple kinds of representation, engagement, and expression. The orange teachers presented information through in a variety of formats. Students used laptop computers to view information in video, audio, and written forms. Students engaged with their peers in small group and whole group settings. Learning activities varied widely from making movies to software design to building aluminum foil boats. Students expressed their learning in many different ways. They presented to the entire class, reflected independently in journals, and created products. Teachers focused on needs of students as well as their interests.

Research Question 3 a: How did the teacher team initially develop the integrated STEM model and how has it evolved since its inception?

Initial team membership

Jeremy recounted being the "first person on the scene" six years prior when the idea for the integrated STEM team first emerged. He was theorized that he was "just randomly selected by the district" to visit two different STEM schools with the superintendent and sixth grade technology teacher by his side. Before this time he had not co-taught with any of his peers. "We would just smile and wave from across the hall." After Jeremy observed models of integrated STEM instruction he conveyed these ideas to the newly assembled team. Jeremy was pragmatic in the degree to which the other integrated STEM schools could be generalized to their particular context. He was always very explicit about that when speaking to other educators interested in replicating the orange team model.

Jeremy admitted that there was little prior research involved in the development of this integrated STEM model.

> Jeremy: it wasn't done legitimately from like, an education standpoint.
>
> Meg: Ok,
>
> Jeremy: Ok, let's start with this theory and then work our way down. It more started with ah, a logistics conversations, which I thought was an interesting way to start it (Interview, 4/5/16).

He did note teacher motivation as an important factor in the initial undertaking of reimagining traditional patterns of instruction. We recounted that all members of the team had an interest in trying something new.

Noel recollected that she just received tenure the year prior to the development of the integrated STEM model. She believed her membership into the orange team resulted from informal conversations with her principal following observations. "One of my things was co-teaching, …you know differentiation benefits everybody." Noel remembered feeling "flattered" by the news, that “she thought enough of me and our conversations” (Interview, 4/5/16). It seemed as though there was a deliberate effort on the part of administration to select team members that were open to innovation. The orange team provided the opportunity to try new approaches with the support of other like-minded teachers. Noel’s feelings of flattery related with Jeremy’s notion of feeling special. The team felt selected to be part of a special mission that brought attention to their practice.

Annie was also part of the team since the start five years ago. She elaborated on the team selection: “ Some of it was expressing interest, some of it was the principal who knowing each of us and our styles and asked certain people to be part of it” (Interview, 4/5/16). Annie found greater agency in this new team position. She was newly able to act on pre-formulated ideas with a group of teachers also willing to experiment with new approaches. Calvin also self-identified as a teacher reformer who “always found myself involved with those conversations about how those things can be done differently. So when the opportunity came up to be on a team, to look at different approaches, I jumped” (Interview, 4/5/16).

During professional development sessions run by the district, Jeremy opened with an extended personal narrative that illuminated for him the need for rethinking traditional teaching practice. He explained a shift in perspective from isolated teaching to intentional and group-directed instructional efforts. As outlined in the example of parent letters first mentioned in the methods section, Jeremy’s story of personal awareness served to illuminate his individual rationale for participation in the integrated STEM model. He assumed a critically reflective stance that resulted in a shift in thinking regarding his practice.

Calvin identified school structures as stifling his ability to differentiate instruction, integrate with other subject areas, and facilitate long-term projects. In the following passage he elaborated on his motivation to participate in this integrated STEM model:

> So where were we, aww, the, was, the rigidity, the schedule being the way it is..., a lot of the times, I wanted to do some more longer term projects and the time that I had. I always felt like I either setting up, breaking down, setting up, breaking down, so the opportunity to play with the time in the schedule, I saw the advantage there... I also was teaching some things that were also being taught in ELA (Interview, 4/5/16).

The roll out phase of implementation

Every team member seemed to enjoy the first year of the project. They felt supported by one another and able to make decisions the impacted their practice for the better.

> Meg: So what was that first year like?
>
> Calvin: Ah, it was, it was, very fun (smiles). It was, there was, some frustrating moments at times, I look back on it fondly, probably didn't experience it as fondly as I look back on it, but it was constantly problem solving, it was like, what needed to be done to come up with the solutions. The first year it was invigorating to have a group of people that were kind of ALL focused on trying to solve the problems, we had different ideas but the fact that we were trying to do something different helped out the situation (Interview, 4/5/16).

In the first year of enactment, the orange team teachers created a system for decision-making that continued to support their collaborative efforts. The first step included the organization of content-area topics. The team considered these content-area expectations as basic parameters. The team designed integrated STEM instruction that directly addressed content area parameters.

During the initial stages of the integrated STEM model development, the teachers wrote topics on post-it notes to visualize each content area needs and find areas of overlap (see Figure 18).

Figure 18: Post-It note team planning activity, *Appendix contains a typed version

> We always tell the story, we literally brought post-it notes and sat down, and wrote down everything ELA-wise that we do, Calvin wrote down everything social studies. So we

> kind of, mapped out just to see where the obvious fits were, you know what I mean? (Interview, 4/5/16).

The second step in the planning process involved the identification of desired outcomes. The team cited three primary goals of the integrated STEM model: (1) sense of community, (2) project-based learning, and (3) co-teaching opportunities. The group then pooled all instructional time and divided class periods based on daily need. In step three, the teachers developed an elaborate schedule system to reflect their goals. These scheduling structures allowed teachers to visit each others' classrooms on a consistent basis. It afforded more large-group opportunities for engineering design challenges and weekly morning meetings. Teachers found that the application of a dynamic scheduling model engaged students throughout the entire day. "Students will ask, 'Is it time to go home?' I just love that" (Jeremy, interview, 6/21/16). Lastly, the team considered connections with technology that transcended content area. Since each student had access to a Chromebook as part of a district initiative, the team used Google classroom to manage assignments and provide feedback (see Figure 18). The teachers revisited this four-step process during periods of group transition. The team planned to move back to the middle school setting during the 2016-2017 school year after two years of displacement due to renovations. Much like the first year, teachers again followed this step-wise process to re-evaluate their curriculum, look for connections, and adapted accordingly. The methodical nature of the process reduced anxieties associated with change and allowed the team to stay focused on student learning outcomes.

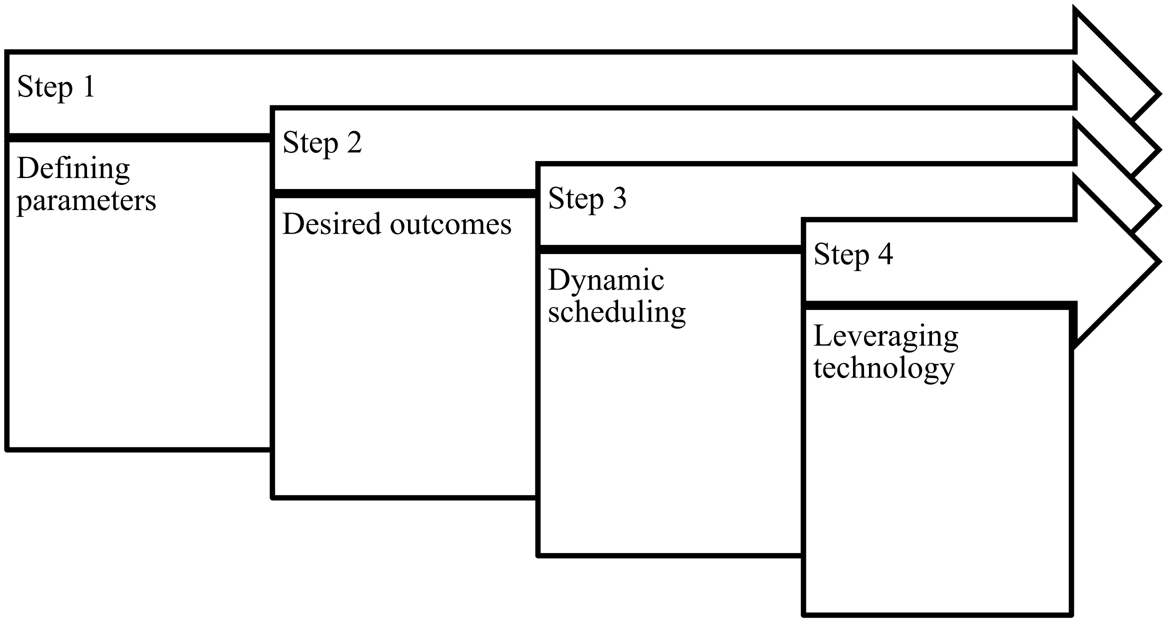

Figure 19: The orange team planning process

Evolution of practice

The teachers incorporated the co-taught lesson that centered on the real-world problem of how many marbles fit into the classroom space for the first time this year. In all other years, Jeremy included a unit on measurement in the very beginning of the school year. In former years, the measurement unit focused on skill building and did not feature any embedded course content. This year, Jeremy distributed the measurement section among different content area units throughout the school year. He mentioned hesitation in changing his practice:

> I, appear I think very flexible, and everybody thinks I am. Some things are very hard, I think to break from. This is the first year that I have not taught measurement in the beginning. Measurement and scientific method. I always say, ‘oh, I’m going to do it differently.’ Here’s what I find, personally, when push comes to shove and I start to get nervous about something. I refer back to something I have done in the past. That’s

> something that I think we've all done. We start getting uncomfortable we retreat back to, 'Well I've been doing this for twenty years, so" (Interview, 5/6/16).

Rather than open with an isolated unit on measurement, the team transformed the first few weeks of school to investigate Isaac Newton through experimentation, research, and writing. ELA teacher, Terri, spoke to this change as well:

> Over the course of the years we developed more and more, especially with science. You know, when they are writing a narratives, you know they research actual people's stories and help them write their narratives, you know we researched Isaac Newton this year and a couple, not exact experiments that he would have done, but an experiment that led to a similar result of which we got, things of that nature (Interview, 4/5/16).

Jeremy found this shift to be a positive experience for all, "It was a cool way to start the year cuz we found that the kids were super engaged" (Interview, 5/4/16).

Jeremy reflected on a change in perspective on student ability as a result of these shifts in instructional roll out:

> We were underestimating the kids ability to do, upper level stuff when you just need to do it. We were there, and the we can trouble shoot with the kids, when we are there we can do something. A lot of kids bring skills to the table. They can already do so that, therefore shifted my entire year (Interview, 5/4/16).

Jeremy acknowledged an internal struggle when the traditional measurement unit was not taught in the beginning of the year. He attempted to isolate the variables that created this discomfort regarding change. He noted:

> Fear, I think a lot of it is, I know it's heavily tested on the state test and I know they will not, have the stuff before the actual date of the state test. I don't mean to have that drive

> it, but it drives it to some degree. You can only move the project then, then I'm moving four people to what they do, just to suit my needs (Interview, 5/4/16).

The format of group projects also changed substantially since the initial launch of this integrated STEM model. Sam recounted the implementation of the first project and the lessons learned:

> One of our first, that first year, one of our first projects, we had to take it to the brainstorm, that we, let kids develop something, like a product to sell, so they had to take it from the brainstorm to the design, to the actual, writing letters to build it, and then actually build it. We created a, online store where they would sell it, and it was going to be like this, who could sell it the most, and as we got into it, it sort of became apparent that towards the end that, this isn't really goin on, there wasn't really any good way to end it. So we just, ENDED it. Haha. The kids didn't really know, the kids were just like, but everyone was fine with it, it was good and it was fun, from everyone's perspective of how much we learned, keeping the end in mind as we start this stuff (Interview, 4/8/16).

Annie also mentioned how projects in the first year needed refinement:

> We had some good projects in the beginning, some fun projects, but not necessarily really hitting on the priority standards in the curriculum, and focusing on the things that were taught in the curriculum, our goal, and our shift right now is now to align our projects with our curriculum and making it meaningful and rigorous for everybody (Interview, 4/5/16).

Noel offered commentary on how adjustments to group projects provided opportunities for multiple forms of expression:

> They [students] need to find their niche and what they are good at, and find their role, um, which has been cool too…we did kind of differentiate, you know, they aren't interested in building but they are a phenomenal writer so maybe they will go into that marketing or communication role so that was kind of cool that first year to see, especially where we started from where we were like, yikes, where each kid had a job and essentially they were all doing different things, they were all. They all were doing it differently, so instead of abandoning ship and saying these kids can make it to the end, we were like awww, ok, everyone needed to be on but they were just doing different roles, it was like, so energizing (Interview, 4/5/16).

Calvin explored new ways of structuring required content to necessitate greater interaction with the other content areas and teachers. Deb described he presentation of content this year as well as student reactions:

> He did the whole (emphasis) timeline of his curriculum in the first two months and then he says, 'Now, we're done.' And the kids were like, 'What?' and my eyes just bugged right out in my head, (eyes widen, smiles) and I was like, 'What?' What do you mean we're done? He was like trust me, trust me on that, yah know? He said you are done with the skeleton and now we are going to start back at the beginning. I gave you all the major events now it's on you to fill in, you know, all the more specific details for the rest of the year. And this is how we are gonna do it. So, like, now were are back up to the civil rights unit where we were in, like, October, now they have all the background, you know, the more, the FULL story (Interview 6/15/16).

Calvin announced early on in the study that his role on the team was to provide historical context for students. He spent the first ten weeks of the school year marking events that would serve as reference points for students. He provided a global overview of his content illuminating critical shifts in political climates or social policy. Through the swift roll out of chronological events, he was able to spend thirty weeks of the school year forging integrative connections. This reconfiguration creates openings for more authentic instruction of scientific concepts. For instance, Calvin dedicated instructional time to delve into concepts such as Western colonialism in connection to Mars exploration. So often, science teaching is conducted devoid of socio-cultural components. Tobias (1990) found that successful science students eventually become disengaged from the discipline because of its lack of historical, philosophical, and sociological foundations. Calvin's work to contextualize science teaching stimulates students cognitively in new ways. Student can more readily ground scientific concepts in their own ways of being through acknowledgement of the greater societal nuances always at play.

Since the first year, the team identified clear roles for each student during project-based activities. Teachers encouraged students to grow existing strengths but also work to expand their skill set. The teachers gained reflective skills over time to build greater student accountability structures into curriculum but also stronger alignment to standards. Sam added, "But I think the other, the other part, is that, teacher's commitment to being open-minded and flexible and setting out of their comfort zone" (Interview, 6/8/16).

Research Question 3: How does the integrated STEM teacher team collaborate to address student need in the context of both school and state standards?

Team planning

Team planning sessions: "Our plans, our team works, twenty-four seven" (Deb, interview, 6/15/16).

Lunchtime discussion seemed like the most fruitful time for generating next steps. Only twenty minutes in length, the team used the morning plan period to finalize plans for that day. Sam explained, "It's very much on-going. Like, this morning, for example, we thought we had a plan. And then it sort of got morphed but everybody was there. So, you know, it's just the constant communication" (Interview, 4/8/16). The teachers sketched on the classroom whiteboard to map out activities during the remainder of the school year (see Figure 12). In May, team conversations tended to focus on next school year, anticipating changes in setting, curriculum, and staff. Noel received word from her administration that she would assist the entire eighth grade as a literacy specialist without a homeroom of her own. Sam and Deb had to wait for district guidance with regard to special education programming for next year. Their future membership on team orange depended on the number of students with IEP labels and overall district needs in the area of special education.

On May 16th of 2016, the team strategized a plan to support a district-wide initiative on content-area literacy. Jeremy positioned himself at the front of the classroom facing the other with his laptop open and soda can to his side. Calvin sat at his desk in the far left corner of the class engrossed by the computer screen; a small cube-shaped cooler resided by his feet. Sam placed his black briefcase on the table and sat closest to the whiteboard on the left side of the classroom. Sam frequently missed lunch due to special education meetings, dashing out between periods to grab something to eat before classes started. Terri sat with her arms crossed and her laptop out on the right side of the classroom. Deb sat in the back of the classroom with her cell phone out, engaged in an unrelated task. She used the time to organize student council activities and rarely engaged in planning discussions unless explicitly asked. Annie was charged with managing study hall during that time. While it was lunchtime, no one actually ate (See Figure 21).

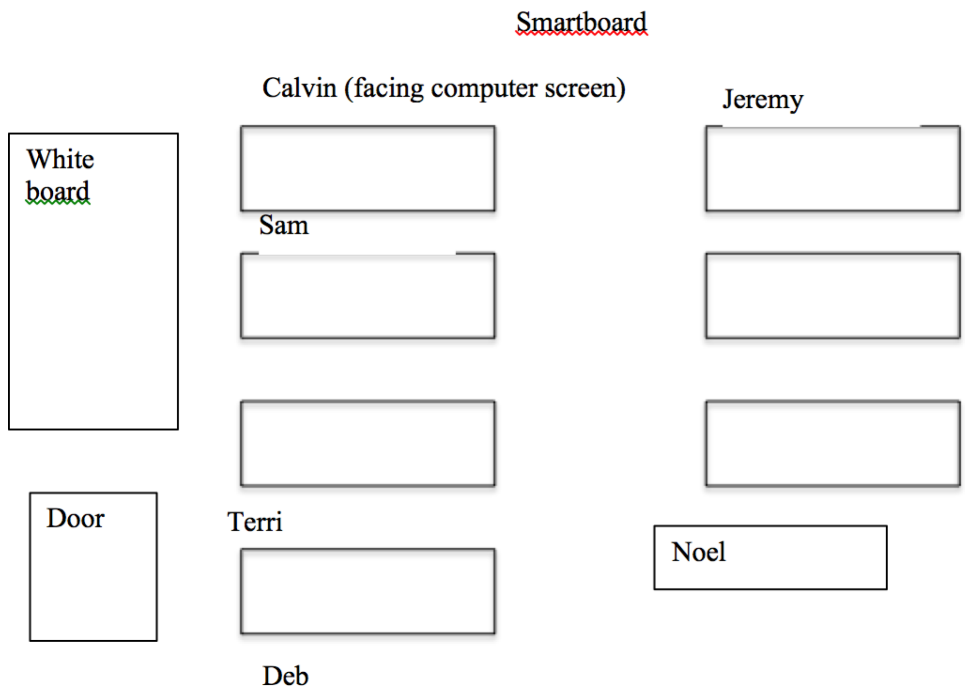

Figure 20: Planning time configurations

The team first marked on the board the standardized testing days in both May and June. The teachers also missed two additional days to grade the tests. Within minutes, the vice-principal of the school popped in to notify the team concerning student horseplay in the bathroom. The team then refocused discussion to center on the CCSS literacy standards on speaking and listening. Jeremy suggested using project presentations to “knock off the speaking and listening piece.” Terri nodded in agreement and said, “That’s true.” Then the conversation turned to procedures associated with Chromebook use in large group settings. Calvin pulled discussion back to literacy standards and the team brainstormed ways to assess student presentations in alignment to speaking and listening expectations.

Noel: How will you be formally assessing? (Glances at Calvin)

Calvin: Integrate and evaluate information.

Terri: I think evaluate is probably a key term there.

Sam: Can that be, two birds, one stone? With your assessment?

Jeremy: That could be the Friday set thing? You know,

Terri: I think you could, it can be really, really structured.

Sam: It could be as simple as a sign in the (Google) classroom, REACT to presentation a (Observation, 5/16/16).

The team engaged in dialogue back and forth about the best way to efficiently assess student speaking and listening skills. Once the interaction slowed Terri mentioned, "Are we] leaving out math?"

The leadership dynamic in the group played out in the placement of teachers during such sessions. Jeremy was at the front of the classroom facing the rest with Calvin seated in closest proximity. Deb was way in the back of the classroom. Noel, who was not going to be involved next year, also sat farther back. Terri and Noel were really the only two that typically switched their seating arrangements. Annie was not even present in the room. Another noteworthy aspect of the conversation was Jeremy's unfamiliarity with CCSS ELA standards. Jeremy relied on Terri to interpret speaking and listening standards using her expertise.

Each planning session generated a distinctively different feel. On May 31st, the team spent the first twenty minutes of lunchtime discussing topics outside of school. They unexpectedly snapped into working mode, initiated by Jeremy. He asked, "Does anybody need anything?" This question was in direct reference to time that week for a particular project or learning activity beyond the assigned 40 minutes. They then spent five minutes scheduling final examinations and carved out a window of time to work on the culminating energy project. He mentioned to me that it is a “shell of a project,” meaning he perceived that more collaboration was needed to shore up learning expectations, activities, and assessment practices. Terri seemed to agree: “I think the roles have to change by the fourth day, I was spinning my wheels.”

In previous years, the teachers tasked some students with writing a research project while others built physical models. Terri observed a disparity in engagement between student researchers and student builders. She encountered that hands-on activities increased student engagement:

> Jeremy: My job was to do a proposal. Then Mitchell would come in with a government piece, like the need for zoning.
>
> Terri: I want both, the only portion I’m invested in is that the free flowing part isn’t as long. I feel like all students should be able to build something. It’s not the same to do research to write a paper.
>
> Jeremy: You bring up a good point, everyone builds.
>
> Terri: It gives the research purpose, that I feel pretty strongly about it (Observation, 5/31/16).

Terri’s comments suggested that students lost motivation the ELA dimension of the project when the activity was strictly research-based. In an interview, Deb also echoed this sentiment, “They decided that was one of the biggest reasons that we are not doing it that way, it used to be for three weeks and it just couldn’t be sustained for three weeks. The kids got so bored” (6/15/16). Interestingly, Terri advocated for the addition of a hands-on element to the project. Her persistence seemed unusual because of her ELA background where literacy practices are obviously foregrounded. This passage demonstrated how teachers blend approaches for the collective benefit of student engagement. That year the team modified the project to include the role of energy company media specialist where students that blogged and posted on Twitter. During observations, students checked their Twitter accounts and literally cheered when they were Retweeted by others. They explicitly learned how to craft research-based claims and counter-claims.

The interactions that took place during lunch helped to illuminate how decisions are made that directly impact instruction. The degree to which each teacher contributed to the conversation varied. Deb usually worked on a task that was organization in nature. For instance, she counted money, or called about grade-level shirts; those kinds of items kept her attention most days. She also used her phone quite a bit and it rang several times during the lunch period. Sam deferred to the other team members before offering his contribution. He credited Calvin with building in accountability aspects of the planning process: “Calvin Mitchell has been, sort of, our guiding light, he’s been like, everyday twelve after til eight thirty-five, we are talking about team stuff, and we do” (Interview, 4/8/16). Sam may have felt less a part of the collective considering his position on the team had only been full-time for two years. Jeremy and Terri tended to make the most logistical decisions like the allocation of time for activities or scheduling events. Calvin’s commentary during planning time centered on approaches to reimagine traditional formats. Noel seemed agreeable to most decisions. Planning decisions made during lunch could not be fully solidified until they were “approved” by Annie. For that reason, the team positioned Annie as resistor of change. A potential source of resistance could be lack of adequate input during planning discussions. There were not many instances where I observed her interact with the team outside of instruction.

The team also experienced moments of frustration that resulted in lack of communication. After attending a content-area literacy conference, teachers came back to deadlines for grades. Below is an excerpt from my field notes from that period:

> Everyone said 'Hi' as I entered as I sat down and then there was complete silence. This is unusual. Typically there is some chatter, either school-related or otherwise. I wonder if the teachers were stressed since they lost a day of instruction? I'm not exactly sure the cause. The teachers that were present were Calvin, seated at his desk, Jeremy, Terri, and Noel. Terri was fixated on her computer, and after a few minutes looked up and said, "Grades are due next week and I only have one grade, so they either get a zero or a hundred for this marking period." With a smile she says, "a lot of the students were pretty excited that they had a one hundred." After ten minutes go by, Jeremy comments, "I guess people don't want to plan today." Regardless, the team did work out a date to all meet for a summer professional development day (Extended memo, 5/20/16).

This lunchtime observation demonstrated that not every moment of team planning was productive and positive. Outside constraints such as state testing requirements, grading, and other administrative tasks took away time typically spent to organize future lessons. There were many occasions where outside factors limited, interrupted, or refocused conversations.

Deb and Jeremy both admitted on the last day of school that the team doesn't get together outside of school-related events and activities. "People think we do but we don't really hang out," Deb stated on the last day of school. This message reinforced the professional relationship of their team. While communication sometimes strayed at times to include personal occurrences, the team primarily centered conversation on the work of improving practice.

Lencioni (2006) described five team dysfunctions that can staunch collaborative efforts, the primary of which was an absence of trust that can stem from a fear of risk and an inability to demonstrate vulnerability. The orange team expressed a constant willingness to experiment with new pedagogical approaches. In order to innovate, they first built trusting bonds that enabled this process. Teachers exposed both their strengths and weaknesses to their team and be open for continual growth. For instance, Calvin explained:

> Meg: Can you tell me a little bit more about what you need to work?
>
> Calvin: Ahh, listening, accepting of other people's ideas. Allowing other people to take the lead sometimes so, still working on those. Work in progress (interview, 4/5/16).

Jeremy noticed that different opinions resulted in an effective balance between traditional and innovative instruction. As he explained, when the instruction became too unfamiliar or "off-the-deep-end," then students were unable to assimilate to the rigors of high school and college. On the orange team each teacher had a different comfort level with innovation. Calvin advocated for more long-term project-based learning modules.

> Calvin: They [projects] are just very small (eye contact) they are not, ah, they are small experiences relative to the whole school year whereas I would like to really drive the school year.
>
> Meg: What are the barriers that…
>
> Calvin: Um, (3 second pause, exhales) I guess, everybody holding on their ways of, teaching? (Interview, 5/31/16).

Annie tended to gravitate towards more traditional schooling formats. Lencioni (2006) argued that the second team dysfunction is the inability to participate in healthy conflict. While often viewed with a negative connotation, conflict can actually assist teams find multi-faceted solutions. Trust enabled the orange team to engage in debate without feeling under personal attack.

After years of collaboration, the team viewed integrated STEM teaching as normative practice. Jeremy mentioned now struggles to separate each other's content because it has been "intermingled for so long" (Interview, 4/5/16). The team relied on each other's content-area knowledge and understanding of pedagogical practice. They leveraged a planning process that allowed them to transition into new spaces, take on additional tasks per district directive, and align their curriculum to the latest state and national standards. The group balanced traditional and innovative elements to achieve collective learning goals, maximize student engagement, and adhere to school-wide expectations.

The ability to navigate social environments is what American phenomenological philosopher Gadamer calls "understanding know-how" (Kerdeman, 1998, p. 249). "Understanding know how" is the ability to recognize one's position within a lived world. With years of experience, this teacher team developed strong social interaction skills that enabled them to navigate their schools with comfort and ease. The participants of this study can all be considered expert teachers with substantial ability to engage in professional discourses within the classroom and beyond. Kerdeman (1998) described the need for participants to have lengthy exposure to the phenomenon of interest:

> To learn about and understand life's purpose and meaning, it is necessary to live through a range of experiences that both affirm and shake up our orientation, such that understanding and self-understanding are not distorted or denied by clarified and furthered (p. 252).

The teachers designed and developed this integrated STEM model yet still lack one concise way of defining this work. Integrated STEM education involves the combination of many complex factors. Researchers or practitioners do not easily label it. The team synthesized a variety of instructional approaches based on collective professional knowledge of teaching and learning. Teachers pushed back on the idea of a “one size fits all” model of instruction. The team created a curricular Frankenstein from project based and collaborative learning approaches, engineering design challenges, responsive and flipped classroom techniques. Intertwined in the curricular approach was the dynamic nature of instructional scheduling. Time was created to efficiently address the learning goals of each unit. In order to manage all these working pieces teachers were constantly engaging in professional conversations.

Teachers perceived labels such as “STEAM” as confining their practice. Teachers relied on collective experiences to describe the development of their integrated STEM model. For instance, all teachers referenced the first year of development where they used Post-it notes to visualize content area connections. When addressing other educators, Jeremy also interpreted his experience through the lens of a parent with middle school aged children. From their view, the teacher team interpreted their roles as innovators to pilot novel approaches that would later be adopted more broadly by the district. All of the teachers expressed comfort using digital technologies including Smart boards, Google classroom, and movie making software. While teachers found professional satisfaction the design and enactment of integrated STEM it also created tension. Each teacher had a different interpretation of the model. Calvin wanted to ground curriculum for the year using four societal problems that connect all content areas. Annie explained that she needed “all math” lessons in order to cover the content demands from the

CCSS. The teachers had to work within the parameters of state and national standards while maintaining the spirit of innovation.

Research Question 4: In what ways do contextual factors related to school and community shape participants' interpretation of integrated STEM education?

"The old model will no longer work out", (Superintendent Dina, 5/10/16).

Administration

> How many of you had a 180-day school year? How many of you went to a school that was organized around school subjects? How many of you had periods of forty minutes or blocks? A single subject and then moved to another? Is that a pretty clear factory model? …What happens when we take some of these and really challenge [them] (PD event, Superintendent Dina, 5/10/16).

VCM district leaders responded positively to the sustained STEM integrated work conducted by the orange team and offered supports whenever possible. The district superintendent attended the first visit to model STEM schools with Jeremy six years prior. She took an active role in professional development sessions that showcase their work. She remained a visible presence throughout the duration of the study. She even Tweets and Re-Tweets posts from the team's Twitter feed. District supports came in the form of material items such as Chromebooks and iPads and money for field trips. The district also does not censor Internet access; "kids have unfettered access" during the school day (Jeremy, observation, 4/12/16). The district curriculum specialists helped to vertically align the team's curriculum and guide its long-term direction. Jeremy used the phrase "peeling away the layers" multiple times in reference to district supports that allowed for a fruitful STEM integrated outcome.

For integrated STEM to become the norm, teachers need support from administration in the form of professional development, resources, and planning time. McEwin and Greene (2010) studied both moderate and high-performing middle schools to compare differences. Researchers discovered that high-performing districts offered greater levels of school and district guidance.

In 2011, the NRC's committee on K-12 STEM integration found that schools that improved student opportunities to learn relied on a strong and supportive school foundation. Teachers and staff at VCM were afforded a multitude of professional experiences that allowed them to reflect and improve upon their practice. Successful districts offered direction for reform initiatives without undermining teacher agency. Leadership at this school placed recruitment of teachers with extensive content-area knowledge and an aligned vision of schooling placed at a premium. Educational landscapes sculpted with the learner in mind found greatest success. Schools viewed as a safe space for creativity and rigorous exploration adopted integrated STEM more readily (NRC, 2011).

The district launched a new initiative on content-area literacy. Sam affirmed this change in the following sentiment: "In our district there is a big focus on literacy across content areas" (Interview, 6/8/16). He viewed this new initiative positively when he stated:

> I'll be, I'm not locked into teaching just an English class or co-teaching an English class. It opens up, you know it's exciting for me to bop around and teaching with other people. As long as I'm supporting the kids (Interview, 6/8/16).

Noel framed the new initiative as directly connected to special education:

> They are reformulating the way they are approaching special-ed next year, so there are some unknowns there, as well. I'm kind of takin' on some different roles (5/20/16).

Calvin outlined the upcoming year's approach from the social studies perspective to address content area literacy.

> More of a literacy focus in the last thirty weeks. I was trying to balance the content, the literacy, I was trying to balance it all, so the first ten weeks, not, there's very, very little literacy focus. Obviously they are going to be doing some reading comprehension and developing some ideas, but it's not gonna be as, history based literacy but the last thirty will be. And will be alternative assessments and ah, engineering design briefs, and um, argumentative writing, so, for social studies (Interview, 5/31/16).

Calvin portrayed district demands as having a stacking effect when he said, "This is another layer that the district has…so now that we've had to do project-based learning, now we are doing literacy, and we had to differentiate" (interview, 5/31/16). This sentiment reflected a view that initiatives can assume a top-down form and feel burdensome to teachers.

None of the orange team teachers expressed interest in pursuing a degree in educational leadership. They enjoyed the role as teachers and their direct impact on students. They also tended to accept district-level mandates with little resistance. Sam remarked on the fluidity of his position, "Our Director of Special Ed met with me last week to go over schedules and what like, you know, I don't have, I'm not gonna tell her what I think. Tell me what to do and I go do it" (Interview, 6/8/16). Calvin echoed this sentiment in his description of the orange team model,

> A team of teachers that are trying to find ways to push forward district initiatives. Um, we just look at our time and our space and what we are expected to do and we don't spend a lot of time complaining about it, we just find time to do what is expected of us (Interview, 5/31/16).

Jeremy assumed that the orange team helped to pilot this new reform before it expanded district-wide. Jeremy described the role of the orange team in supporting district level innovation:

> I think that where we played a role we helped in pushing the envelope of what it might look like? And there are some aspects that resonated with the district and they are allow those things to take place on a larger scale. I think it's that simple, but I think that we are under leadership and we are moving in a direction and it feels good. Because, I felt like we were just unchecked for so long, but now I feel like it was part of a plan, let these guys go and see what they come up with, we were runnin' like reconnaissance or something? These guys will do anything. Let them mess up and come back and tell us what doesn't. Which I'm happy playin' that role, that role is fun. Ah, yeah. We're movin' in a direction (Interview, 5/16/16).

Assessment

"To be a better teacher and to look at assessments and try to assess if they understand more, rather than, did it feel really good and did the kids have conversations about it which is all I want," (Jeremy, observation, 4/12/16). The team found certain group projects easier to grade than others. Jeremy cited the "Keep it Cool" project as an activity with a clear method for evaluation. On the two days leading up to spring break, students worked collaboratively to construct an insulating box with a fixed set of materials. Students built their insulating boxes in their homerooms while all teachers supervised. "Keep It Cool" is part of a curriculum package called "Engineering is Elementary" that the team applied periodically throughout the school year. They typically picked four or five projects to complete each year, relating engineering content directly to scientific concepts or other coursework if possible. For the "Keep It Cool" project, Jeremy taught heat transfer during 40-minute periods on the days the students worked on the project in their homerooms. Students then practically applied their knowledge of conduction, convection, and radiation to build an insulating box. Once the construction phase was over, the team tested each icebox to see what percentage of ice cubes melted at the end of the day prior to leaving for break. Sean recalled this project as one of his favorites from the year:

> Sean: Um, we had, like ice, and we had to ah, structure with foam materials and we put it out in the sun until three o'clock until school ends and then we take the ice out to see how many ice is left.
>
> Meg: How'd you do?
>
> Sean: Pretty well.
>
> Meg: Was there any ice left over?
>
> Sean: Yeah, there was. There was kids, they take like the foam and like in little pieces and put it in for like, the air current. We didn't do that.

Figure 21: Insulated box creations as part of the Keep It Cool project

As part of the project, student received a grade that equaled the percentage of ice that remained in the insulating box. Of the students I interviewed, they received grades ranging from 78-85. Jeremy Tweeted the results of the test with the following picture. He boasted, “The winner of Keep It Cool 2016 had almost 90% of ice remaining after 5 hours!!!!!” (4/22/16).

Figure 22: Insulated boxes during test phase of the Keep It Cool project

Jeremy preferred assessments with straightforward grading aspects:

> There are a couple are like project based things that are really clear, like Keep It Cool. They have to keep an ice cube frozen. That's a convection, conduction, and radiation lab. Assessing within the project, it is, so clear (Observation, 4/12/16)

Noel also spoke about the importance of organization when developing assignments.

> The, that, idea of the portfolio is something that we took from Ford and it was SUPER effective and something that we've got but I thought, I really liked it, it was a very organized way of grading it was consistent. They understood it and they knew what to expect coming to class. That year was one of my favorites because it was very formal and clear (Interview, 5/20/16).

The orange team also valued leadership and responsibility skills as part of the 21st century framework that the district adopted. In an effort to focus assessment on this aspect, Jeremy and the team developed a ranking system to identify active leadership in the classroom. A rank of 4 out of 4 meant that the student worked as an emerging leader, assisting peers when necessary, and maintained a respectful classroom climate. Students were assigned ranks on a daily basis as feedback on their progress as both learners and community members. He said that most students are rated as number 3.

The team recognized areas of growth with regard to assessment of student work. In the following passage Jeremy mentioned the need to look beyond the presentation aspect of the project and focus on the content:

> Something that I've gotten much better with, is, asking myself, what am I assessing? I used to be like, get really cool pictures, 'oh yeah, you have really good pictures' but it has nothing to do with, you know what I mean? …The point is not the picture, or finding the picture. At the same time you're trying to get kids really excited about this, you don't want to be, taking the opportunity away to find these really cool pictures (Observation, 4/12/16).

Students also expressed frustration regarding the team's assessment framework for group projects.

> Caiden: Um, one person usually does ninety nine percent of the work and everybody else sits and watches and then takes credit for the work.

Caiden explained that while each team member had a unique role assigned, "I did every single role" (Interview, 5/5/16). He felt as though his grades suffered as a result of group projects.

Jeremy transitioned his grading system to be more focused on achievement of particular standards. Attendance of a standards-based professional development session prompted this shift. He described his thinking below:

> But I'm starting to now, cuz I'm getting more into like, the standards-based. To be a better teacher and to look at assessments and try to assess if they understand more rather than did it feel really good and did the kids have conversations about it which is all I want, um (Observation, 4/12/16).

Danforth (2014) states that as an outcome of instruction students create some form of product that demonstrates what they learned. This product comes in many different forms including documents, objects, or performances. Teachers use these products to evaluate student learning and identify future instructional goals. In traditional settings, teachers administer a test or quiz that reflects the goals of the unit. Students are then expected to represent their understanding in a single way. This format privileges a certain kind of skill and talent.

"The solution is to retain intense and purposeful focus on the content of the curricular unit while creating flexibility in ways that students can demonstrate what they have learned" (Danforth, 2014, p. 156). The orange team used a wide array of assessments to evaluate student learning. Students were responsible for creating science portfolios to demonstrate growth over time. Students also participated in traditional assessment forms such as tests and essays. Products and performances were also incorporated. Students made videos and physical products that they sold on eBay. Formal presentations occurred after nearly every whole group lesson.

Standardized testing: "I'm not driven by tests" (Jeremy, observation, 4/12/16).

"I kind of don't care about test grades. I never looked at them as an assessment of what they've learned" (Jeremy, observation, 4/12/16). While Jeremy strongly resisted a teach for the test attitude, he still was obligated to administer state examinations. During the month of April alone, standardized testing in math and science consumed six out of 14 total instructional days. Since this school adhered to state standards, teacher evaluation relied on student performance data from annual tests. Jeremy posted in front of his classroom a list of nearly sixty content area standards that he needed to accomplish before state testing season. He stated, "I've been checking them off as I go" (Observation, 4/12/16). Jeremy used the content area state standards as a guideline to frame his instruction during science lessons. Large group periods of instruction extended science instruction beyond this list of state approved concepts to be covered.

In the weeks leading up to state testing, Jeremy covered the following topics in accordance with the content area expectation for eighth grade: light, refraction/diffraction, electromagnetic spectrum (EMS), Doppler effect, and sound. EMS was part of three day learning segment while the remaining topics were the focus of only a single day of instruction. Jeremy incorporated an alternative assessment on the last day of the EMS learning segment. The students were tasked with the creation of a video that explained the major components of the EMS. Sarah explained the project in this way:

> He [Mr. Ford] didn't want a video of us talking, he wanted pictures and voiceovers so we had to talk about electro, electromagnetic spectrum (smiles) that's a mouthful! Wavelengths of frequencies, the crest, and all that, for each slide it had to be radiowaves, microwaves, infrared waves, visible light, ultraviolet, x-ray, and gamma rays (Interview, 4/15/16).

Noel co-taught with Jeremy to demonstrate for students the production of voiceovers as part of a video segment students were responsible for creating using a particular online software package called Wevideo. Jeremy provided some further rationale for this assessment decision in the following passage:

> We rolled out Wevideo, [it] was the tie in component. So, [Calvin] Mitchell, we're using the medium as the tie. He is doing something, ah, great depression confessions, that's going to use a different Wevideo component. Then Spanish, is using Wevideo now. We needed to train all the students. So that the Spanish teacher could do this, we could do this, all happened as a backdrop. Do this as an alternate assessment. So the technology piece, which we consider to be in our curriculum, is the tie in point. Noel has been, was here for the other periods. A lot of times our co-teach will be the, get up and running (Observation, 4/12/16).

After Jeremy noted the connections made between content areas through the use of common technologies he then described the role of state and national standards and their influence on assessment designs. Specifically, he talked about how the state standard on EMS in part dictated the type of assessment used.

In between periods, Jeremy explained the assessment decisions he made with regard to the Electromagnetic Spectrum lesson series.

> The, electromagnetic spectrum chapter is viewed as little like, an anomaly. The first, um, goal that I gave is the actual state standard. It's only tied to one, standard. I have like, I have fifty-nine…So, the flip side of that is, that that standard is really boring. Ok, if you really read it. But as a science teacher, I feel like the electromagnetic spectrum is fascinating. There's where my professionalism as a teacher comes in. I'm gonna give them something to tie it to and teach them the whole spectrum. And teach them the relationships that are in the spectrum cuz those are the nuances and also I know they need

> it next year. For earth science next year, their better their understanding of the electromagnetic spectrum, the better off we are…Cuz I only have one objective, it's a great opportunity for alternative assessment (Observation, 4/12/16).

The team tried to minimize the impact of standardized testing on their integrated focus. Students were expected to pick up where they left off on projects and group assignments directly following episodes of testing. Teachers purposefully incorporated project-based tasks in afternoons after morning testing in order to give students an outlet for creative expression.

For the team they have to actively confront what Kerdeman (1998) describes as a tension between familiar and strange. Standardized testing has become an all too familiar concept to those with experience in K-12 education sector. Teachers want to enact engaging curriculum that focuses on in-depth connections between subject areas. However, teachers must also prepare students for and administer standardized tests as part of professional responsibilities. The team draws from their professional practice to try to simultaneously comply and confront these forms of assessment. "The concepts are the same, the standards that we are addressing are the same. The difference is the teaching of the lesson, and its been exploited so that we can overcome some of these constraints" (Jeremy, PD event, 5/10/16). The team uses standards to guide their instructional decisions without succumbing to explicit test preparation. The team maintained the stance that integrated STEM approaches enhanced the learning process making test preparation unnecessary.

Jeremy also considered how the NGSS impacted his assessment decisions. At the time of this study, however, they were not yet approved by the state.

> The Next Generation Science Standards has an electromagnetic section that is substantially more robust, so I'm look at that, so this all of a sudden has a place. And

> kind of allows me to assess it differently. So I'm looking at this assessment, cuz it's a pretty tight assessment, so. It's not a test, they haven't memorized anything, so. We're moving away from that anyway (Observation, 4/12/16).

The team remained un-waivered by national standards reforms. They built capacities and processes to adapt to outside change. The team handled shifting in Common Core State Standards and associated assessments with ease. Terri noted, "We haven't had a ton of changes to adapt to the Common Core, I wouldn't say, because um, we just use our curriculum as a conduit to teach those" (5/20/16). While state and district mandates created navigable barriers, the team struggled most communicating integrated STEM work with community partners.

Innovation framed as deficit: "quote unquote, stupid team" (Lee, Interview, 6/15/16)

The teachers and students noted an obstacle that emerged based on outside interpretations of the integrated STEM model from various stakeholders. While my study focused on how the teacher and students made sense of STEM integrated instruction it was also important to note the ways that the broader school community also framed this model.

Differentiated instruction is one of the six district-wide initiatives. The VCM district gained a reputation for serving students with special needs labels. There is a high rate of movement into the district by families with children with special needs because of the perceived increased level of support. In my first interview with Noel she stressed the importance of representing material in multiple ways: "You know differentiation benefits everybody" (interview, 4/5/16). Noel believed she was selected for the team by the administration because of her inclusive stance. She said, "I did my masters program in special ed, um, it's an area of interest for me. So one of my things was co-teaching" (interview, 4/5/16).

The team enacted this district-level goal by blending instructional approaches, collaborative groupings, and technological educational supports. Jeremy told a reporter conducting a story on the team, “We have 96 kids on our team. We had 96 different jobs, and if that job is not done by that one student, then the job is not completed for the project” (Newspaper article, 3/9/16). They valued each student and prepared them to interact with one another, communicate their learning to others, and express understanding through a multitude of media.

In past years, both Jeremy and Annie taught accelerated classes as part of a tracking program for math and science. Both programs featured content-dense coursework with a strict pacing schedule. When this integrated STEM model was developed they no longer taught the high ability courses because of scheduling conflicts and the need for greater latitude to present curriculum in new ways.

Annie commented on the stigma associated with their integrated STEM model.

> Annie: Um, I think, we’re, we’re trying to give all kids the same opportunities within the building. Um, honestly there has been a negative impression of the team, from the public view…and we are really looking to change that perception, um, from the outside so that they can see that we can gear it, and we can make all kids successful using project based learning.
>
> Meg: How did you get an understanding that it was like, a negative?
>
> Annie: We, when we first started, we had a large population of special ed students, it’s just how it PLAYED out…
>
> Meg: Ahh, huh.

> Annie: …The whole new thing that excel piece, I think people just jumped on to THAT, they said, and just 'There's just making this, for the not so smart kids (whispers)' (Interview, 5/19/16).

The students also internalize this negative perception that they are somehow lesser due to their participation on the orange team. Despite Lee's tremendous academic success he described the orange team collectively as the "quote unquote, stupid team" (Interview, 6/15/16).

Student recounted on orange team participation brought to light the social stratification that actively played out in the school based on areas of difference such as disability, gender, and race. "We all view people through socialized lens of group membership-theirs and ours. This socialization is always at play," as it was at play in this school (Sensoy & Di'Angelo, 2011, p. 38). Students perceived to diverge from social norms gained an acute awareness of the structures in place that continued to disadvantage them from counterparts that adhere more closely to dominant groupings. Out of the ten students I interviewed, only two students explicitly noted the stigmatization of the orange team. One student, Lee, had a distinctive speech pattern and worked in the resource room during study hall periods. Zara, female student of Color, mentioned that she had difficulty sitting for long periods of time. Both seemed to possess an intimate awareness of the greater social stigmas and questioned their own placement in the orange team as a result.

Below is how Zara explained the process of separation due to perceived intellectual ability:

> Zara: I probably would say that the grade is split into two groups and one team is, some people call it the smart team,
>
> Meg: Oh really?
>
> Zara: But I don't really think so, yea know, I don't think that's true, it's, how you learn. They split you up into two groups for how you learn (Interview, 5/13/16).

The team re-branded the model in order to combat this deficit framing. Each grade level divided into orange and blue teams. The seventh grade equivalent group, STREAM team, was known as the blue team while the eighth grade integrated STEM team was coded as the orange team. Within the school both teams referred to themselves by their color and not by their approach. “But, last year was very different because the blue team was the orange team and the orange team was the blue team,” Zara mentioned (interview, 5/13/16). It seemed as though reversing the color from year to year was a deliberate action on the part of leadership. This strategy hoped to equalize the groups and mask participation.

The following excerpt illuminated Lee’s feelings that accepted the orange team as somehow inferior to the other team. Sensoy and Di’Angelo (2011) defined internalized oppression as “internalizing or acting out (often unintentionally) that you and your group are inferior to the dominant group and thus are inferior” (p. 49). He disparaged his peers for not being intellectual enough or lacking social aptitude.

> Lee: So, I’ve been my own personal goal to not get out of the team for the benefit of being stupid (emphasis) quote unquote but to prove that while some of our team members are not the best representatives in that broad generalizations in all matters are in factual (inaudible because of pennies spilling on the floor).
>
> Meg: What do you think makes people think that?
>
> Lee: … We do have a lot of more people with a less than respectable demeanor and grade point.

Lee presents his own theory as to why this deficit framing had pervaded.

> Lee: When you think of orange team or STEAM team you think of the occasional, [2 seconds pause] flaws and inconsistencies we have. Those hold more weight, those are remembered far better (Interview, 6/15/16).

To address the stigmatized view of this model as less rigorous, Jeremy began to teach an accelerated biology course in addition to his participation on the integrated team. Jeremy openly rejected notions of tracking but was tasked with teaching an accelerated biology course. He said, "I do not personally agree with any concept of tracking what-so-ever that's my, I have very few soap boxes, that's one that I'll be willing to get on" (Interview, 6/21/16). The biology content area did not overlap with the 8th grade physical science curriculum. The accelerated course also had to be taught in forty period segments much like the high school schedule. It remained a challenge to innovate since the class presented yet another layer of complexity to Jeremy's teaching. Jeremy found it important to teach this course to send a message to the community that all ability levels can benefit from integrated STEM instructional models. Also, Jeremy had multiple years of experience using this model to draw from. Professionally it offered a new way to direct creativity and energy.

The reframing of integrated STEM as a deficit connects to stakeholder perceptions of constructivism overall. Hancy, Lumpe, and Czerniak (2003) explored school stakeholder beliefs about constructivism and the science-learning environment. Administrators, teachers, students, and community members were surveyed based on the following categories: (1) teaching for understanding, (2) instructional approach, (3) valuing the learner as an individual, (4) questioning habits, and (5) extensions of students' thinking. Administrators possessed more frequent positive constructivist beliefs than any other stakeholder group, much more so than community members. People tend to cling to traditional beliefs regarding teaching styles that typically include didactic teaching approaches (Hancy et. al, 2003). Constructivist classroom practices that view meaning making as a collective process directly contradict historical approaches. For this reason, community members may find it difficult to accept innovative curricular approaches. This integrated STEM model was positioned as unfamiliar to the community, contradicting status quo teaching. The stigmatization of this model could potentially be rooted in community beliefs of what teaching and learning "should" look like. Promoting mutual respect, possessing a sincere desire to work with students, and clearly communicating content remains generally uncontested in prior studies. The orange team contributed to student growth through authentic explorations of content within an environment that valued cooperation, creativity, and care.

In summary, STEM integration serves as a complex business that is not easily labeled. The orange team uses a combination of organizational and pedagogical approaches to redefine middle school STEM integration. Each day is carefully planned by the team collective to fit specific instructional needs through a practice referred to as dynamic scheduling. Daily instruction proved to be highly variable. Students engaged in design challenges, multi-day projects, field trips, and experimentation.

Teacher participants all assume clearly defined roles on the STEM integrated team and require the support of others in order to function. The team sought out opportunities to learn from one another. Teachers perceived labels such as STEAM as confining their practice. As a mechanism to adapt to new challenges, the team developed a four-step framework to guide decision-making. Curriculum was constantly adapted and negotiated by the team with a strong reflection on past practice. District supports in place assist teachers by limiting constraints for materials and resources.

The ways that the content areas are woven together as part of this team instructional model was also a noteworthy outcome. Due to some overlap with computational content, math and science are closest in topical alignment. All teacher team members were adept in the use of technological applications. Students were expected to use technology appropriately and independently troubleshoot. Technology mainly referred to digital spaces such Google classroom and software packages such as Wemovie and TinkerCad. Engineering design challenges are sporadic but serve to build a platform to concretely apply science concepts. Engineering projects also fostered team community because all team members are actively involved. Social studies provided science content with rich contextual connections. ELA reinforced scientific practices related to communication such as argumentation and technical writing. Math adhered to stricter curricular guidelines than the rest of the team that limited opportunities for integration. When math and science did combine, students were able to engage in real life scenarios that evoked critical thinking and collaboration. Students struggled to engage in the highly social aspects of instructional tasks but recognized its importance as part of their growth and development.

With the push for interconnections between science and engineering explicitly named in the NGSS, as well as literacy across disciplines as outlined in CCSS documents, research on STEM integration will only expand (NRC, 2012).

CHAPTER 5: DISCUSSION, CONCLUSION AND FUTURE RESEARCH

"The new fabric, the new design, with intentionality" (Dr. Dina, PD event, 5/10/16).

Overview of study purpose and findings

Through interviews and observations of students and teachers, I gathered a sense of the personal journey of participation in this integrated STEM model. I wanted to understand how one integrated STEM team characterized this instructional approach. I explored the collaborative teacher process involved in the creation of an innovative curriculum and instructional models. I hoped to convey the common experiences of participation in this integrated STEM model to inform others interested in developing their own program or curricular packages. Using the hermeneutic circle of interpretation, I was able to understand the model both from a system level and from the experience of participation. I examined how the context shaped how this model was enacted as well as how participants dynamically influenced the model through interactions and interpretations.

I opened the black box of this integrated STEM classroom to inform show others what this form of teaching and learning looks like. I found a series of essential elements of experience that were used to characterize this model. The following aspects were extracted as themes based on data from the observations and interviews: (1) project-based learning, (2) flexible scheduling, (3) co-teaching, (4) social skill building, (5) technology and (6) innovative use of space. I found that teachers collaborated constantly and viewed one another as resources. Collaboration was one way the teachers defined this integrated STEM model: "It is just planning together, taking advantage of opportunities and flexibilities you have together as opposed to just doing it separately" (Jeremy, interview, 6/21/16). This integrated STEM model varied from year to year depending on physical parameters, such as space for projects, staffing changes and student needs.

Teachers reported feelings of professional invigoration from participating in this model. Students found learning activities engaging, particularly design challenges that explicitly combined all of the STEM disciplines. These findings emphasize the dynamic nature between contextual aspects of the model and the active participation of teachers and students. These findings support the use of integrated STEM to bridge the gap between the science classroom and the real world.

In this chapter, I discuss how the findings from my study connect to similar studies within the field of education. I also articulate the implications of the study, addressing the teachers, K-12 administrators and professional developers. I have also identified five considerations for the implementation of integrated STEM models, including potential challenges that may surface. Finally, I discuss the limitations of this study as well as future directions. I also found it important to reveal my own positions on education and this research process in the form of an autobiographical reflection.

Situating findings using prior research

I argue that integrated STEM instruction makes science more accessible to students. Under this model, students receive science information bundled with other subject areas. This approach more closely mirrors our interactions with science in the real world. Students can draw more readily from their prior experiences to engage in science learning. Assimilation of knowledge from the classroom to the new situations becomes a smoother process. Bransford, Brown and Cocking (2000) have outlined the transition from novice to expert. To reach expert status requires opportunities to connect knowledge from one area of study and apply it to new situations. By situating science content among other disciplines, students were able to gain a more holistic view of all involved concepts. Students were expected to use science knowledge to solve authentic problems. Through STEM integration, students can more readily relate classroom concepts to real world contexts.

This study revealed that approaches such as project-based learning and use of latest technologies retained student interest. Students that express an early interest in STEM tend to gravitate toward STEM careers later in life. Prior research has suggested that grades five through eight are pivotal years for building STEM interest. Osborne, Simon and Collins (2003) have reported that often student interest in STEM declines during the middle school years. Guzey et al. (2016) have further noted “providing quality-learning opportunities for students is necessary to help students develop and maintain interest in STEM fields” (p. 411). Eighth grade is a pivotal year for identity formation. Opportunities to engage in integrated STEM open the door to interest in future STEM experiences. The orange team also offered extracurricular activities such as Arduino Club, an electronic prototyping group, that extended integrated STEM beyond the classroom.

Stinson (2004) has referenced the situated perspective of math education as a way for students to build knowledge as a community of emerging scholars. He further claimed that “mathematics is not learned from a mathematics textbook and then applied to real-world contexts, but is negotiated in communities that exist in real-world contexts” (p. 15). Through the use of real-world contexts, the subject area becomes more attainable to all students in the classroom. The notion of empowering inclusion, as defined by Stinson (2004), is that it provides greater opportunities for students that may not initially be recognized as having mathematical abilities because it is inconsistent with dominant white, middle class conceptions of the subject matter.

Szybek (2002) has described two approaches to science education: one in which pure science is applied and one in which science knowledge is used. Szybek (2002) has argued that science knowledge put to use offers more opportunity for students to be included in the development of science knowledge. Through discussion, students and teachers collectively determine a problem that requires some form of solution. Students then work to remedy this problem by engaging in scientific work, such as experimentation. The model Szybek (2002) used to represent this process includes the following: (1) The delimitation of something as an experience of difficulty; (2) The construction of a well-formulated problem; (3) Solving the problem; and (4) Evaluating the relevance of the solution as a remedy for the difficulty pointed out in the first step (p. 550). This framework allows science meaning to emerge in a way that is compatible with students' lifeworlds. Lifeworlds or ways of being in the world are informed by our surroundings and the people with engage with on a daily basis (Heidegger, Macquarrie, & Robinson, 1962). The orange team's integrated STEM model aligned closely with Szybek's (2002) framework to build lifeworld connections with science at school. This integrated STEM team focused much of their whole group instruction on open-ended problems with multiple solutions. Problems posed to students were contextualized on either a local or global scale. Students were encouraged to pose new problems, investigate these problems and evaluate each other's work. Meaning-making in these instances became generative and relatable to home and community.

Beane's assertion that "disciplinary transcendence does not necessarily mean cutting oneself off from the ground where one stands, but rather widening one's horizons (Giri, 2002; Wall & Shankar, 2008, p. 552), has been affirmed by others in the field. This integrated STEM model interpreted the purpose of instruction more broadly. Social engagement was incorporated by design. Students were expected to communicate their understandings and justify their positions on social issues. Science concepts were embedded within a wide array of learning activities.

Price and McNeil have supported the notion that “a basic goal of science education is for students to take on and, in some respects, embody what they are learning in science in order to live and act in the world, either as citizen and/or scientist” (2013, p. 503). This integrated STEM model allowed students to be active science learners. As part of this approach, participating teachers presented science as situated within a larger societal context. The teachers transformed the classroom into a space where subject areas’ boundaries were minimized. Teachers encouraged students to look for interconnections between all content areas to solve authentic problems. Holland et al. (1998) have described “spaces of authoring” as student responses that include “arranging the identifiable social discourses/practices that are one’s resources” (Holland et al., 1998, p. 272). In this way, students are able to apply their experiences as classroom learners and community members to develop and enhance the science inquiry process. This integrated STEM team transformed “spaces of authoring” through the use of cooperative groupings and dynamic instruction that involved multiple teacher perspectives (Price & McNeil, 2013).

Study implications

I studied one integrated STEM model of instruction at length to understand how it operated on a daily basis. While this was only one version of STEM integration, a number of lessons can be learned from this close investigation to extend conversations in both research and practical circles.

The teacher teams acted in a nearly autonomous manner to develop and sustain the integrated STEM model of instruction. This particular teacher team identified opportunities within their system and structure that they could manipulate. They found that pooling instructional time was one aspect of the existing infrastructure that they could actively modify. Once they viewed instructional minutes differently, they were able to gain traction to innovate. This teacher team further engaged with other professionals outside of their district on a regular basis through professional development events. These professional development sessions served as sites of exchange for new pedagogical approaches. Jeremy and the team were able to openly reflect upon and communicate their engagement within this model. Since this model has existed for five years, a number of aspects emerged as portions that had been taken for granted by participants. Teachers referred to daily schedules using insider terminology and rebranded all classroom spaces based not on subject, but function. Multiple modes of digital communication, for example Twitter, were a norm for both teachers and students.

The group, comprising six teachers and one paraprofessional, developed the entire model from scratch with minimal support from the district or outside organizations. Beyond the visitation of two other STEM schools, there was no other major professional development or external funds used during the creation of the model. The teachers enacted their vision of innovative schooling and continually modified their instruction. For instance, the energy project was conducted in June during the final weeks of the 2015-2016 school year. Every year the energy project is launched as a culminating activity. The implementation of this project varied based on student feedback, content area goals and physical parameters. During this study, the orange team was relocated to the high school, placing limitations on use of classroom space. For this reason, the teachers used a digital software package, Tinkercad, to create digital models of power facilities rather than physical representations that would require space and storage. Instructional decisions were made as a collective team that leveraged individual strengths.

This teacher team evaluated one another's curricular goals and dedicated time based on instructional need. The team rejected the school-wide practice of 40-minute periods. They created a unique scheduling system that viewed instructional time as dynamic. The team streamlined the scheduling process to maximize the efficiency of the classroom interaction. Lesson periods ranged from 10 to 128 minutes depending on the increment of content and associated learning activities. Technology also influenced the use of instructional time. Jeremy recounted a major shift in his practice as a result of technology. Before students had open access to the Internet, Jeremy reported that his teaching focused more on factual items, such as the distance from Earth to Mars. With the onset of computers, students were able to access this factual information quickly and as a result, no longer required factual recitation from the teacher. Consequently, Jeremy was able to spend more time on critical thinking skills and the application of science knowledge. Computers acted as a reference tool as well as an area of storage. Through Google classroom, students accessed notes outside of class, participated in activities that reinforced concepts and turned in assignments during free periods, without disruption. Manipulation of time allowed for greater instructional efficiency. The team was thus able to utilize more time for long-term projects that promoted critical thinking and real-world application.

With increased agency to schedule time and design curricula, outside reforms did not pose as noticeable a threat to this integrated STEM teacher team. The team anticipated latest standards-based shifts in teaching and learning expectations through professional networking. For instance, the team incorporated engineering design practices into project-based learning projects five years before the NGSS were approved by their state. The shift toward focusing on informational texts, as outlined by CCSS, occurred gradually over a 5-year period. Since this integrated STEM model combined content areas and contextualized STEM subjects, all of the teachers on the team were responsible for the development of reading and writing exercises. Scientific information was communicated using multiple mediums. Students were also given opportunities to build and support evidence-based claims during blended English and science instructional periods.

Teachers enhanced one another's knowledge of their own subject areas through co-teaching and team schedules dedicated time to observe each other on a daily basis. Of the 1,383 minutes of recorded classroom footage, Jeremy taught independently for only 14 minutes. Nearly one third of observed lessons were conducted with all team teachers present. Teachers considered teaching a social endeavor as well as a continual learning opportunity. This integrated team was constructed "as a community rather than a collection" (Giri, 2002; Wall & Shankar, 2008, p. 552).

Healthy relationships grow from collective trust, personal chemistry and feelings of emotional safety. Support for each other came in multiple forms, from emotional to informational. For instance, Deb covered classes when teachers were ill. Jeremy reconfigured the daily schedule to reduce frustration during standardized testing. This particular teacher team learned from one another through open dialogue and constant observation. Since each teacher played a different and valuable role on the team, the group relied on one another to collectively function. This form of teaching involved the synthesis of many different content areas, a multitude of approaches and additional obligations, such as leading professional development sessions. The interconnectedness of the team not only enhanced the content covered in class, but also served to motivate and reinvigorate these professionals. All orange team teachers described the integrated STEM experience as "fun."

Co-teaching reshapes traditional models of instruction by providing space for the co-construction of teacher narratives based on classroom experiences. Roth (1998) conducted a 3-month intensive study of science teachers participating in a co-teaching model of instruction as part of a school-wide improvement plan. The goal of the co-teaching experience was to pair novice teachers with veterans to bolster skills such as questioning and providing feedback. Roth (1998) found that three types of teacher learning emerged as a result: (1) in-practice learning; (2) ability to engage in conversations about practice; and (3) ability to synthesize theory and practice. Storytelling revealed aspects of teaching that would otherwise not have been unearthed: "Once explicit, these aspects contributed to a change in their professional discourse in which they made sense of classroom events" (p. 387). Expert teachers could support novice learners in ways that allow for continual growth. Opportunities for reflection on experience allows for the emergence of a new identity, one of an integrated STEM teacher.

Wall and Shankar (2008) have argued that teacher experiences should be central to the process of integrated model design and development. The teacher team claimed that their model of integrated STEM was not explicitly informed by educational research. Jeremy noted that the development of this model, "wasn't done legitimately from like, an educational standpoint. Ok, let's start with this theory and work our way down" (Interview, 4/5/16). Teachers also carry with them certain "ways of being" that shape their instructional decisions and scientific understanding. For instance, Noel and Terri train horses after school, while Sam's previous career was in the field of carpentry. This integrated STEM team took advantage of personal experiences to create science lessons that connected with both the students and the teachers. Each member of the teacher team brought a different set of pedagogical strategies to integrate into the STEM approach. While teachers de-emphasized the theoretical aspects of their work, many components of the model were well substantiated within the educational field. For instance, cooperative student grouping is central to constructivist learning practices that recognize social interaction as fundamental to meaning making (Panitz, 1999).

Eger (1992) has argued that there is a significant disconnect between students' lifeworld and scienceworlds. The term scienceworld means the socially constructed setting where science is conducted. In traditional settings the tools of science teaching render learning unfamiliar and distinctly different from experiences outside of school. I contend that integrated STEM curricula serves to bridge the gap between student lifeworlds and scienceworlds through teaching tools that are more recognizable to the student. Indeed, Bevilacqua and Giannetto (1995) have even opposed the use of textbooks to support science learning, claiming that "they leave out extraordinary science, but also the science they deal with is not that normal" (p. 6). Textbooks do not include the historical nature of discovery, excluding multiple interpretations and neglecting to make transparent the process of theory generation. As part of this integrated STEM model, students wrote narratives about Sir Isaac Newton in the beginning of the school year. These narratives were based on multiple texts that positioned Isaac Newton and his discoveries in conflicting ways. Students were responsible for interpreting Isaac Newton's work as well as situating his actions within a historical context. Alternative interpretations of science were not hidden from students, but encouraged (Bevilacqua & Giannetto, 1995).

The focus students from this study represent a cross-section of the school-wide student population. The interviewed students expressed their intersectionality across multiple areas, including gender, race, ability and language. Nearly all of the focus students reported an interest in pursuing a STEM career. Students who participated in this integrated STEM model felt motivated to learn through hands-on approaches. This integrated STEM model gave students the opportunity to confront complex problems and develop solutions with their peers. These skills can support their STEM learning throughout their academic careers. Students who experience integrated STEM approaches to instruction may be more motivated to learn STEM coursework in the future.

This study found that the teachers employed many inclusive practices such as audio-visual representations of lesson materials and performance based assessments. These practices served to increase accessibility to STEM content. The 2005 National Assessment of Educational Progress reported that less than 30% of students with disabilities perform at the most basic level of STEM area proficiency. Struggle in schools leads to minimal representation career settings, people with disabilities comprise a meager 5-6% of the total STEM workforce (Leddy, 2010). STEM integrated instruction may offer one small pathway for more students to gain better access to STEM (Bargerhuff, 2013).

Implications for practitioners

Phenomenological inquiry emphasizes the experience of engagement within a specific context. This study provided an insider's look into the work of integrated STEM teaching and learning. This study was meant to inform other teachers, administrators and professional developers that are interested in developing similar models of instruction at their own school or within their own district. Many prior studies that concern STEM integrated instruction have focused on short-term interventions that were supported by universities or outside organizations. This model is significant because it was created entirely by teachers. The orange team collaborated on a daily basis, both in-person and through text messages, to sustain this model over a 5-year period. Herro and Quigley (2016) have discussed the need for long-term teacher commitments to sustain integrated models. They found that new adopters of integrated instruction struggled to seamlessly blend tradition with novelty. In the following, I identify five considerations for integrated STEM teachers:

- Planning time and development of process
- Close proximity and space variety
- Openness to innovate
- One-to-one student access to computers
- District support from a distance

Planning time and development of process

The teacher team dedicated one block of planning time each morning to the development of this model. They also used a common lunchtime to negotiate instructional decisions. The team developed a stepwise process that defined parameters, generated communal learning goals and explored creative ways in which to use both time and technology. This process enabled them to circumnavigate many barriers created by the pre-existing school structure and mandated policies.

In order to combine compelling instruction with richly interconnected content exploration, the teacher team planned constantly and engaged in reflective conversations about their practice. The schedule allowed the teachers to convene at multiple points throughout the day to discuss their work and adjust accordingly. The team was so accustomed to these procedures that at one point Jeremy extended class by 10 minutes without causing a major disruption to the other classes. The team felt professionally enriched by one another and appeared to enjoy imparting their knowledge to other educators. Without any formal designation, the team interacted symbiotically in a way DuFour and Fullan (2013) have described as a “professional learning community.”

Close proximity and space variety

Clustered classrooms allowed for continual collaboration by the teachers. Wall and Shankar (2008) have confirmed the importance of geographical proximity to foster collaborative efforts. Students also benefit from classroom spaces that are in close proximity to one another. When classrooms are located near each other, students are able to move freely from one to the next. Students are further able to work on design challenges at their own pace and easily consult multiple teachers. The orange team required a wide array of spaces to accomplish their work, including a large group room, a work area for design challenges and smaller breakout areas for debriefing. During this study, teachers reserved the auditorium on a weekly basis for whole group meetings and instruction. Students used the hallway for small-group breakout spaces.

Since the completion of this study, the team has returned to a renovated middle school that addressed the need for fluid classroom spaces. The science classroom has since expanded and now contains workstations. The renovation reconfigured the other classrooms as well and equipped them with moveable walls to accommodate large groups. All of the orange team teachers had classrooms that were within feet from one another. Visitors to the school could easily identify the team based on the bright orange walls throughout the designated wing.

Interest in innovation

The team based lessons on open-ended problems that celebrated discovery and strengthened student-to-student interactions. The team also exposed students to unpredictability within integrated STEM contexts. Students gained encouragement from teachers to develop their own process with proper justification for their decisions. Dalke et. al (2007) have identified a change in teacher's roles within innovative models of instruction. Teachers simultaneously act as facilitators, coaches and cheerleaders. Teachers require sufficient experience to guide students in the process of reflection and the synthesis of content. Problems such as the volume of the classroom space evoked emergent pedagogies as referred to by Dalke et al. (2007). Students were challenged to strategize to determine the best answer. The teacher team observed within the present study enjoyed the journey of learning alongside students. They remained open to new ideas and demonstrated a willingness to experiment with new pedagogical approaches. Wall and Shankar (2008) have also found that a readiness to innovate is an important factor of long-term success of interaction across disciplines. Critical reflection of teaching decisions is not perceived as discordant to innovation but rather, a necessity (Wall & Shankar, 2008).

One-to-one open access to computers

This integrated STEM model infused technology into daily practice as a vital component of instructional delivery and assessment. Students received all-day open Internet access that allowed them to learn how to engage in digital communication and informational platforms. Student used Chromebooks on a daily basis to create and manage a majority of their assignments on Google classroom. Black and William (2010) have associated increases in student achievement to sustained use of technology. The team continues to expand their technological repertoire to maximize digital spaces for content area expression. Technology allowed the teachers to design differentiated curriculum further increasing content accessibility. Furthermore, the use of technology bolsters critical thinking skills by increasing the cognitive demand of learning tasks. During group projects, orange team students divided learning tasks, coordinated their efforts and produced results. Students learned to responsibly engage with each other, with digital communication platforms and with a wide array of software.

District supports from a distance

The team worked multiple days in the summer to strategize for the upcoming year. The teachers received classroom coverage to participate in district-led professional development sessions: 78 in total over a 5-year period. Wall and Shankar (2008) have also expressed a need for administrative resources and support in the form of stipends, conference funding and mentoring opportunities. The district in the present study encouraged the team, but did not intrude on daily decision-making.

Adams (2012) has suggested that school systems with high levels of trust encourage greater capacity across all levels, from leaders to teachers and students. Administrators supported teacher efforts from afar, offering technological resources or expertise upon request. While the teachers did receive recognition for their work, they found it beneficial to maintain a low profile to maintain positive relations with the greater school community. An overabundance of accolades from the administration created tension between the team and the greater school community. Brookfield (2015) has referred to this as cultural suicide, or the alienation of innovative teachers from their school community. Brookfield (2015) has further stated "raising critical questions regarding commonly held cultural assumptions engenders resentment and suspicion" (p. 62). To cultivate a unified school community, administrators should consider protecting teacher innovators through discrete encouragement.

Rich and Almozlino (1999) have also found that department policies and school norms heavily influence the educational goals set for student learning. Districts can play a role in creating environments suitable for innovating STEM. The superintendent at VCM expected teachers to model the process of decision-making. The school leadership provided common planning time and professional development days for curriculum design. Educational leaders encouraged this teacher team to modify existing organizational structures. Instructional time could be manipulated free from administrative oversight. Administration placed minimal limits on the use of non-traditional spaces, such as hallways, for instruction. The district also purchased laptop computers in the ratio of one-to-one for student use that supported the integrated STEM learning goals.

A sustainable STEM integrated curriculum requires a supportive school culture. McEwin and Greene (2010) have found that 90% of schools deemed “high performing” were organized into interdisciplinary teams. Common planning time was also afforded more readily in high performing schools, 40% offered weekly opportunities compared to 28% in random schools. School schedules in high performing districts are also more flexible and include greater levels of cooperative learning. In such schools, inquiry-based instruction is predominate, with less emphasis on direct instruction.

Implementation challenges

The studied integrated STEM team also encountered barriers that hindered the envisioned implementation of the model. The obstacles faced by the team can inform others by drawing parallels between the present contexts and other educators’ own contexts. Jeremy shared during the professional development session, “We have limited space, class size, we have all these reasons why you can’t do it” (5/10/16). Four major constraints to this particular model of integrated STEM instruction emerged:

- Assessment of projects
- Traditional spaces
- Standardized testing
- Feelings of isolation

Assessment of projects

Negative student feedback centered on methods of grading group projects. Teachers found it difficult to incorporate accountability structures during long-term projects. During interviews, three students perceived the division of work to be unequal and that they felt themselves to have completed a majority of the work. In the first year of implementation, the team provided one scenario for students and required them to divide labor. This practice proved challenging for students. Over the years, the teachers communicated roles and responsibilities for each student and a timeline for completion. Assessments tended to be based on the creation of a product and not a reflection of the learning process.

Dalke et al. (2007) have distinguished between assessment and evaluative practices as follows:

> Assessment is commonly described as a formative process designed to support the learning of meaningful academic content. It differs from evaluation, where the focus is summative and involves judgment about the attainment of some standard level of performance. Assessment can be used to determine how well educational goals are being met and how to alter instruction to meet those goals more effectively. Evaluation, on the other hand, is an effort to pass a definitive judgment on the achievements of particular students and, in many cases, on particular teachers and pedagogical practices as well (p. 124).

Based on the definition provided by Dalke et al. (2007), the orange team focused much of its grading efforts on evaluating the final products of project-based instruction.

A myriad of contextual factors can challenge the sustainability of integrated STEM curriculum and instruction. Many of these obstacles are pragmatic in nature, ranging from discipline-focused standardized assessments, school-sanctioned curriculum guides and strict instructional periods (Venville et al., 2002). School structure can limit the viability of integrated models due to incompatibility with current systems of planning time, resource access and scheduling. Organizational parameters are indicative of an educational ideology that historically favors silo subject areas and the transmission of discrete factual information (Wall & Shankar, 2008).

Traditional spaces

On 20 separate occasions, the orange team teachers mentioned the inadequacy of instructional spaces. Space limitations emerged as a constraint for the teachers, especially during the year in which this study was conducted. During the 2014-2015 school year, the team was located in a single wing of the local high school. Classrooms were shared with teachers and the music department frequently booked the auditorium. The team searched for areas beyond the classroom that are typically not used for instruction. They used hallways for breakout sessions during design challenges. Whole group activities needed to accommodate over 100 people and the only space that could sufficiently accommodate so many people was the auditorium. While the auditorium worked well for formal presentations, it did not easily allow for face-to-face interactions. The team anticipated a renovated space that could accommodate their dynamic needs. A study conducted on Project Lead the Way, by Stohlmann, Moore, McClelland and Roehrig (2011), has echoed these concerns. Stohlmann et al. (2011) found a general lack of appropriate space for work and storage to complete project-based learning activities.

Standardized testing

Standardized testing interfered with over six instructional days in the month of April alone for this integrated STEM team. The team faced pressure to cover a great deal of content and skills prior to these examinations. Standardized testing disrupted the integrated STEM teaching approach.

Feelings of isolation

This model of integrated STEM was applauded by the district and received national attention. Based on teacher accounts, publicity from the outside created rifts between the team and the other middle school teachers. Jeremy reflected on this:

> I think that we polarize in the sense that the kids early on REALLY identify with it and then they almost view themselves as something different and then we were so far out and enjoying it, we viewed ourselves as a real community and I think it was that I think it was the difference in community between the kids then meshing back together that really polarized it early on (Interview, 6/21/16).

This polarization of the integrated STEM model led to attempts to rebrand. It also contributed to the interpretation of the orange team as a model of instruction only for students with hands-on learning styles.

Teacher participants also experienced feelings of isolation within the team setting. The math teacher, Annie, mentioned in three audiotaped sessions that she felt isolated from the rest of the orange team teachers, claiming: "I still struggle A LOT with the projects and being part of the projects…science and social studies, even like, ELA, we have a bit more, to play with there" (Annie, interview, 5/19/16). Feelings of isolation may be due in part to district-level expectations and organization. The school neglected to ask her to attend professional development sessions on content area literacies. Annie's schedule also conflicted with the other teachers' lunch time. She ate the period after her teammates and usually by herself. Since many professional conversations occurred during lunch, the team felt obligated to ask Annie's approval for plans that had been made. The team positioned Annie as a gatekeeper with the ultimate authority to either approve or deny projects. However, many of these feelings of isolation came from administrative decisions. Integrated STEM teachers all need to have an understanding of content area literacy. Common lunch periods for integrated STEM teachers should include all members in order to properly function as a mid-day check in.

Study limitations

I chose to apply a unique methodology to study this integrated STEM model. Phenomenology as a method has been criticized due to the possibility of limitless interpretations. Bruns has referred to hermeneutic phenomenology as a “loose and baggy monster” (Kerdeman, 1998, p. 241). Furthermore, integrated STEM education as a concept is also ill-defined. Lederman and Niess (1998) have advocated for the standardization of language associated with integrated STEM models and are critical of the integrated STEM movement because of the perceived degradation of subject area. From their perspective, subject areas are viewed as unified wholes that lose core meaning when fragmented or blended with other disciplines. Venville, Wallace, Rennie and Malone (2002) have acknowledged that “integration is a particular ideological stance which is at odds with the hegemonic disciplinary structure of schooling” (p. 46). Rationalizing the use of a complex methodology to study a debated and emerging instructional model proved a considerable challenge.

Due to the complexities of the human experience and the poetic nature of phenomenology, I struggled to present a coherent interpretation of the lived experience of my participants. Using phenomenology as a method also limited my ability to generalize my work for use in other contexts. However, since each context is inherently different, it is impossible uncover the single, most suitable context for students to engage in science understanding. Therefore, I position my findings as merely tentative suggestions to those interested in the practice of integrated STEM education.

From a methodological standpoint, verbatim transcription was completed in several instances after the 24-hour window, when memory retention is greatest. However, the richness of my data may have been impacted by the decision to delay. In future studies I will strive to transcribe interviews at a faster pace.

Hermeneutics allowed me to more closely examine the interrelatedness of context and participation with a context. I used hermeneutics to more accurately interpret what was conveyed through the use of observations and interviews. However, one instance from my investigation stands out as a misinterpretation of the studied integrated STEM model. I used research techniques such as member checks and peer debriefing to improve the trustworthiness of my data. I share a misinterpretation of the orange team model by other educators from my observations in the field:

> During professional development sessions organized by the district, visitors are encouraged to observe the orange team in action. In small groups the educators from all over the state and multiple countries, 20 in total, sprinkle into each classroom to observe the orange team model. The entire observation lasted 5-10 minutes. On May 10, 2016 a group of visiting educators inspected Annie's classroom, the "Think Tank." At that point in time, Annie was teaching her students an acronym to remember a mathematical computation. After the visitors left the classroom space Annie stuck her head out from the classroom and with a big smile on her face said: "They thought I was teaching English." The visitor rendition of the experience vastly differed from Annie's account. First, this flagrant misinterpretation stems from lack of time spent at the study site. Second, the visitors came with presuppositions concerning what teaching and learning should look like within this unique model without an awareness of such bias. I wanted the

depiction of the orange team to closely overlap with that of my participants. To accomplish this goal, I needed to spend ample time with the participants as they taught, planned and ate lunch. From April to June, I was fully engrossed in my study site, collecting a variety of data sets.

Access

An excerpt from my research memo depicted one struggle I encountered entering the space: "The attendance person did not want to allow me to enter today. She was not the usual employee there and was not familiar with my research. Jeremy had to come down to pick me up at the door. He found me a substitute teacher badge for me to wear for the rest of the duration of the research study." Jeremy seemed exasperated by the lengthy protocol required for me to gain access to the classroom. I negotiated my access by gaining a favorable position with clerical staff and undermining the front desk authority. Jeremy basically outsmarted the system to provide me with badge access. Interestingly, this positioned me as a substitute teacher to other staff members. Staff mistook me several times as a fill-in for teachers who were out (Memo, 5/6/16). Since Maple Tree High School temporarily housed Elm Tree Middle School, the staff that monitored the entranceway lacked familiarity with the orange team, its staff and this research project.

Furthermore, the teachers limited my access to digital communications. For instance, Jeremy initially offered to put me on the text message group, but then later rescinded his invitation. I think because this program had been considered rather high profile they may have been fearful that I could report something that was not complimentary. The text messaging served as a main outlet for planning, but also may be used as a space to "let loose" in some respects. Deb mentioned that the text messages can get a bit unprofessional. While I would have loved to be privy to these conversations, I also understood the need to distance themselves from me as a researcher. The teachers opened up their classrooms to me and used time from their free periods for the purpose of my study, both of which require a certain degree of vulnerability.

They also discussed placing the focus students in one group. This would have made my role as a researcher much easier. However, the team did not end up carrying out this option, demonstrating dedication to the students and not to my needs as a researcher. I actually found this decision to be refreshing since it proved that student groups were formulated entirely based on need.

Space and time

In my very first interview with Jeremy he stressed that this year was unusual because of the team's displacement from their normal site of instruction. "We are currently at the high school, not in our ideal situation so we are trying to take a non-traditional approach in a very traditional setting," he said (Interview, 4/5/16). The team spent the last two years at the district's only high school in anticipation of an updated facility. One wing of the high school was provided for the eighth graders and there was little flexibility with regard to space. This study investigated the phenomenon of science teaching within integrated contexts from April to June of a single school year. During that time, the orange team had to accomplish instruction in a space designed for high school students. A reoccurring theme during teacher interviews involved the constraint of space. This temporary location left teachers feeling a lack of ownership. An extended study could provide a better barometer for spatial constraints and their long-term impact on novel curricular enactment. Furthermore, the state had not yet approved the NGSS standards. Thus, it will be interesting to observe how developments in standards shape the planning and instruction of the orange team model in the future.

Autobiographical reflection

I am currently a faculty member in a largely cultural foundations of education department at a liberal arts institution in the Northeast, as well as a fourth year doctoral candidate in science education. I gravitate toward innovative approaches to teaching and learning that promote conceptual understanding and real-world connections. My professional teaching experience has strongly shaped my current views. I taught middle school science at an alternative school where the school's leadership embraced innovation. I also taught for four years in the public school system as an "integrated" science teacher, where I blended discipline-specific content with coursework related to vocational trades.

As part of my experience in the K-12 setting, I developed a project-based curriculum for natural resource management students that responded directly to their interests and the local environment. My students participated in a two-year long aquatics exploration that first involved the watershed mapping and water quality sampling of local streams. Students were responsible for tracking patterns of change associated with variability of discharge rates and macro invertebrate indices. Students discovered first-hand the implications of environmental changes and human development on stream health and biodiversity. Another outcome of this project was that students were made aware of the fact that their scientific work was not conducted in isolation. Students sent macro invertebrate samples to expert entomologists and connected with these scientists through academic virtual chat rooms. Students then brought their knowledge of aquatic systems back into the classroom by designing their own aquaculture set-up, complete with three 200-gallon tanks. Students shared responsibility for raising native trout species for eventual release as part of a greater conservation initiative. I tasked students with collecting and fertilizing eggs, maintaining proper water chemistry levels and temperature and calculating feeding rates based on overall mass. After conducting research and visiting local systems, they increased their operation from 50 to 200 gallons. They devised a commercial operating system that could sustainably generate both fish and plant products. Students drove the curriculum and content of the course and gained practical skills along the way. My formative years as a professional helped solidify a love of teaching within interdisciplinary spaces.

I believe that the classroom should be an all-inclusive environment where students are able to express their ideas even if those ideas stray from conventional beliefs. Students should retain ultimate control over their own learning and be provided with opportunities to demonstrate their understanding in multiple ways. With the learner at the helm, the teacher accepts a new role as facilitator. While some may perceive lack of authority as uncomfortable, I view it as empowering. Giving students the ability to leverage content in the ways they find most fitting provides a sound foundation for long-term retention.

I also envision a school setting in which there are no boundaries for learning. The four-walled relic must be replaced with technologies that make the collective knowledge base of all mankind readily accessible. Teaching styles such as lectures are as antiquated as the physical spaces in which they are enacted. Students should feel as though their roles as learners do not end when they leave the confines of school. There is an entire world outside the school walls that contains troves of knowledge for students to explore. I want students to make continual connections with school content, both inside and outside of the lecture hall. Technology is a critical component in opening the borders of the school structure so that students can learn about scientific endeavors in various contexts through digital dialogue and research.

As a first-year PhD student in the fall of 2013, my formal supervisory role for student teachers rekindled my fascination with integrated STEM. One of the student teachers that I supervised was placed in the eighth grade classroom central to this study. I observed the teacher candidate on four separate occasions in the classroom setting and maintained open communication pathways with the science teacher, Jeremy, throughout the placement duration. I found Jeremy to be highly enthusiastic about his position and open to explaining his experiences. I briefly met the other members of Jeremy's teaching team that were associated with the grade level.

I supervised student teachers and observed them on a regular basis as part of my role as a university-level educator. I taught methodology classes on lesson planning, science pedagogies and assessment approaches. Through the data I collected and my personal biases associated with science, I tended to report on science practices in more depth than the other disciplines involved in the integrated STEM model.

When I viewed the video footage that I had gathered from the team of teachers at Maple Tree High School, I was completely impressed not only by their work and the rapport they had established between professional peers, but also their ability to create classroom climates that present challenges that attain the zone of proximal development which gives students the optimal level of cognitive challenge (Vygotsky, 1978). I considered all orange team teachers expert teachers. They expressed an eagerness to improve and wanted to receive evaluation as part of our interactions. During my initial observation, Calvin asked me, "Well? How did I do?". Given my former role as a university-level supervisor, I found it difficult to reposition myself not as an evaluator but as a researcher.

Based on my background as a researcher and science teacher, I argue that integrated STEM models should be applied more universally within K-12 settings. Based on past research experiences, I noticed that students exposed to integrated curricular investigations ask more in-depth questions and collaborate more readily with peers. As a high school integrated science teacher, I found that student engagement increased during real-world applications of content. Collegiality between integrated STEM teachers also increased due to the level of trust and interest in one another's content and pedagogical practice. A universal integrated STEM model of curriculum and instruction should be considered due to the advantages for both students and teachers.

Future research directions

The NRC (2014) reported that only three studies have been conducted on student development of integrated STEM identity. Outcomes from these initial studies suggest that STEM integrated instruction supports a wider array of knowing allowing more diverse students to feel included as experts. While the ways in which students build STEM identities was not central to my study, it did support these tentative results. Further investigation is needed to fully understand how STEM and disability identities intersect.

In future studies I plan to apply grounded theory to generate a broader understanding of the integrated STEM experience. I would like to expand my research to encompass multiple settings and for a longer period of time. I would personally like to research how teachers balance multiple competing identities, and I am also interested in continuing my relationship with this team in the future for research and professional development. Since the completion of this study, the team returned to their original middle school setting. The influence of physical space on their work would be an additional area of interest for future research.

The ways in which educational leaders can promote the interaction of content area is also a potential avenue for further research. Jeremy referred to administration as "peeling away the layers" of constraints that teachers face when enacting STEM integrated instruction. Additional investigations are needed to understand the role of administration during the creation and sustained implementation of STEM integrated learning.

Phenomenology, while used in this study to learn about how science teaching and learning function, could also be leveraged as a tool for educators to reflect on their own practice. Baird (1999) recruited twelve science teachers to participate in guided phenomenological reflection over a 4-year duration. Teachers periodically answered four open-ended questions regarding their practice, such as: “What is it to be a science teacher?” and “What is science teaching?”. The teachers returned to their weekly entries and responded to these prior comments. Teachers from this study interpreted science teaching as challenging students to critically analyze their world. A third of the teachers who participated reported frustration and periodic bouts of depression, which they associated with their profession (Baird, 1999). I am also interested in developing reflective phenomenological methods to support integrated STEM teaching. Integrated STEM models, such as the one investigated in this study, involve new approaches to science classroom instruction. A reflective account of the journey from development to long-term implementation could serve useful to informing practice.

Study contribution

Understanding teaching and learning practices have been compared to a black box where inputs and outputs are recorded but little is know with regard to its function. “Researchers need to document the curriculum, program, or other intervention in greater detail, with particular attention to the nature of the integration and how it was supported” (NRC, 2014, p. 9). I opened the black box of the integrated STEM classroom to inform the literature base and interested practitioners. I reported certain localized “truths” that became central to the integrated STEM model, as experienced by the participants; these include: (1) project-based learning; (2) flexible scheduling; (3) co-teaching; (4) social skill building; (5) technology; and (6) use of space. My study focused on a suburban public school with average achievement scores and resource allocations. Many K-12 stakeholders can relate to the obstacles presented during the formation of the integrated STEM model and its long-term implementation. My study not only reveals how one integrated STEM model operates, but how it operates over an extended period of time. Indeed, in this study I highlight how teachers, students, content and context combine to create one interpretation of integrated STEM education.

This study supports the development of integrated STEM educational models to leverage lifeworld experience from both teachers and students. The pervading system of subject area silos limits the accessibility of science by narrowly depicting scientific content. The disintegration of subject silos has the potential to embrace more diverse learners and bridge the gap between lifeworld and scienceworld. Integrated STEM portrays science as a problem-solving venture that encourages multiple forms of expression. Students more freely interact with one another to co-construct knowledge as a community of engagement. The design and implementation of an integrated STEM model within a traditional school structure is a challenging endeavor. Outcomes of this study suggest that teachers can forge stronger connections with content, peers, and students through integrated STEM experiences.

APPENDIX

A-1. Protocol questions for semi-structured interview-teacher interview:

What does a “typical” day look like? What would I see? Hear?

How would you describe the teaching and learning model that you have created?

What process did you follow to create this model?

In what ways do you collaborate with your peers?

What have you learned from participation in this model of curriculum and instruction?

How has this model shaped your development as a teacher?

How has the model changed over its duration of implementation?

Describe for me a particularly memorable lesson?

How have learning outcomes been shaped by this model?

Describe some of your questioning strategies.

What is your lesson planning process like?

How do you utilize the physical spaces at the school during lessons?

What are some challenges associated with this model?

How would you describe this model to other teachers? Parents?

What does transdisciplinary mean?

What does flexible scheduling mean?

Debrief after observation:

What was the goal of the lesson?

Did the lesson go as planned?

How did the collaboration process work for you?

Are there ways you would have modified the lesson?

Explain your thinking behind the questions you posed to students?

A-2. Protocol questions for semi-structured interview-student interview:

What is a typical day like in 8^{th} grade? What would I see you doing? Hear you saying?

What things do you learn about in 8^{th} grade?

Explain to me a lesson that you remember from class so far?

What things are you interested in learning about at home?

What questions do you ask in school?

Who do you usually turn to when you need help with schoolwork during the day?

***What's it like to be on team "orange"?**

***How would you describe team "orange" to someone who hasn't heard of it?**

Debrief after an observation:

What did you learn?

What parts of the lesson did you really like?

What parts of the lesson would you change?

What questions were you thinking about during the lesson?

A3. Typed copy of Figure 18 (Post It Note activity)

TOPICS OF STUDY

Physical Science 8	Accelerated Biology	ELA	Math 8	Accelerated Math	Social Studies
Introduction	Life Processes	Science Fiction	Real #	Properties	Reconstruction
Inquiry Freedom SciMethod		(*The Giver*)	Exponents	Pythagorean Theorum Slope	
Force + Motion Newton's Laws Gravity	Homeostasis	*The Outsiders*	Scientific Notation		Industry, immigration Urban growth GREED
Energy Transformation PE + KE	Biochemistry	Peak	Solve Equations	Functions	Expansion and imperialism
HEAT conduction convection radiation	Cells		Slopes of linear Equations	Systems Graphing inequalities	World War I + 1920s change, equality?
Electromagnetic Energy	Genetics	The Holocaust unit	Systems of Equations	Polynomials And Factoring	Great Depression Role of government
Electricity	Evolution		Functions	Quadratic Equations	World War II Civil liberties
States of Matter Solid, liquid, gas, ETC.	Reproduction		Statistics	Experiential Gravity/Decay Analyze functions	Foreign Policy Cold War
Atomic Structure	Equilibrium		Transformations	Central Tendency Statistics 2-way tables	Demographics Suburbs Domestic politics PROTEST
Chemical Properties And reactions	Interdependence		Angles		
			Pythagorean Theorum		

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VITA

Margery Gardner, M.S.

EDUCATION

Syracuse University 2013-present
Ph.D. Candidate, School of Education, Science Education
Certificate of Advanced Study in Educational Leadership

Utica College 2010
Master of Science, Adolescence Education

Cornell University 2003
Bachelor of Science, Natural Resources Policy and Management

PROFESSIONAL EXPERIENCE

Director of Teacher Preparation, Colgate University,
Educational Studies Department
Courses:

- American School
- Seminar on curriculum and instruction for math and science
- Student teaching

Teaching Assistant, Syracuse University, 2013-present
Department of Science Teaching, School of Education
Courses:

- Curriculum problems in science
- Teacher development
- Secondary science methods
- Methods for physical science

Secondary Science Field Supervisor, Syracuse University, Fall 2013
Department of Science Teaching, School of Education

Curriculum Developer, Herkimer BOCES, Career and Technical Education, Natural Resource Management program Fall 2013

Secondary Science Instructor, Career and Technical Education, 2009-2013
Herkimer BOCES, Herkimer, NY

Middle School Science Instructor, Alternative Education, 2008-2009
Oneida BOCES, Utica, NY

Zoo Educator, Utica Zoo, Utica, NY, 2007-2008

Forestry Extension Agent, Peace Corps, Malawi, 2004-2006
Central Africa

PUBLICATIONS

Gardner, M. (2014). The classroom and beyond: Insights on inquiry. *Legacy,* pp. 24-25.

GRANTS

Program evaluator (2015), Terra Science Education Foundation Grant, Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE)

Data analyst (2014-2015), NSF TUES grant, New York State University of Environmental Science and Forestry, ($500,000/3 years)

Gardner, M. (2012). Using informal science reading to means to improve student motivation and achievement. Mohawk Valley Regional Teacher Center ($500).

CONFERENCE PRESENTATIONS

Comet, M. Gardner, J., Gardner, M. & (2010). Trout in the Classroom: Lessons in conservation. Presented at the Science Teachers of New York State Annual Conference, November 3.

Gardner, M. & Mahon, C. (2010). Teaching 21st century skills through renewable energies. Presented at the Association of Career & Technical Education Administrators Annual Conference, March 11.

PROFESSIONAL DEVELOPMENT WORKSHOPS

Gardner, M. & Tucker, B. (2014). Science, ethics, and its connection to the Holocaust. Presentation for Spector/Warren Fellows, January 11.

Gardner, M. & Tracy-Bronson, C. (2013). Deciphering the Common Core. Presentation to Parent Teacher Organization members, Dolgeville Central School, December 8.

Gardner, M. (2009). Building inquiry through student centered approaches and experiential education. Presentation to secondary science instructors, Kakwale Day Secondary School, Malawi, Africa, June 5-10.

Gardner, M. (2008). Using informal settings as classroom research tools. Presentation to Mohawk Valley science instructors, Utica Zoo, April 15.

SERVICE

Interpretative materials designer (80 volunteer hours), The New York State Zoo at Thompson Park, 2014

Secretary, Trout Unlimited (Mohawk Valley Chapter), 2009-2013

Curriculum design and development committee member, Herkimer BOCES, 2012

New teacher mentor, Herkimer BOCES, 2012

Science Fair Judge, Poland Central School, 2008

Wildlife test developer, Oneida County Envirothon, Soil and Water Conservation District, 2008

HONORS AND AWARDS

Spector/Warren Fellow, Houston Holocaust Museum, 2014

PROFESSIONAL LICENSES

New York State Professional Certificate, Living Environment, 7-12, 2012

Solar Power as Renewable Energy (SPARE) Photovoltaic Installer Course, 2011

PROFESSIONAL MEMBERSHIPS

Future Professoriate Program (FPP) at Syracuse University, 2014-2015

Women in Science and Engineering (WISE) at Syracuse University, 2014-2015

Science Teachers Association of New York State (STANYS), 2009-2014

Kappa Delta Pi Honor Society, 2008