4-2016

A collaborative integrated stem teaching: Examination of a science and math teacher collaboration on an integrated stem unit

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Graduate School Form
30 Updated 12/26/2015

PURDUE UNIVERSITY
GRADUATE SCHOOL
Thesis/Dissertation Acceptance

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By Drew C Ayres

Entitled
A COLLABORATIVE INTEGRATED STEM TEACHING: EXAMINATION OF A SCIENCE AND MATH TEACHER COLLABORATION ON AN INTEGRATED STEM UNIT

For the degree of Master of Science in Education

Is approved by the final examining committee:

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Approved by: PHILLIP VAN FOSSEN 4/24/2016

Head of the Departmental Graduate Program Date

A COLLABORATIVE INTEGRATED STEM TEACHING: EXAMINATION OF A SCIENCE AND MATH TEACHER COLLABORATION ON AN INTEGRATED STEM UNIT

A Thesis

Submitted to the Faculty

of

Purdue University

by

Drew C. Ayres

In Partial Fulfillment of the

Requirements for the Degree

of

Master of Science in Education

May 2016

Purdue University

West Lafayette, IN

ACKNOWLEDGEMENTS

I want to recognize the efforts Dr. Lynn Bryan has put forth to help me succeed thus far in my career. Our relationship began with her providing me a scholarship during my undergraduate studies. She has been incredibly helpful ever since. She has spent many hours mentoring me in scholarship and in life. We will forever share a commonality in our family life that many will never understand. Thank you for your help and support.

I would like to thank Dr. Nathan Mentzer for the time he has invested in making me a better instructor. Thank you for supporting me throughout my studies. I would not have been able to financially survive graduate school without the job. Thank you.

I want to thank Dr. Selcen Guzey for her suggestions during our Friday morning meetings. She invested many hours in helping me develop a research question and identifying the most useful way to analyze the data. We had many conversations on our trips to local schools that helped me immensely. Thank you for your support throughout my studies.

Lastly, I want to thank Leann for her support throughout my undergraduate and graduate studies. She has put up with countless hours of discussions regarding my research. She listened as I got my ideas out in the open. Thank you! I love you!

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ABSTRACT

Ayres, Drew C. M.S.Ed, Purdue University, May 2016. Collaborative Integrated STEM Teaching: Examination of the Effects of Science and Math Teacher Collaboration on Common iSTEM Unit. Major Professor: Lynn Bryan

The integration of science, technology, engineering and mathematics curriculum in middle school science and math classrooms is a reform effort currently taking place. The teachers are being encouraged to teach integrated content through national and state standards. The teachers have not been trained to do this form of teaching, which has led to feelings of discomfort or incompetence to fulfill those standards. This has led to a need for professional developments to train these teachers. Those developing the professional developments are seeking to identify ways to encourage teachers to continue to implement integrated units.

The purpose of this study was to examine the impact of a collaborative teaching relationship between a math and science teacher following a professional development. The teachers used a common integrated STEM unit to teach math and science standards by using engineering design as the integrator. The teachers provided lesson plans, were video recorded during implementation, interviewed pre and post-implementation, and made daily journal entries. These data were analyzed to document the collaboration and identify impacts of the collaboration.

CHAPTER 1: INTRODUCTION

Is has become common knowledge that our country is not in the top tier of science, math and technology education as compared to other developed countries. Many documents (Atkinson & Mayo, 2010; Bybee, 2010; Moore, Johnson, Peters-Burton & Guzey, 2015; National Academy of Science [NAS], 2007) identify the lack of competitiveness U.S. educated students offer in our ever more globalized world. This emerging threat has become more real as the Program for International Student Assessment (PISA) scores reveal that the United States does not meet the average of countries in the Organization for Economic Cooperation and Development (OECD) in mathematics, problem solving, or scientific literacy (Lemke, Palke, Partelow, Miller, Williams, Kastberg & Jocelyn, 2004). This has led to an increase in research around science, technology, engineering, and mathematics (STEM) education practices in the United States, particularly in the area of integrated STEM education. There has been a call for increasing the number of students prepared to innovate and enter this competitive workforce (NAS, 2007).

This case study contributes to the growing body of STEM education research. I conducted the study with two middle school teachers, one math teacher, Mrs. Lew, and one science teacher, Mrs. Jane. The teachers were selected from a group of 17 teachers who were invited to attend a professional development focused on integrated STEM education in middle school classrooms. The study participants were selected due to the unique teaching collaboration in which they engaged.

1.1 Research Question

The following research question guided this study: What is the nature of teacher collaboration as they implement an integrated STEM unit across two subject areas?

1.1.1 Significance

The goal of this study is to examine how collaboration works for a middle school implementation of an integrated STEM unit across two subject areas. Why should we be concerned with integrated STEM education? Bybee (2013) suggests that STEM literacy offers the opportunity to learn to “apply basic content and practices of the STEM disciplines to situations they encounter in life” (p. 5). These practices allow students understand problem solving, inquiry and design (Bybee, 2013). There is the challenge of teaching concepts in a field outside of one’s own discipline. But, many schools are not equipped with technology and engineering courses to fill the T and E in STEM (Bybee, 2013). The significance arises as one of six recommendations from a research agenda provided in *STEM Integration in K-12 Education: Status, Prospectus, and an Agenda for Research* (National Academy of Science, 2014). The National Academy of Science (2014) suggests some specifics in which identifying the curriculum and nature of the integration are of most importance. They also highlight the necessity to identify the support mechanisms in place for the teachers that will make the teaching and learning of integrated STEM successful.

As outlined in *Rising Above the Gathering Storm* (NAS, 2007) the United States must vastly increase the talent pool through the improvement of K-12 science and math education in order to ensure that the U.S. remain the premier place for learning, research and innovation. To enact that vision students must be literate in math and science, which necessitates teachers who are highly qualified in these disciplines. Currently, a teacher who never received a math degree teaches approximately 30 percent of high school math students. In physical sciences, 60 percent of students have teachers without a related degree. Further, 70 percent of low-income students in the United States are instructed by math teachers who have a degree in a non-math field (NAS, 2007). Therefore, the committee calls for the addition of 100,000 qualified STEM teachers. This study will provide suggestions to all these new teachers with ways to be successful in initial integrated STEM implementations through a collaboration effort between a science and math teacher. It is important for new teachers to learn from the successes of highly qualified teachers.

This study was a centered on a professional development that provided training for novice and veteran teachers on integrated STEM education. The teachers were exploring ways to be successful in implementing integrated STEM curriculum by collaborating. It is important for new teachers to learn from the successes of highly qualified teachers. The participants in this study are highly qualified teachers that were capable of trying a new method to learn successes and failures of that method. The conclusions from this study can provide recommendations to the additional 100,000 teachers that will be entering the field (NAS, 2007).

The education system must generate students STEM literate students, for it is the driving force of an innovative American economy (NAS, 2007). There is a push for students to become workforce ready in the STEM fields (NAS, 2014). This push arises from a staggering ranking of 16^{th} out of 17 in the ratio between natural science and engineering degrees versus other degrees (NAS, 2007). The National Academy of Science (2007) places an emphasis on incentives to innovate in the United States. They specifically call the states to action to create high paying jobs, invest in manufacturing and marketing, and encourage innovation. The goal is for an emergence of experts in the United States who lead the world in science and engineering, therefore; creating a workforce bound for innovation. In order for students to become ready for these jobs, they need to experience robust STEM instruction from teachers who possess the knowledge and skills for teaching, using integrated STEM approaches (National Research Council [NRC], 2009).

The *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013) and *The Framework for K-12 Science Education* (National Research Council [NRC], 2009) have included engineering design concepts to move toward a more innovative generation. However, many teachers are not prepared to integrate engineering design into science instruction, nor do they feel adequate to teach these concepts (Stohlman et al., 2014; Capobianco, 2010). This places a heavy burden on the teachers to address concepts that they are no comfortable addressing. This case study focuses on two teachers' who are in the process of learning to integrate engineering design into their math and science instruction by collaboratively planning and enacting an integrated STEM unit. The results of this study will inform future integrated STEM implementation strategies. The implementation of integrated STEM education will aide in an increase in students who are STEM literate and ready for a STEM workforce.

CHAPTER 2: REVIEW OF THE LITERATURE

2.1 Definitions

In this chapter, I will define key terms and phrases used in this study. The term STEM is currently used in many capacities. The specific definition for the acronym varies even within the related STEM fields (Bybee, 2013). Breiner, Johnson, Harkness & Koehler (2012) asked the question “What is STEM” to many faculties across departments at a large university. He found that some faculty related the term to stem cell research. Yet others identified the terms as individual silos such as science, technology, engineering and medicine. Others substituted the “E” for electricity. A large number (27%) claimed they did not know what the term meant (Breiner et al., 2012). Another study from the Entertainment Industries Council found that out of 5,000 people surveyed, eighty-six percent did not connect the definition to science, technology, engineering and mathematics (Angier, 2010). Why do we care about the STEM disciplines?

2.2 The Need for a STEM Workforce

The education system is the supply chain for the pool of future workers in the United States. The National Academy of Sciences (2007) explains the importance of American students entering the STEM workforce. According to the Bureau of Labor Statistics report in 2010 the projected growth of STEM jobs is double (19%) of other non-STEM jobs (10%). The troubling aspect of this statistic is due to the fact that students who will be reaching for these jobs are competing with students from other countries. The 15 year olds in the U.S. received an average score lower than the average score of students from 29 other countries on the PISA (Programme for International Student Assessment) exams (Atkinson and Mayo, 2010). This trend is already unveiling itself in the form of STEM degrees received. There are four times more Chinese students graduating with science and engineering degrees than American students (Atkinson and Mayo, 2010). This alarming number gives reason to believe there is a problem in the foreseeable future. The jobs STEM jobs coming but the American students are not prepared to be in competition with students from other countries.

2.2.1 Educations Role in creating the next STEM Workforce

The education system must invest in and increase the number of qualified workers for the STEM fields. *Rising Above the Gathering Storm* (NAS, 2007) emphasizes the numbers—29 percent of fourth grade students—32 percent of eighth grade students—and 18 percent of twelfth grade students scored at or above proficiency levels ((Institute of Medicine, National Academy of Sciences, & National Academy of Engineering, 2007), 2005). To solidify the importance of these numbers—71 percent of fourth grade students—68 percent of eighth grade students—and 82 percent of twelfth grade students scored below the proficiency level. This raises a large concern and (Atkinson & Mayo, 2010) (2005) says "…mathematics and science teachers are, as a group, largely ill-prepared" (p. 95). He continues by saying one way the scores could be improved is by increasing student interest in the STEM fields. Increasing interest in the disciplines would improve learning and in turn would aide problem solving skills needed in the STEM fields (Institute of Medicine, National Academy of Sciences and National Academy of

Engineering, 2007). The system is not working well according to the aforementioned numbers. In order for change to occur it is important to have goals set for the teachers as well as the students. It is not only important to set goals, but to give the teachers the resources and skills needed to attain to the goals. Researching qualified teachers and sharing their successes with those ill-prepared teachers can aid the preparation of qualified students for entering college and the workforce.

2.3 Goals of STEM Education

There needs to be support of the goals in STEM education in order that the goals are successfully met. The federal policy makers have approved funding to enhance STEM initiatives. In 2007 the America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Act was approved. The goal of this was to "…improve the competitiveness of the United States (GPO, 2007, p. 1)" (Koehler, Binns and Bloom, 2015). The National Science and Technology Council (2013, p. 15) identified five general goals for STEM education including:

1. Improve STEM instruction by prepping 100,000 excellent new k-12 STEM teachers by 2020, and support the existing STEM teacher workforce;

2. Increase and sustain youth and public engagement in STEM by supporting a 50% increase in the number of U.S. youths who have authentic STEM experiences each year prior to completing in high school;

3. Enhance STEM experience for undergraduate students by graduating one million additional students with degrees in STEM fields over the next 10 years;

4. Better serve groups historically under-represented in STEM fields by increasing the number of underrepresented in STEM fields with STEM degrees (including women) over the next 10 years;

5. Design graduate education for tomorrow's STEM workforce by providing graduate-trained STEM professionals with basic and applied research expertise to acquire specialized skills in areas of national importance (Koehler et al., 2015).

These goals can be achieved by setting some goals for K-12 students and teachers. The goals set forth for students by NAS (2014) are:

- STEM Literacy
- 21st Century Competencies
- STEM Workforce Readiness
- Interest and Engagement
- Ability to Make Connections among STEM Disciplines

These goals for students need to be known by educators and must be the focus of classroom instruction. STEM literacy according to NAS (2014) has not yet been clearly defined due to a lack of a definition for STEM. The authors do provide three identifiers they believe would label a student as STEM literate. They explain it as potentially including a combination of the:

> "(1) Awareness of the roles of science, technology, engineering, and mathematics in modern society, (2) familiarity with at least some of the fundamental concepts from each area, and (3) a basic level of application fluency (e.g., the ability to critically evaluate the science or engineering content in a news report, conduct basic troubleshooting of common technologies, and perform basic mathematical operations relevant to daily life)" (NAS, 2014, p. 34).

2.3.1 STEM Literacy

STEM literacy is an important characteristic all 21st century students need in order to be successful in the newly coming STEM jobs (NAS, 2007). Without STEM literacy it is tough to succeed in a world where science and technology are the norm (NAS, 2007). Bybee (2010) says STEM literacy is the ability to understand procedures and the ability to solve problems at the global scale that affect all humans, such as the Global Grand Challenges set out by the National Academy of Engineering (2015), as well as personal and social challenges. Some of these challenges affect all of society such as clean water, public health, transportation, sustainable food production and air quality (NAS, 2007).

2.3.2 21st Century Skills

The next goal for STEM k-12 education is to help students develop 21st century competencies. The competencies explained by NAS (2014) are characteristics that "…support deeper learning and knowledge transfer" (p. 35). The authors also address critical thinking and innovation as key 21st century competencies. These can be addressed through integrated STEM curriculum with engineering tasks that will require students to work as a team to solve real world problems of our era (Bybee, 2010).

2.3.3 STEM Workforce Readiness

The remaining two goals for students are STEM workforce readiness and opportunities for all students to experience engineering design. STEM workforce readiness is tied to the goal of creating interest and engagement. The latter goal will create a generation of students who are motivated to tackle the challenges previously presented. Students who are presented with integrated STEM curriculum will have the opportunity to experience engineering design within the context of some of those grand challenges. This opportunity to experience design relates back to the goals set by NSTC (2013). The exposure to the design experience is important (NAS, 2014).

2.4 STEM Education Goals for Teachers

The question then becomes, what does this look like and how is it carried out pragmatically? These goals of education can begin within the context of integrated STEM education. Integrated STEM education in classrooms has to begin with the teachers. NAS (2014) says the goal for teachers is (1) increased STEM content knowledge and (2) increased pedagogical content knowledge. The content knowledge has been addressed within each of the individual disciplines. But, the pedagogical knowledge has yet to be discussed. The professional development, that will be discussed later, was focused on increasing STEM content knowledge and increasing pedagogical content knowledge for the attending teachers.

2.4.1 Emergence of the term STEM

The term STEM emerged from the National Science Foundation's work in the 1990's. The educational reports from the 1980's showed a need for better math and science education (Breiner et al., 2012). The early acronym that was used to identify the four disciplines was "SMET." There was belief that this term was not professional; therefore, the acronym was changed to STEM (Sanders, 2009). This began a movement in policy and in school curriculum within the fields of science, technology, engineering and mathematics.

The term "STEM" was not given a concrete definition and was left open for interpretation. The term has been used at all educational and policy levels, but without a clear definition. However, Breiner et al. (2012) suggest a clear definition may lead to further compartmentalizing of the individual disciplines into silos and may exclude some fields. Nevertheless, those who use the STEM acronym should provide their definition in the context of their work or research. For the purposes of this study the term STEM refers to the individual disciplines of science, technology, engineering and mathematics.

2.4.2 STEM Education

The context of this study was in education. Sanders (2009) stated that people use the term STEM to refer to educational and non-educational contexts. But, the term STEM can also refer to the fields in which the professional scientists, engineers and mathematicians conduct their work. Sanders (2009) further stated that STEM and STEM education are different. STEM education refers to the learning that happens within those fields. He also clarified that a person teaching within one of the STEM disciplines should be referred to as a STEM teacher.

2.4.3 STEM Integration

The concept of integrating the STEM disciplines in an educational context was a major focus of this study. While “STEM” has historically referred to each of the individual disciplines within their own independent silos, (Sanders, 2009) many experts believe the four disciplines should be integrated for a more meaningful learning experience for students (Bryan, Moore, Johnson & Roehrig, 2015; Nathan et al., 2012; NAS, 2014; NRC, 2009; Sanders, 2009; Wang, Moore, Roehrig and Park, 2011). But, what does it mean to integrate the disciplines? The National Research Council (2009) stated that the STEM acronym is too often used to refer to science or mathematics. They asserted that those two disciplines are commonly held as individual areas of learning and “do not reflect the natural connections among the four subjects, which are reflected in the real world of research and technology development” (p. 12).

Understanding the depth and nature of integration is complex. Lederman and Niess (1997) provide a mental image of their perspective of STEM integration by using a soup metaphor, the difference between chicken noodle soup and tomato soup. In chicken noodle soup, it is easy to distinguish between the parts. But, in tomato soup, it is difficult to separate the individual constituents. However, the nature and depth of the integration is on a continuum. Bybee (2013) provides a range of integration perspectives from the Lederman and Niess (1997) perspective to a perspective of teachers in differing courses discussing concepts from other disciplines. The Bybee perspectives that follow will help a teacher understand the differing levels and forms of integration that can utilized.

> 1) Science = STEM. Bybee explains this as the most confusing perspective due to the acronym referring to multiple disciplines. The presented idea is that if a discipline falls under the broad umbrella STEM then it can be called STEM. In which case engineering design can be called STEM or mathematics can be called STEM. 2) STEM = both Math and Science. This perspective infers that STEM is science and math. It does not need to include design in order to be called STEM. 3) STEM = Science and incorporates Technology, Engineering, or Math. This perspective places science as the core with technology, engineering or math as aides to teach the science content. 4) STEM = a quartet of separate disciplines. This perspective is where many schools are currently residing. Bybee describes it as separate courses. The courses each are

individual disciplines instructing on the concepts within that discipline. 5) STEM = Science and Math are connected by either a Technology or Engineering program. Within this perspective science and math are independent programs but a third program exists that emphasizes technology and engineering. 6) STEM = coordination across disciplines. This perspective begins to include content from one course utilized in another course. The math material learned may be used in science class. 7) STEM = combining two or three disciplines. Bybee describes this combination as producing a new product by merging the two old products together. 8) STEM = complementary overlapping across disciplines. This perspective is compared to an automobile manufacturing plant. The students will follow a path that will lead them from one discipline to another. The disciplines are connected and need each other but remain independent. 9) STEM = a trans-disciplinary course or program. This perspective is compared to a quartet of musicians playing to create a song. The music is all coming together at the same time and is tough to separate (p. 74-79).

Sanders (2009) stated that integrated STEM education should remove itself from the "disconnected STEM education"(p. 21) that currently exists and become comprised of a more meaningful experience for students involving "purposeful design and inquiry" (p. 21). Sanders (2009) proposed the integration are between "two or more of the STEM subject areas" (p. 21). Sanders and Wells (2005) make the argument that integration will include two or more disciplines. But, the integration is not truly STEM integration if math and science are paired or if engineering and technology are paired. They believe the integration only happens when a design science—engineering or technology—is paired with a natural science such as science or math. Nathan et al. (2013) further supports this argument by saying “Foremost, curriculum content across the STEM fields is integrated rather than merely combined” (p. 82) (Dyer, Reed, & Berry, 2006; Satchwell & Loepp, 2002).

The integrated STEM curriculum may differ depending on demographics within a classroom. Bryan et al. (2015) explain the background of students being an important factor to consider when creating curriculum. The authors describe learning as constructive. The students must build upon “(t)heir existing understandings, experiences, beliefs, and interest…” (p. 26). The teacher must be aware of the students backgrounds and build integrated STEM units that are culturally inclusive, socially relevant, and situated in authentic contexts (Bryan et al., 2015). This addresses the need to create student motivation within the STEM disciplines. It is important to know the framework a teacher will work within while instructing an integrated curriculum.

A definition and multiple perspectives have been explored for integrated STEM education but it is not yet clear what each of the individual disciplines bring to the integrated STEM education table. Bryan et al. (2015) clearly state their definition “as the teaching and learning of the content and practices of disciplinary knowledge which include science and/or mathematics through the integration of the practices of engineering and engineering design of relevant technologies” (p. 24). This definition provides the framework in which this study was designed.

2.5 Characteristics of the STEM disciplines

In this section, I will identify characteristics of each of the STEM disciplines. Each discipline is characterized by content and practices. Science education as described in the Next Generation Science Standards (NGSS Lead States, 2013) should "…Reflect the interconnected Nature of Science as it is Practiced and Experienced in the Real World." The National Research Council (2012) explains how the science standards need to focus on "scientific explanations (i.e., content knowledge) and the practices needed to engage in scientific inquiry and engineering design" (p. 11). Both NGSS (NGSS Lead States, 2013) and the Framework (NRC, 2012) emphasize inquiry and design as key components in science education. Table 2.1 below provides details of essential characteristics that should be included in integrated STEM curriculum. The units should have an anchor discipline of either math or science, integrated through practices of engineering and engineering design, include design justification, 21st century skills, and be set in a real-world context (Bryan et al., 2015). The following sections will provide details for what is meant by scientific inquiry, mathematics, engineering, technology and design, while in the context of integrated STEM curricula.

Table 2.1 Characteristics of Integrated STEM Instruction

Distinguishing Characteristic	Description
The content and practices of one or more **anchor science and mathematics disciplines** define some of the primary learning goals.	Anchor disciplines are the primary disciplines from which the learning goals for instruction are derived. Learning goals (what you want students to know) provide coherence between the instructional activities (how students will come to know what you want them to know) and assessments (how you determine whether students have come to know what you want them to know) (Wiggins & McTighe, 2005). Explicit attention is given within the learning goals to the connections between disciplines.

Table 2.1 continued

The integrator is the **practices of engineering and engineering design** as the context and/or an intentional component of the content to be learned.	An 'integrator' brings together different parts in a way that requires those parts to work together for a whole. As the integrator in integrated STEM, the practices of engineering and engineering design provide real world, problem-solving contexts for learning and applying science and mathematics, as well as meaningfully bring in other disciplines.
The engineering design or engineering practices related to relevant technologies requires the scientific and mathematical concepts through **design justification**.	High quality STEM integration learning experiences meaningfully integrate the engineering design/practices with the science and mathematics content. Design justification is one way to require the students to apply the mathematics and science to the engineering design. For example, students should make recommendations for the design to their client that are supported by the background information and content and the results from their tests as data for their decisions.
The development of **21st century skills** is emphasized.	The phrase, "21st century skills," refers to the knowledge, skills, and character traits that are deemed necessary to effectively function as citizens, workers, and leaders in the 21st century workplace (Bybee, 2010; NRC, 2012b; Partnership for 21st Century Skills, 2011).
The context of instruction requires **solving a real-world problem or task** through teamwork and communication.	A real-world problem or task centers on an authentic issue or meaningful challenge. As opposed to decontextualized or contrived tasks (e.g., "cook-book" labs in science or rote problem solving in mathematics), real-world problems engage students in issues that are significant in everyday life and have more personal and/or social relevance.

Note. Descriptive note. Adapted from STEM Road Map: A framework for integrated STEM education (p. 25), by Bryan, L.A., Moore, T.J., Johnson, C.C. & Roehrig, G.H. 2015, New York, NY: Routledge, 2015. Reprinted with permission.

2.5.1 Scientific Inquiry in Integrated STEM Education

Scientific inquiry is emphasized in NGSS (NGSS Lead States, 2013) but science education is not limited to inquiry as the only approach to teach science. However, inquiry holds value in science education because it includes

> …Making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results (NRC, 1999, p. 23).

It is important to notice inquiry as it relates to design in problem solving, critical thinking, and consideration of alternative explanations (NRC, 1999). Inquiry is the identified by Bryan et al. (2015) as a STEM practice that should be focused on in integrated STEM curriculum.

The NGSS Lead States (2013) specified the importance of scientific core ideas, practices and crosscutting concepts. The emerging themes from these texts identify inquiry as a practice or process that is conducted through knowing the concepts. The students will be expected to learn the content knowledge and apply the knowledge to engage in scientific practices. The practices are those that are used to question, examine, and answer questions about the natural world (NGSS Lead States, 2013). The education K-12 students are receiving in an integrated STEM classroom should have them engaged in units that reflect the aforementioned style of inquiry. The student should learn content and know how that content was obtained in order to understand the nature of science.

According to Karacam (2015) the teacher will have students "…work as scientists, have them feel like scientists and ensure changing their scientists image" (p. 205). The NGSS (NGSS Lead States, 2013) make it clear that science should be taught with engineering concepts. Specifically design is provided as a key concept in the Framework (NRC, 2012).

2.5.2 Engineering and Technology in Integrated STEM Education

Engineering concepts, and specifically engineering design, are a central component of integrated STEM instruction (Sanders, 2009). What does it mean to teach engineering? Moore, Glancy, Tank, Kersten, Ntow & Smith (2013) provide a list of concepts (Table 2.1) and an explanation for each concept that should be used to teach engineering.

1. Apply science, engineering and mathematics
2. Process of design
    a. Problem and background
    b. Plan and implement
    c. Test and evaluate
3. Conceptions of engineers and engineering
4. Engineering thinking
5. Teamwork
6. Issues, solutions, and impacts
7. Ethics
8. Communication skills
9. Engineering communication skills
10. General communication skills

Note. Descriptive note. Adapted from A framework for implementing quality k-12 engineering education, by Moore, T.J., Glancy, A.W., Tank, K.M., Kersten, J.A., Stohlmann, M.S., Ntow, F.D., Smith, K.A., 2013, American Society for Engineering Education, (p. 15).

Moore et al. (2013) explain how the indicators provide a framework but need not be taught every lesson. A teacher should be able to identify at least one of the said concepts in any particular unit claiming to teach engineering. The teacher; however, does not need to teach all the concepts in every unit.

The indicator headlines provide only a brief explanation but further details are needed in order to understand the concepts. The first indicator, apply science, engineering, mathematics knowledge (SEM), is a concept that is addressed when it allows students to apply SEM knowledge to solve engineering problems.

The next indicator, process of design (POD), is a central component of solving engineering problems. The process is used to identify a problem through research and empathizing with the need of the client. Once the problem has been identified, the students can begin to brainstorm multiple solutions, generate criteria and constraints they can use to evaluate solutions, select a solution and finally build a prototype. The prototype needs to be tested. The test will provide data the students can use to evaluate the solution and redesign, if necessary.

The next indicator is engineering thinking (EThink) where students learn to be independent, take risks, learn from failure in order to generate improved solutions. The students need to be in an environment where a single answer "right" answer is not an expectation. The students should be allowed to learn from failure and make improvements.

Conceptions of engineers and engineering (CEE) are an indicator that a teacher can use to help students understand the job an engineer is responsible for completing. The students will learn the requirements to become an engineer. They can also learn about the job market while engaging in material that addresses this indicator.

The indicator, issue, solutions, and impacts (ISI), is addressed by having students think about the impact solutions might have on all things surrounding the solution. The impact may be negative or positive and may span from the environment to economic impact.

The ethics indicator is one that teachers may use to encourage students to empathize with the stakeholders. The stakeholders may be directly involved or indirectly impacted by the solution. The students should think about the regulations related to the solution as well as the integrity it takes to be an engineer to avoid taking advantage of others.

The teamwork aspect of engineering is one of the most necessary to teach students to communicate well in order to accomplish a common goal. The participation of all students will not always be equal and students will have to learn to deal with the conflict that may arise.

Lastly, communication related to engineering (Comm-Engr) is an indicator that is addressed by teaching students to write technical reports and communicate solutions using language that all people can understand. The more technical solutions pose difficulty in understanding for those not in the field. This indicator should be addressed to help students develop written and verbal communication skills for sharing their solutions.

2.5.3 Design

The Standards for Technological Literacy (ITEEA, 2007) emphasize design and the impact that the designed world has on society. Technology standards are commonly misinterpreted to mean computers and the Internet (ITEEA, 2007). In actuality, the standards aim to build students understanding of the designed world or the world that has been engineered. According to Lewis (2005): “design is arguably the single most important content category set forth in the standards [Standards for Technological Literacy], because it is a concept that situates the subject more completely within the domain of engineering" (p. 37). The two disciplines of engineering and technology meet at design. Atman (2005) asserted, "design is a critical element of engineering education and a competency that students need to acquire" (p. 359). The emerging theme from the literature is that the "T" and the "E" in STEM are centrally grounded in design.

2.5.4 Design in Integrated STEM Education

Design according to Sanders (2009) is an important aspect of any integrated STEM curriculum and instruction. Design is a process, as described previously by Moore et al. in Table 2.1, that students learn as a part of the "T" and "E" in STEM. As noted earlier, the design of relevant technologies, or engineering, is the integrator of the STEM disciplines. The design process involves creative problem solving used while facing engineering challenges. The problem solving within the scope of integrated STEM education entails solving a real-world problem by designing a product, system or process and optimizing by utilizing math and science concepts (Bryan et al., 2015). The "S", "T" and "E" have all been characterized but mathematics has yet to be discussed.

2.5.5 Mathematics in Integrated STEM Education

Mathematics is often thought of as the practice of applied mathematics, i.e., the study of numbers and the computational operations of those numbers (Gilfeather & del Regato, 1999). However, Gilfeather & del Regato (1999) provide a deeper understanding of mathematical practices. The mathematics practices should entail an "…area of investigation which logically analyzes ordering, operational, and structural relationships" (p. 2). Bryan et al. (2015) suggest the fundamental goal of mathematics education is for students to be able to think and reason within different situations. The students need to be able to justify their mathematical statements in order to apply them to less familiar tasks (Common Core State Standards Initiative, 2010). This places mathematics well within the realm of integrated STEM education due to the differing situations and problem-solving students will face while engaging with integrated STEM curriculum. The students will have the opportunity to use their mathematics knowledge to justify solutions and solution optimization.

With an understanding of the integration and the characteristics each discipline brings to the integration, it is time to unravel the need for integrated STEM education. Education has undergone many reforms over the years and integrated STEM is yet another reform initiative.

2.6 Integrated STEM Challenges

The perspectives of Bybee (2013) provide a means to begin identifying a framework to utilize in order to implement integrated STEM education into classrooms. Bybee (2013) says a major challenge with implementation is the low number of schools that have technology and engineering programs. NGSS (NGSS Lead States, 2013) says science teachers should be incorporating engineering concepts into their curriculum. A Framework for k-12 Science Education (2012) includes scientific and engineering practices as core competencies taught in k-12 science classes. So why are science teachers not including design in their curriculum?

In order for a curriculum change to be successful, Bryan, Moore, Johnson and Roehrig (2015) say, “(the teachers) need to demonstrate deep, flexible subject-matter knowledge…” (p. 27). The reform efforts are difficult and require a deep shift in teacher thinking (Nadelson and Seifert, 2013). These challenges pertaining to content knowledge and pedagogical shifts make the integrated STEM reform slow. Nadelson and Seifert (2013) say the teachers must "…have a high level of comfort with ambiguity, change, and innovation" (p. 246). The difficulty of learning to implement curriculum outside a teacher's comfort zone is difficult from the start. Capobianco (2010) unveils some of those difficulties experienced by a teacher implementing an integrated unit for the first time. The teacher was unsure where to even begin. The teacher experienced difficulty in finding ways to include science in the design. She was not confident in her ability to teach science through engineering design. The teacher struggled to edit the role of a teacher in an integrated STEM classroom. The teacher in front of the room had to evolve to a facilitator working within the student groups.

A study conducted by Stohlmann et al. (2014) provided more insight to the question, why are teachers slow to implement integrated STEM into their curriculum. The study participants were a math and science teacher that was hired to teach integrated curriculum. At the end of the study the teachers were interviewed and provided some telling results. The teachers said they were uncomfortable teaching the material outside their expertise. They did not feel they were able to help students learn important content. The teachers were not sure if they wanted to continue to teach the content.

The literature displays a lack of teacher confidence and willingness to continue to teach integrated STEM units (Capobianco, 2010; Stohlman et al., 2014). The national standards (NGSS, 2013) emphasize the teaching of engineering concepts in science class. There are teachers that are feeling inadequately prepared to teach these concepts (Capobianco, 2010; Stohlman et al., 2014). Bandura (1977) provided explained the impact a person’s feelings or self-efficacy might have on their ability to cope, expend effort, and sustain the behaviors in which they feel inadequate. The self-efficacy a teacher holds will impact their effort put forth on new concepts or instructional strategies. The needs of these teachers can be addressed through professional development, experience with implementation and collaboration with teachers from other fields. This case study will document and evaluate the experience of a science and math teacher. The teachers attended a professional development, began a collaborative relationship and implemented a unit collaboratively. The goal of this study is to identify the impact collaboration has on the challenges facing integrated STEM teachers. The professional development was the source of teachers to study. The study is not focused on the impact of the professional development but it is important to understand the background of the teachers. This leads me to ask questions about ways to overcome the challenges related to integrating STEM education. The collaborative relationship that was built at the professional development emerged as a potential solution. What is the nature of teacher collaboration as they implement an integrated STEM unit across two subject areas?

CHAPTER 3: METHODS

3.1 Research Design

In this study, I employed a classic qualitative case study design (Yin, 2014) in which the case consisted of two middle school teachers' collaborative implementation of an integrated STEM unit on energy. This type of study was selected because there is little research in the field of integrated STEM. Creswell (2011) says qualitative research is merited if little research exists. This qualitative case study was for exploring a collaborative integrated STEM implementation (Creswell, 2011). The methods of data collection included teacher interviews, lesson planning analysis, video analysis and journal analysis as recommended by Creswell (2011) in qualitative research.

3.2 Context

The study took place in a private catholic school, Riverside Catholic Schools[1], located in a small city in the Midwest. The school serves seventh through twelfth grade students, with an average class size of seventy-two pupils. The school population includes 83 percent white students; 12 percent Hispanic students and the remaining 6 percent of the population are African American students, Native Hawaiian students and Asian students.

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[1] The school name, Riverside Catholic Schools, is a pseudonym.

The school has 85.3 percent of students self-pay for meals. Approximately 8 percent of students receive free meals, and 7 percent of students receive a reduced price meal.

Over the previous 5 years the school has had an average test-passing rate of 84.5 percent on the state mandated standardized exams in English-Language arts and Mathematics. This is in contrast to the state average test-passing rate of 68.5 percent (INDOE, 2016). The school has had an average graduation rate of 99.22 percent over the same previous 5 years compared to the state average of 88.8 percent. The school received a state determined grade of "A" or "Exemplary Progress" each year in the past 5 years. This grade places the school in the top 53 percent of schools in the state in the most recent data available (INDOE, 2013).

3.3 Participants

The teachers[2], one junior high (Grades 7 and 8) mathematics teacher and one junior high science teacher, participated in this study. The study took place in their respective 7th grade mathematics and science classes for which the teachers shared the same students. The teachers implemented a unit on thermal energy, which was based on content that they learned during their participation in summer professional development courses on teaching science through STEM integration.

At the time of the study, Mrs. Lew had six years experience teaching middle grades (6-8) mathematics. Mrs. Lew had a career before becoming a teacher. Prior to teaching, Mrs. Lew had a career involving database management, data warehousing and medical

[2] The participants' names, Mrs. Jane and Mrs. Lew, are pseudonyms.

business management. She holds a Bachelor's degree in Electrical Engineering and a Masters degree in mathematics education.

Mrs. Lew's interest in STEM education emerges from a desire to allow students to participate in curriculum that explicitly makes connections between the STEM disciplines. She would like students to be able to see the interconnectedness of STEM concepts. Mrs. Lew's goal for the unit is for students to develop a passion for exploration and discovery in math and science.

Mrs. Lew is a novice with regards to integrated STEM education. The first unit implemented in that math classroom was an electricity unit. The unit included identifying insulators, conductors, and electricity terminology: such as voltage, current and resistance, and circuitry. The design phase of the unit was based around a locker problem. The students needed a way to alarm people surrounding the locker if an unauthorized person opened it. Mrs. Lew had the help of one of the professional development faculty, physics professor, for this initial implementation. The work on the unit was conducted every Friday for several weeks. The teacher utilized the expert in integrated STEM education to introduce students to this type of instruction. Therefore, the unit in this study is the second unit conducted by this teacher. However, this is the first integrated STEM unit the teacher has done in independently in her room while collaborating with a colleague.

Mrs. Jane has also been teaching for six years but has been teaching in a science classroom. The background of Mrs. Jane was with the Indiana Department of Natural Resources in dealing with wildlife management.

Mrs. Jane's interest in a collaborative effort, with Mrs. Lew, is from the desire to show the students how real life problems are not split up into individual subjects. The teacher's hope for the unit is for students to learn about energy, energy transformation and the design process. Additionally, the teachers desire is to teach students to work in a team while seeing problems holistically. The teacher wants students to learn and have fun while learning.

Mrs. Jane's first integrated STEM unit implementation was a board game design. The students were studying the periodic table of elements. She allowed the students to work in groups to design a board game that would teach the user concepts related to the periodic table of elements. This unit was not from the DesignSTEM professional development. Therefore, the unit being studied in this case is Mrs. Jane's second implementation of an integrated STEM unit. However, it is the first time she has collaborated with a colleague.

It is important to identify the quality of the teachers in the study. The effectiveness of each teacher is evaluated by the RISE rubric. The rubric places a teacher in one of four categories based on the score received. The four categories are labeled as ineffective (score of 1.0-1.75), improvement necessary (score of 1.75-2.5), effective (score of 2.5-3.5) and highly effective (3.5-4.0).

The Indiana Department of Education (2013) has provided the following measures of teacher effectiveness.

> An ineffective teacher consistently fails to meet expectations for professional practice, student achievement and contribution to the school or corporation. The teacher who receives improvement necessary has

> room for growth in professional practice, student achievement and professional contribution to the school or corporation. An effective teacher consistently meets expectations for professional practice, student achievement and professional contribution to the school or corporation. Lastly, the highly effective teacher consistently exceeds expectations for professional practice, student achievement and professional contribution to the school or corporation.

The principal at the school is required to evaluate the teachers and provide them a rating based on the Teacher Effectiveness Rubric, Individual Growth Model, Student Learning Objective and the School-wide Learning Measure. The teacher will receive a score (1-4) in each of these domains. This score is based on principal observations, student test scores, teacher growth measures and the school grade assigned by the state (INDOE, 2013). (Education, DOE Compass, 2016)Each domain is weighted as follows: Teacher Effectiveness Rubric (.5), Individual Growth Model Data (.35), Student Learning Objectives (.10) and School-wide Learning Measure (.05). These domains, after being weighted, are calculated to provide the teacher with a total effectiveness grade.

The aforementioned model was used to evaluate the teachers in this study. Mrs. Lew received a 3.6 (highly effective) score on her last evaluation. Mrs. Jane also received a 3.6 (highly effective) score on her last evaluation. This score is important in understanding the quality of the teachers in the study. The teachers are highly qualified in their individual discipline. The teachers rate in the top third of teachers in the state. The state has 35 percent rated as highly effective, fifty-three percent of teachers rated as effective, two percent who need improvement and .4 percent of the state's teachers are ineffective (INDOE, 2016).

3.3.1 Teachers' Professional Development

Both Mrs. Jane and Mrs. Lew attended a year-long professional development program that focused on the teaching and learning of science through STEM integration. Four faculty members in curriculum and instruction as well as a graduate student in curriculum and instruction conceptualized the professional development program. After acceptance and receiving funding, the professional development enrollement was open to middle school science, math and technology teachers. The researchers needed 20 teachers in attendance according to the funding agency. The researchers recruited the middle school teachers through email and school visits. The teachers were informed of the goals of the professional development.

The teachers with full participation would receive a stipend, graduate course credit, funding for classroom materials and curriculum utilized throughout the program. The full program is available to teachers for two years with the same incentives offered both years. The program was designed to include a 40-hour, two-week online course as well as a 40-hour one-week face-to-face course.

The online section of the program was designed to introduce the participants to integrated STEM education models, perspectives, classroom examples and goals. The participants of the program were required to read materials. The course included material about each individual discipline. These were things such as scientific inquiry, mathematic reasoning and user-centered design. The course facilitators then lead online course discussions based on the materials previously read. The online section ended with the facilitators providing a design challenge to the teacher participants. The participants were paired with another participant in the course. The participants were expected to interview the partner, ideate, sketch, prototype and present the object to the partner. This served as an introduction to the face-to-face section of the program.

The face-to-face section of the program began on day one with an introduction to teaching strategies in integrated STEM education. The following 3 days were designated as a physics day, chemistry day and biology day. These days were used to present the material to the teacher participants as if they were students. This allowed all the teachers to experience the material from the student perspective. The teachers were able to design a product each day and learn science content based around the specific content area. An expert faculty in each field of physics, chemistry and biology served as the facilitator for the day of the content area the serve.

The last day of the program was to inform the teacher participants of assessment techniques in the field of integrated STEM education. It also served as a day for the participants to create their own integrated STEM material for the classroom in which they teach. This is when the researcher identified the teachers for the purposes of this study.

These two teachers were selected as research participants due to the unique nature of their implementation. The teachers decided on the last day of the program to implement a unit that would happen concurrently in each classroom.

3.4 Data Collection

The data for this study was collected and analyzed to provide a robust description and in-depth view of the major themes that characterized the teachers' collaboration. The data collection methods were selected due to the exploratory nature of the study (Creswell, 2011). The methods that were utilized include pre and post implementation interviews, collection of documents (lesson plans, teachers' daily journals), observations and video recording of the teachers' instruction, observations of teaching planning meetings, and field notes from the observations.

I collected the video recordings, observations and field notes by sitting in the back of the classroom each day of the unit implementation. I did not instruct the classes or provide consultations to the teachers. I was there only to observe and video record.

3.4.1 Interview

I conducted both pre- and post-implementation interviews with Mrs. Jane and Mrs. Lew. The interviews were semi-structured, meaning that I used an interview protocol but asked clarification questions when necessary that were not on the protocol. The interview protocols may be found in Appendix A. I audio-recorded all interviews and transcribed them for analysis.

The first interview with the teachers occurred after the school day had concluded. The teachers met with the researcher in teacher B's classroom. The two teachers were involved in the initial interview together. The teachers were able to answer questions independently or collaboratively. The interview lasted approximately 45 minutes. The time was spent discussing the plan for the unit with the researcher. There was some planning that occurred during this time. The teachers were explaining the plans to the researcher and realized there were missing pieces. The teachers were able to work out those details or make plans to work out the details during this meeting. The direct questioning from the researcher lasted for around 10 minutes. This was time for the teachers to summarize the unit plans and respond to questions.

The post unit interview was conducted with each teacher independently. The unit concluded on a Friday and the interview occurred with the teachers the following Monday. The interview was conducted after school in each of the teacher’s classrooms. The teachers were able to answer questions independently and without the influence of the other collaborating teacher.

3.4.2 Lesson Plans

The plan for the unit was documented through the initial meeting with the teachers. At their request, the teachers were provided much of the unit’s instructional material from the Design STEM project. The additional instructional materials that the teachers used were provided to the researcher through email. The teachers provided the daily informal assessments from the previous day’s instruction. The teachers also provided any prompts provided to the students during the unit. I also observed the teachers planning meeting that occurred during the professional development and one week prior to the implementation. The observation and field notes provided insight into their planning.

3.4.3 Daily Journal

The teachers were provided a document containing five questions. The teachers were asked to respond to these questions at the end of each day during the unit. This journal is a daily reflection of the material the teacher covered as well as their competence related to that material. I collected these daily reflections via email at the conclusion of the unit.

Mrs. Jane provided daily responses to the prompts in the journal. However, Mrs. Lew did not provide daily responses.

3.4.4 Video Recording

I visited the classroom each day during the unit. My interaction with the students and teachers during this time was very minimal. I had a seat in the rear of the room and set a video recorder nearby to capture the teacher’s presentation and interaction with students. The camera was in plain view of all people in the room. The school approved the recording of the classroom. The recording was at a distance from the teacher; therefore, the teacher carried an audio recording device. This device provided a back-up if the video recording did not capture the teacher speaking.

3.5 Data Analysis

The data were analyzed at the completion of the unit. The video and audio data were transcribed for analysis. The field notes were placed with the transcription of each day. I read through the data and watched the videos to look for trends in the data. I then began to identify themes from the data. I triangulated between all data sources to identify commonalities such as the teachers' self-efficacy, planning methods, and the time they spent on certain topics. These themes were then placed on sticky notes. The evidence to support the themes was headlined on additional sticky notes. The sticky notes were then organized into a tree-diagram for organization. The themes were then elaborated on and detailed descriptions were written from the data.

The data needed to be verified by the participants. The member check was used to verify that findings were accurately depicted. Mrs. Jane and Mrs. Lew were presented the findings in one-on-one meetings and asked to provide feedback. They both indicated the findings were accurate. Mrs. Jane was happy to what went well and areas where she could improve her instruction.

3.6 Limitations

The scope of the research study is limited in the following ways:

- I could not control for previous experience the participants had in the fields of science, technology, engineering or math such as practicing engineers, mathematicians or scientists. These previous experiences may have influenced the teacher beyond the professional development they received. Therefore, the findings of the study may be transferable to similar teachers and contexts, but generalizability may be reduced.
- (Sciences, 2014)The sample was limited to two teachers who participated in a summer professional development focused on integrated STEM in middle school science, so the training and support they received might have influenced the findings.
- I could not control the preparation that the teachers conducted prior to implementing the unit. The teachers are limited on time and resources.
- I could not control the timing of implementation. The unit was implemented late fall semester.

3.7 Delimitations

The following items will not be a focus of the study due to the researcher narrowing the scope of the study.

- This study did not focus on students or learning. The focus was on teacher collaboration, teacher self-efficacy and motivation to continue to teach integrated STEM units.
- The study did not focus on student motivation or engagement.
- The study did not focus on student interest in the curriculum.
- The study did not evaluate teaching methods, abilities or qualities.
- The study did not evaluate the effectiveness of the professional development or the impact the faculty might have had on the teachers.

CHAPTER 4: DESCRIPTION OF DAILY INSTRUCTION

This chapter will provide a detailed description of the context in which the study took place. It is important to understand the unit the teachers implemented. The following sections will detail the day-to-day activities in both Mrs. Lew and Mrs. Jane's classroom. The study was not intended to evaluate the teachers' instruction. However, I believe it is important for the reader to understand all details of the unit as it was implemented. The next chapter will detail the findings of the study.

4.1 Introduction of the teaching material

The faculty member, whose expertise is in chemistry, presented the unit, and provided its details to the teachers in this study. The unit's focus was thermal energy transfer. The teachers identified this unit as a potential area of overlap between the math and science classroom. They utilized the time provided during the professional development to begin a collaborative relationship to create, plan, and implement a successful integrated STEM unit across their two classrooms. Due to both teachers participating in the unit during the professional development, both had knowledge of how the unit would look holistically.

The teachers were provided the curricular materials for implementing the unit. These materials included the PowerPoint presentations, student worksheets, inquiry activities and the story used to set the context for the unit. They were allowed to utilize the unit how it was created. However, they decided to change the unit in order for it to better fit their classroom needs. A calendar of the unit is provided in table 4.1.

Table 4.1 Unit Calendar

Day	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
Mrs.Jane (Science) Activity each day	Unit intro Context Problem identification Heat Terminology	Ice Activity Conductors Insulators	Book activity Conduction Convection Radiation	Mini Design (cup)	Mini Design Continued	House Design Build Day	Test Day	Report and reflection
Mrs.Lew (Math) Activity each day	Area Surface Area Volume	Area Surface Area Volume	Initial Ideation Sketches Materials Exploration	Area Surface Area Volume (Practice)	Worksheet and practice Create Materials List Cost Analysis	Build Day	Data Analysis Graphing Data reporting	Report and Reflection

4.2 The Unit Implementation: Science Class Day 1

Mrs. Jane began the first lesson of the unit by discussing group norms. The students provided some suggestions, prompted by the teacher’s questions, for working in groups and the teacher reiterated their points as well as added to the list. These included things such as:

1. Be “ok” with uncertainty
2. Be responsible for yourselves
3. Responsible for others (accountability)
    a. Help others understand
    b. Provide examples

The teacher explained that the next unit would require students to work collaboratively. She explicitly stated to the students that success would be easier if the list they generated would be put into practice. Mrs. Jane told the students the project would be taught collaboratively with Mrs. Lew. Her explanation included the expectations of group-work in both science and math class. Further, she explained how Mrs. Lew and herself would be working together to teach this unit. It was clear that the students would be utilizing the content they would be learning in math and science class. It was also clear that the students would be expected to apply those mathematical concepts, as well as the science concepts, in the design that would be completed for both the math and science class.

Table 4.2 The Story of Andrea's House

Andrea's House
Andrea recently moved to Indiana from Monterey, Mexico with her parents. She was very excited to move to and live in a new place but a little bit worried about the cold weather of Indiana. After their relocation, Andrea had her first winter in Indiana. She realized it was not too bad. Her home had a heating system run by electricity and it kept her home warm. When she went outside, she wore layers. In early December, however, she overheard her parents worrying about their electricity bills. They were charged a very high electricity bill for the first winter month in Indiana. Andrea would like to do something to lower their electricity bills. Can we help Andrea's family?

Note. Descriptive note. Ryu, M. (2015). Retrieved from "Lower your energy bills!" (Personal communication 10/18/2015.)

The original unit began with the story in table 4.1. The story provided a context, with a real-world problem, that needed a solution. Introducing an integrated STEM unit with a story is a best practice suggested by Bybee (2013). The story of Andrea is used to introduce students to this unit's context.

Mrs. Jane, in this case study, provided the entry point for the unit to be based around group-work, but then students proceeded to read the story about Andrea. Mrs. Jane facilitated a large group discussion about the story to encourage students to think about the problem that is facing Andrea. They discussed the issues that were facing Andrea and began to empathize with the problems. Mrs. Jane, after the introduction, asked what differences exists between Monterrey, Mexico and Indianapolis, Indiana. They provided answers such as temperature differences, home construction techniques and clothing differences. She proceeded to show them the average high and low for each location. They saw there is a clear difference in the temperature Andrea's family is used to experiencing and the temperature at their new location. She then asked the students to summarize the problem in one sentence. Each student wrote his or her own problem statement individually. They identified and shared aloud problems such as:

- Andrea's house is producing an excess amount of heat costing her too much money.
- Andrea is paying too much for her bills so we need to get her a warm house but cost her less than what it is currently.
- Andrea's family is trying to keep the electric bill down but her family is not used to the cold.
- They need to reduce the electric bill because the home cannot hold enough heat.

The teachers utilized the methodology of individual thinking to group thinking many times throughout the unit. Both teachers provided students the opportunity to work independently and then share those thoughts with the group.

The teacher asked the students to identify some key pieces of information that would be needed to solve Andrea's problem. They identified important factors such as her home size, her previous month's bills, the number of windows in her home, insulation material used in her home, her families current uses electricity, the average heating bill for Indiana and the number of people in her house. The teacher provided time to think about each of these factors and then she asked students to try to think of two possible solutions to the problem. They shared these solutions aloud. She directed the students to think about a commonality among all the solutions. They identified heat as a common factor in all the solutions. This provided a transition for her to begin her direct instruction about heat.

She asked the students to define heat. She proceeded to show them a definition and asked them how that definition is different than how the word is used in everyday language. They were asked to copy the definition of heat into their notebooks. The definition the students were presented, discussed the thermal energy of the particles in matter.

The last few minutes of class were used to review how particles acted depending on their thermal energy. The students were asked to draw a box and draw particles in the box if it were a solid, then a liquid and lastly a gas. The teacher asked the students to explain their drawings to the class. She proceeded to show them a video of particle motion of a solid, liquid and gas.

4.2.1 Science Class: Day 2

The second day of the unit began with the teacher showing unique thermometers to catch the students' attention. She showed them a thermometer invented by Galileo. She also showed a bulb thermometer and infrared thermometer. The students were able to see how each thermometer worked and its proper use. This was used to introduce students to heat as the movement of energy. She explained to the students how heat moves from high-energy concentrations to low energy concentrations.

The discussion about energy transfer allowed for a smooth introduction of the activity for the day. The teacher had a wooden cup, plastic cup, foam cup, stainless steel cup, and a copper cup. She asked the students what types of material would conduct thermal energy the best. She told them to predict which cup would remain the most constant temperature and would resist change. The students provided her answers such as stainless steel, plastic and metal. She proceeded to ask a student to place one ice cube in each cup. The cups are made of different materials and the ice cubes melted at different rates. The teacher measured the temperature from the outside of each cup with a infrared thermometer and she instructed students to record the temperature readings. She told the students they would return to the cups later and she moved on to a discussion about heat transfer.

She asked the students about the different types of heat transfer. The PowerPoint slides containing definitions for conduction, radiation and convection were displayed while the teacher explained each.

The teacher then referred back to Andrea's house. She asked the students to think about how people stay warm in other countries. She displayed pictures of homes in places such as Japan, Italy and Korea. She explained that in the United States, the homes have a furnace that pumps heat into the home. The students began to talk about how they kept their own homes warm. The teacher asked the students to think about where heat might be escaping from Andrea's house. She reminded them of thermal energy traveling from high-energy states (hot) to low energy states (cold). The students explained the loss might be through the walls, windows, ceiling and floors. She told the students to think about these places the heat might escape. She explained that they would be brainstorming ideas to help Andrea in math class the following day and remembering how energy transfer happens and where it happens would be important factors in their home design.

The teacher returned to the cups with ice and had students come to the front of the room to see which had the most water from the melting ice cube. The students quickly saw the metallic cups had much water and little remaining ice. The students identified the foam and wood cups to be good at resisting change. The teacher reminded them to keep these material properties in their minds as they brainstormed the next day in math class.

4.2.2 Science Class: Day 3

The third day of the unit was a workday for the students. The teacher provided students with paper. She instructed them to fold it in such a way that it would make a booklet. They wrote definitions of conduction, convection and radiation in their booklet. This was a way to help them remember the words as well as to provide a study tool.

4.2.3 Math Class: Day 1 and 2

Mrs. Lew, the math teacher at the school, had been preparing students to work on the same problem for Andrea. They had learned about surface area, volume and area during day 1 and 2 of the project. Mrs. Lew provided the students with the relationship between the content they had learned and the design project they were about to begin. She explained the importance of considering volume, area and surface area in heat loss. They would need to calculate the total area of the base of the their home, while designing a home that will reduce Andrea’s heating bill. She also addressed the importance of surface area and volume in regards to heat loss. The two days spent on area, volume and surface area consisted of direct instruction and student work time.

4.2.4 Math Class: Day 3

The third day of the project in math class was spent brainstorming solutions for Andrea's problem. The students were instructed to think about the problem they have been studying in science class. They have already generated a problem statement, explored heat and considered material properties and resistance to change in regards to heat in science. Mrs. Lew asked students to generate ideas for a solution to solve the problem they identified. The solution was required to have 1) $\geq$ 90 square inches of floor space with a height $\geq$ 10 inches 2) contain four walls, a roof and a floor 3) contain a 4 inch by 4 inch hole in the floor to insert the heat source (light bulb) 5) contain a total window area $\geq$ 30 square inches and 6) contain a hole in the roof large enough to allow the thermometer to be inserted.

The teacher provided the students with a class period to talk with their peers about the problem and sketch their own ideas independently. The students were able to ask each other about ideas, but each student was responsible for submitting individual sketches of the their solution. They spent much time brainstorming solutions between this day of brainstorming and the following two days in science class.

4.2.5 Science Class: Day 4 and 5

The focus of the fourth day of the unit is the design process. The day's activities were put here to precede the larger design challenge. The teacher asked the students to think about a drink in a cup that they would want to be cold with ice. Are there any problems related to this system? She provided them time to identify some problems. She then introduced to them to a real-world problem that exists with a festival company.

The students were presented with a small design challenge to encourage them to begin thinking of design as a process. The teacher introduced them to the challenge by telling them about their client, the festival company. The client, of the mini challenge, is a company that hosts festivals. The festival produces a lot of waste, such as cups for drinking. The cups the company had been using were not environmentally friendly. The company decided to switch to a recyclable cup made of plastic. The problem with this cup is the amount of time it takes for the ice to melt. The cup allows the ice to melt and the drink to become warm and watered down much too quickly. The teacher asked them, “What is causing the ice to melt so quickly?” The students began to apply their knowledge of radiation and conduction to this problem. They began to think of problems such as the warm hands of the person holding the cup. The open top of the cup poses the problem of energy transfer on a warm day.

The teacher introduced the design process to the students through facilitating a small design challenge. She encouraged them to identify a problem with the cup situation. She then encouraged them to narrow the problem by asking them why the problem exists. She asked them to think about the previous days learning on radiation, convection and conduction. The students were applying the content they learned to a real-world task. She also had made a reference to the surface area and volume calculations the students had been doing in math class. The teacher asked students to think about their learning in both math and science class and said, “How do those help you in this problem.”

The teacher proceeded to ask them to individually to think of solutions to the problem of the cups inability to keep the drink cool and prevent the ice from melting quickly. She told students they were constrained by designing a product that would create no landfill waste. She then told them not to be limited at this point in their ideation. She told them to use their computers to research existing solutions. The students who researched existing solutions were instructed to think about how those products could be improved. She provided them with some time to brainstorm and instructed them to sketch their solutions. The students then shared their solutions with their neighboring peers. The small groups then decided on a single solution by voting on the one they thought was best suited to solve the problem.

She provided time for students to share some of their ideas aloud. The ideas were broad solutions. A few of the solutions were to place a barrier between the hand and cup. One student wanted to create a cup that allowed the user to have less surface area of their hand on the cup. Another student wanted the cup to be a mini cooler that would operate on a battery. The students were creatively generated a list of ideas. These ideas were shared within the groups.

The proceeding day, the students were given time to select the idea in their group that best solved the problem. The students were provided three minutes to narrow the solutions to one. At the end of these three minutes, the teacher explained the importance of clear communication between the engineer (students) and the client (festival company). She informed them of some additional constraints and criteria the company felt were important. The company wanted to be sure the design team created a low-cost solution, due to the festivals not having an entry fee. This required the company to pay for the cups without reimbursement. Therefore, the cups must be low-cost. The company also wanted the design team to generate solutions that were safe and created no landfill waste.

The teacher used these additional criteria as a path to further student brainstorming. The teacher told the students they needed to analyze the solution the team selected. The team needed to decide if the current solution would meet all constraints and criteria the company communicated to them. If the solution did not meet the constraints and criteria, the team would have to generate additional ideas that would meet all the specifications.

The final stage of the design challenge was to select the solution and share it with the class. They were given ten minutes to brainstorm, narrow and select the final solution. The students were instructed to select a spokesperson from the design team. There were a total of five design groups. The teacher instructed them to utilize a peer gallery walk in order to receive feedback on their solution. The spokesperson from each group was expected to explain the solution to the group members from the other design teams. This process allowed all the students to learn about the solutions of all the design teams.

The two days spent on the short design challenge provided students the opportunity to enter the environment of design. The students took steps through the design process by identifying a problem, narrowing the problem, identifying a client, identifying constraints, identifying existing solutions, brainstorming solutions, sketching solutions, narrowing solutions and finally sharing the solution and receiving feedback. The students did not prototype their solutions. The teacher only wanted them to go through a quick design challenge to encourage their creative thinking. She provided the students the opportunity to think like a designer. The students were able to learn design as a process.

The students also were able to see the freedom to have multiple solutions for the same problem. This small design challenge prepared the students for the unit design.

4.2.6 Math Class: Day 4

In math class on the fourth day of the project the teacher spent time reviewing content the students would be utilizing in the proceeding couple of days. She provided them with problems that required them to use formulas for area, volume and surface area. The students had some time to work through problems themselves as a form of practice. She spent time helping students and formatively assessing their work as she stopped by each student's desk.

4.2.7 Math Class: Day 5

The fifth day of the project, in math class, the students were introduced to the materials list and material costs. She presented each type of material available to them. The students could select insulation materials based on insulating quality and price.

- $3 for 12 inch by 12 inch square of Styrofoam
- $1 for 12 inch by 12 inch square of foam sheet
- $0.20 for 12 inch by 12 inch square of bubble wrap
- $0.50 for 12 inch by 12 inch square of felt

The teacher facilitated a short discussion of material properties such as ability to restrict energy transfer and material uses. The students were given time to feel the material and talk about it's perceived properties with their peers. The students were instructed to have a final design by the end of day five. They shared each individual's ideas and explored the options for materials they could utilize in their design. The students then created sketches and a material list for their final iteration of the design.

4.2.8 Science and Math Class: Day 6

The sixth day of the project is where the math instruction and science instruction begin to merge. The students had heard the teachers discuss the collaboration but have not seen much collaboration. The next few classes were the point at which the classes came together.

The students were given a scenario and identified a problem for Andrea. The class then returned to the original problem to continue through the process of identifying a solution. In the math class, the students had been exploring the materials provided and generating ideas toward a solution for Andrea. Mrs. Jane has been preparing students to use their knowledge of thermal energy transfer to design a home that would reduce Andrea's heating bill.

The students selected and finalized a solution including a sketch and a materials list. Mrs. Lew used the materials list to fulfill the requests of the design team before the students arrived to class. The items were placed in a bag, ready for the design team to build their product.

The teams were given time in both math class and science class to build their solution. The build, for both class periods, occurred in the science classroom. The teachers decided to use the science room because of the space and tables available in the room. The teams spent the entire class period, for their scheduled math class and their scheduled science class, building the product. By the end of their second period of building, the students were required to have a finished product. The product needed to be ready for testing. They were required to cut a four-inch by four-inch hole in the bottom of their house. This hole would allow for the heat source (light bulb) to be inserted through the bottom to test how well the house could hold thermal energy. They also needed to have a small hole for inserting the thermometer in the bottom of the house and a small hole in the top of the house.

4.2.9 Science Class: Day 7

The students have generated ideas, refined the ideas to a final solution and built the product. The next phase of the design process was for students to conduct a test. The students were provided instructions on the testing procedures and required to follow those instructions. The students did not plan the test or have input on how the test was conducted.

The teacher required students to place their house on the stand with the light bulb inserted into the house. Each student in the group was assigned a task during the test. One student was the data recorder. Another student was the temperature reader. Another student was the timekeeper. The last student was in charge of turning the light to the "on" and "off" position. The student turned the light bulb to the "on" position and began the timer. The students recorded a temperature reading every two minutes. The data point was measured and recorded in degrees Fahrenheit. Once the bulb had been in the "on" position for ten minutes, it was switched to the "off" position. The temperature reading inside the house was once again recorded every two minutes. The students collected readings until ten minutes had passed. This allowed the students to gather data on the rate of heat loss. Once the data had been collected, the student recording the data shared the data with the entire group. The students returned the testing equipment to conclude the day.

4.2.10 Math Class: Day 7

The same day the students were collecting data in science class, they began to graph and analyze the data in math class. They had previously learned to use a database program on their computers. The program allowed the user to enter data points and create graphs to display that data. Mrs. Lew instructed them to enter all their test data including time and temperature readings, from science class. The students were each individually responsible for creating a graph to display the collected data. The data, in graphical form, allowed the students to visually understand the increase in temperature inside the house. The graph also displayed the rate of decrease or heat loss. The students used this graph to inform their conclusions and reflection on their design.

4.2.11 Science Class: Day 8

The last day of the unit in science class was a day to write a report containing conclusions, reflections and final thoughts. The students were given the class time to formally document their findings from the house design after testing. Mrs. Jane required students to use the collected data to formulate a conclusion. The students were specifically asked to formulate conclusions and then reflect on the project based on those conclusions.

Conclusion

1. Write out a justification for your design based on the science concepts we learned in class this week. (Why did you choose those materials? Why did you choose that shape of a house? Why did you create your window the way you did? Etc.)

2. Explain whether or not your data supports your justification.

3. What did you learn during this project?

Reflection

1. Explain the problem you were trying to solve.

2. Use your data to describe how you would redesign your house if we were going to repeat the test and explain why.

3. Think back through the whole week and answer the following questions.

    a. What are some strengths of your design?

    b. Were there any errors or bias in your experiment?

    c. If you could change anything about the project, what would you change and why?

The students wrote about the experience from both math class and science class. The data was organized and analyzed in math class but collected in science class. The students were forced to merge the deliverables from the two classes in order to write these documents.

4.2.12 Math Class: Day 8

The last day of the project in math class was spent writing a final report of the project. The students were required to complete a report similar to the report in science class but the contents of the report were different. She asked the students to include four parts in the report. The entirety of the class time was used to create the report. The students would work together but the report was due individually.

1. Plan
    a. How well did your design plan work when the team went into the building phase
    b. How did it not work well for the build?
2. Test
    a. How did your house perform on test day?
    b. What did not work well on test day?
3. Data
    a. Make the table and graph – copy/paste it in the report
    b. Discuss what happened when the house was heating and cooling.
4. Teamwork
    a. What did your team members do well? (Use specific student names)
    b. What did the team members not do well?

CHAPTER 5: FINDINGS

The data were analyzed and there emerged three major themes that revealed an impact from the collaboration. There was an impact on the teachers' perception toward their ability to teach integrated STEM content, an impact on their perception of possible outcomes from the integrated STEM unit, and an impact on their perception toward their planning for a collaborative integrated STEM unit. However, the teachers' self-efficacy was found to have an impact on their behavior and performance as a teacher.

5.1 Theme 1: Teachers' Perception of their ability to teach integrated STEM content

The work of Bandura (1977) provides evidence to support a claim that their behavior in class is related to their perception of their ability to teach integrated STEM content. Bandura (1977) further states, "…that expectations of personal efficacy determine whether coping behavior will be initiated, how much effort will be expended, and how long it will be sustained in the face of obstacles and adverse experiences" (p. 191). Additionally, the teachers' self-efficacy has a large impact on their success or failure in the classroom.

The results of the case study were based on the teachers' pre-unit and post-unit interviews, teacher lesson plans, teacher daily journals and the video recordings. The focus in this chapter is to provide evidence toward answering the question, "what affect does collaborative integrated STEM teaching have on teachers?"

5.1.1 Mrs. Jane's perceived ability to teach science and math concepts

Teacher self-efficacy can have an impact on their behaviors and outcomes in the classroom. From the teachers' behavior in class and their responses in the interviews emerged a theme related to their perception of their ability to teach the integrated STEM content.

Mrs. Jane was comfortable teaching the science content within the integrated STEM unit. She said, "I think I am very comfortable with the science portion and as long as the math is junior high level math, then I feel comfortable with that as well" (Interview, 11/12). Her comfort level with these two disciplines was revealed through her teaching. She provided students with demonstrations that supported the science content they were learning (Observations and field notes 12/2-12/8). She conducted some basic calculations with students looking to identify area and volume calculations.

Following the implementation, her feelings about her ability to teach the science and math had not changed. When asked about her comfort level with teaching the science and math concepts during the integrated STEM unit she said, "I felt comfortable with the science and math part" (Interview, 12/14).

5.1.2 Mrs. Jane's own perceived ability to teach engineering concepts

Mrs. Jane, however, did not feel as confident teaching the engineering concepts. She said, "The engineering side, I am not as familiar with but the class [Professional Development] has definitely helped me. And doing my other unit first, helped me too. So that is nice" (Interview, 11/12). She was able to gain some experience through facilitating a short design challenge, but she was still not "familiar" with the concepts.

Following the unit implementation she maintained her feelings of discomfort. She stated,

> But the engineering part, I felt ok with as long as they didn't ask too many questions. But, we have a lot of bright kids who can ask some pretty in depth questions. And so that, you know, I didn't feel as comfortable explaining the design process and stuff. But I think the more I do it the more comfortable I will feel…(Interview, 12/14).

She was making attempts to address the engineering concepts. However, she did this through the use of videos. She said,

> So I did have them watch a video that somebody else had made about it. I think that helped but as I get more comfortable with it. I can really push that point harder. Because I think that was something that was missed, was the whole engineering portion.

Mrs. Jane was uncomfortable, from the beginning, teaching engineering concepts. She choose to use was able to identify the lack of time spent on the engineering concepts. These actions follow Bandura's (1977) statement about the relationship between a person's perceived ability toward a behavior and the time spent on that behavior. She chooses not to engage in direct instruction of the engineering concepts, but instead showed the students videos.

5.1.3 Mrs. Lew's perceived ability to teach science and math concepts

Mrs. Lew was clear about her ability to teach the science and math concepts in the integrated STEM unit. She has a degree in electrical engineering. In her interview, she said that her work in the field had an impact on her confidence to teach. She said, "Now I come from an electrical engineering background. I have worked in machine shop and have done data warehousing. You know I don't have any problem with any of it so really (Interview, 11/12). She addressed the math standards regarding area, surface area, and volume. She also engaged the students in discussions about heat transfer (Observations/Field notes, 12/7). Mrs. Lew's comfort with the science and math content was observed through her willingness to engage students in content outside of her discipline.

5.1.4 Mrs. Lew's perceived ability to teach engineering concepts

Mrs. Lew engaged the students in engineering tasks such as ideation, sketching, solution evaluation and selection, solution development and prototyping (Observation/Field notes, 12/7-12/8). She stated early on that she was comfortable addressing the engineering concepts. She facilitated the build days by using Mrs. Jane's classroom. Mrs. Jane wanted to let Mrs. Lew facilitate the build and suggested they switched classrooms due to the science room being conducive to lab work.

In the interview following the implementation, Mrs. Lew said she was "actually surprised at how easy it (engineering aspects of the unit) was and how excited and involved they (the students) were. So they did phenomenally well" (Interview, 12/14). She was surprised at the ease of implementation since it was their first attempt to collaborate and implement an integrated STEM unit. She said, "we will definitely do this next year" (Interview, 12/14).

5.1.5 Perception of other teacher's ability to teach

The teachers were both confident in their colleague's ability to teach the content that was needed to complete the project. Mrs. Jane was uncomfortable teaching the engineering concepts; therefore, she let Mrs. Lew teach those concepts. She said “I know she felt more comfortable with the engineering [concepts] than I did, so I don’t know what she did with that in her class” (Interview, 12/14). This response reveals her confidence in her colleague’s ability to teach the engineering concepts. Mrs. Jane knew Mrs. Lew was confident in her own ability to teach the engineering concepts; therefore, Mrs. Jane left that aspect of the unit as Mrs. Lew’s responsibility.

Mrs. Lew made several comments about her Mrs. Jane’s ability to teach the science concepts. She was confident in her colleague’s ability to provide students the concepts they would need to design the house. Mrs. Lew said, “She is being modest. She is brilliant so I’m sure she is not even blinking an eye at her comfort level teaching this [science concepts]” (Interview, 11/12). She further stated “I have 100 percent confidence in Mrs. Jane” (Interview 11/12). Mrs. Lew knew the students’ designs required knowledge that was being taught in the science class and she was confident in Mrs. Jane’s ability to teach those concepts. Even after the implementation, Mrs. Lew said, “Mrs. Jane did all of the science and so they were very well versed in what an insulator was and what it was going to do for them” (Interview, 12/14). She had full confidence in her colleague’s ability to provide students the conceptual understanding of the content that was needed for a successful house design.

5.2 Theme 2: Teacher’s perceptions of possible outcomes

The teachers had hopes for positive outcomes before the unit began. Additionally, after the unit concluded, they had the perception that there were positive outcomes from the implementation.

5.2.1 Pre-Implementation expectations

The teachers were asked about the reasons they wanted to collaborate. Mrs. Jane replied by saying “We both thought the collaboration is useful or is beneficial to the students, so that’s where we came up with the idea” (Interview, 11/12). She wanted students to see that problems they may encounter in the real world are not compartmentalized. The students are used to an environment in school where they learn math in math class and science in science class. But she says, “…That’s not real life. Real life is not compartmentalized into subjects” (Interview, 11/12). Further, she had hopes that “…Students will have a better understanding of the material. Getting it twice per day. Even though it’s not the same content, linking it will just make it stick better in their minds. A better understanding, better retention of the material; you know, that’s what I’m hoping for” (Interview, 11/12).

Mrs. Lew provided similar responses to Mrs. Jane toward their hopes for the collaboration. She said, “We thought it would be useful for them to see that crossover, that they do link. And no, you don’t get to say that there can’t be something that relates to science on my math test” (Interview, 11/12). She added that students say, “Wait a minute! That’s science. Why are we being asked a science question in math class? Or they come to me sometimes and they are like, isn’t this math? Should Mrs. Jane be teaching this” (Interview, 11/12)?

Mrs. Lew also wanted students to see the relationship between the teachers. She felt that students were under the impression that the teachers do not communicate with each other. She said, “…Like we have never spoken to each other. They could sit there and copy off each other's science homework and I wouldn't say, excuse me. What are you doing? So I think it's beneficial that way too" (Interview, 11/12).

5.2.2 Perceived outcomes: post-implementation

The teachers were hopeful for better student learning, the students' ability to see the connections between the STEM content, and the students' ability to see the teachers working collaboratively. The interview with the teachers following the implementation provided evidence of their perceived outcomes that the unit produced.

The teachers' had the perception that there was an improvement in student learning through the integrated STEM unit. Mrs. Lew said, "Obviously surface area and volume is something that 7th ad 8th graders don't care for at all. And in fact, high school students don't care for it. But, the extent to which it affected their heating of the house, where the heat would escape a house, they were all over it. So yes, it definitely contributed to their understanding of the mathematical concepts as well as their interest in learning the mathematical concepts for the purpose of the build" (Interview, 12/14). She also was conclusive that their motivation was increased and that motivation tied to a better understanding of the material (Interview, 12/14). Mrs. Lew, after reading the student reports, said, "I'm really enjoying reading their reports that they have written on it. It's fascinating what they got out of it" (Interview, 12/14). These responses provide evidence toward an increase in student learning and an increase in student motivation. However, it is difficult to determine, through these remarks, if these were increases due to the collaboration or the integration of the STEM content.

The benefits of the STEM unit that the teachers perceived were not only in student learning, but the collaboration also provided the students the opportunity to see the interconnectedness of STEM concepts. The teachers had hopes that the collaboration would allow students to see the connections. Mrs. Jane said, “I thought it [the collaboration] really helped students see that subjects aren’t isolated and as teachers we work together” (Interview, 12/14). The teachers were able to see that this collaboration effort helped the students see the connections. They want to include the social studies teacher in the future. Mrs. Jane said, “I know we really want to do it with the math and science. We want to see if we can incorporate some of the economics from the social studies class as well” (Interview, 12/14).

5.3 Theme 3: Planning

The teachers’ planning was impacted by the collaboration. The teachers began the planning process during the professional development in June. Their initial planning consisted of a discussion, based on the unit plan provided by Dr. Ryu, about the layout of the unit (Observation, 6/19).

They proceeded to plan the distribution of the content across the days they were willing to devote to the unit. However, the planning began to reduce as the unit implementation time drew nearer. Mrs. Jane said, “We didn’t really plan out when we would be meeting but I assume we will be talking. You know after school and before school” (Interview, 11/12). They placed a large emphasis on the building materials and the timing of the unit. Their perception of the pre-planned aspects of the unit was positive. Mrs. Jane said, “Well, I think we planned out the unit well. I think now we just need to make sure we have all the materials we need” (Interview, 11/12). Mrs. Lew followed that by saying, “Ya, and what does she need from me…and creating the groups.

We need to plan the groups well so that everything runs smoothly" (Interview, 11/12). The planning the teachers conducted was toward grouping and timing.

The results of the interview following the implementation provided insight into areas the teachers realized were in need of better planning. Mrs. Jane realized that they had not planned explicit connections between the content of the two classes. She said, " I think the most of what I did was say, this is the data you're going to be using in your math class. And we're going to now use the designs that you made in math class. So that's probably about it (Interview, 12/14). She realized that she had not planned to connect the content in a meaningful way. Mrs. Lew further stated, "It's really our fault. We didn't get together more in the beginning but we didn't know what to anticipate" (Interview, 12/14). She added, "I didn't really get involved in her aspects and she didn't really get involved with mine. So…the individual curriculum content, I don't think was affected by the collaboration at all" (Interview, 12/14). Mrs. Jane implied that a remedy for this lack of a connection was due to a lack of planning. She said, "Take the time to plan it and be specific about days, how long you want the kids to be working on each aspect of it" (Interview, 12/14).

The teachers also realized the need for additional time for an integrated unit. Mrs. Jane made multiple comments about needing more time for to address engineering concepts. She also thought the students could have produced better products if they would have had more time to build them.

CHAPTER 6: DISCUSSION, IMPLICATIONS AND CONCLUSION

This study was conducted to examine the impact of a collaborative teaching relationship between a math and science teacher following a professional development. The results of recent PISA exams encouraged many (Atkinson & Mayo, 2010; Bybee, 2010; Moore, Johnson, Peters-Burton & Guzey, 2015; NAS, 2007) to discuss the lack of competitive students the United States education system is providing. The country is graduating students that do not meet the average scores of students from other countries in the Organization for Economic Cooperation and Development (OECD) (Lemke et al., 2004). The Next Generation Science Standards (NGSS Lead States, 2013) now address engineering standards and are to be taught in science classes. *The Framework for K-12 Science Education* (NRC, 2009) includes engineering design concepts and states that this will help move the next generation to be more innovative.

The National Academy of Science (2014) recommends research to identify the curriculum and nature of integrated curriculum. They also suggest research to identify support mechanisms the teachers need for a lasting reform. Bybee (2013), Sanders & Wells (2009), Breiner et al. (2012) and Bryan, Moore, Johnson & Roehrig, (2015) have provided documents that define integrated STEM education, provide suggestions on the nature and depth of integration that should be utilized.

6.1 Discussion

The data collected through the observations, field notes, interviews, lesson plans and daily reflection journals provide insight into the impact the collaborative experience had on the teachers. The teachers in the Stohlman (2014) study were not ready to continue integrated STEM curriculum. The teacher in the Capobianco (2010) study was uncertain of her abilities to teach integrated STEM curriculum, student learning that was occurring and her uncertainty of how to improve is evidence that teachers are struggling to implement integrated STEM curriculum.

In comparison, the teachers in this study who worked collaboratively to implement the unit were found to be facing similar challenges. The benefits of the collaboration show the teachers were able to rely on their partner teacher to help them through the difficulties. Mrs. Jane relied on her math partner to help her through the engineering aspects. Mrs. Lew relied on Mrs. Jane to prepare the students with the needed science content.

6.1.1 Perception of Ability to Provide Integrated STEM Instruction

The teachers in this study perceived their ability to provide integrated STEM instruction from two ends of a continuum. Mrs. Lew felt her ability to instruct an integrated STEM unit was satisfactory. She was confident in her ability to cover concepts in all aspects of the unit. However, Mrs. Jane was not confident in her ability to teach the engineering aspects of the unit. In comparison to other teachers who were feeling the same lack of confidence Mrs. Jane experienced, she differs in her willingness to continue to implement integrated material. Her perception of her ability to implement engineering curriculum in her classroom was negative. Therefore, she chose not to address the concepts in depth, but instead let Mrs. Lew address those concepts. She ended up seeing the need for the engineering concepts. She acknowledged her lack of comfort but indicated a willingness to try to address them next time. She even stated that she realized the need for additional time for the engineering aspects of the unit. She acknowledged that she wanted to include these aspects in her own classroom because she saw the students could have benefited from that addition.

The teachers provided responses that are evidence of an increase in confidence in their ability to instruct in an integrated STEM classroom. They made statements about the ease at which the unit was implemented. They also were willing to add additional members to their collaborative relationship in the coming year.

This study provides important implications for science and math educators who are uncertain about their ability to implement integrated STEM curriculum. Those hosting professional developments for these teachers can suggest collaborating. Collaboration has shown to be advantageous for those implementing for the first time.

In the future there should be a quantitative study on the teachers self-efficacy. The evidence from such a study could identify if the collaboration has a significant impact on a teachers self-efficacy.

6.1.2 Perception of Possible Outcomes

The teachers perceived that the outcome of the unit was positive. They were convinced that the students learning increased, the students' ability to see the connections between the STEM content, and the students' ability to see the teachers working collaboratively.

The teachers indicated an increase in student learning. The teachers discussed the students' reports as an indicator of learning. They also discussed the motivation of the students increased and therefore increase in learning. Mrs. Lew made many comments about student motivation as compared to previous years. She attributed this difference in motivation to the design task.

The teachers indicated that students were able to see connections between the STEM disciplines. However, when the teachers were asked about the explicit connections they made between the disciplines, they said they did not make many connections between the disciplines.

According to Sanders & Wells (2009) the connections need to be meaningful. The teachers were able to successfully implement an integrated STEM unit and they are willing to continue to implement future units. However, the connections during the unit should be meaningful.

The teachers acknowledged that the collaboration provided a time for students to see the teachers work together to provide instruction. The teachers believed this was beneficial because the students see them as disconnected and thus see the content as disconnected.

Future research is needed to provide quantitative data to support an increase in learning. I think the teachers could see a larger increase in learning if they would identify explicit connections between the disciplines. In order to make these connections the teachers need to communicate their plans more clearly.

6.1.3 Planning

The teachers mentioned their planning throughout the interviews. They spent most of their meetings planning groups and timing of the implementation. The teachers did not spend much time discussing clear connections between the content. The teachers realized throughout the unit that they needed to utilize a different type of planning.

In the future, it would be helpful for the teachers to spend time planning the integration of the content as discussed in NAS (2014). The connections need to be clearly planned and emphasized to the students. The teachers stated that they did not interfere with each other's instruction. It is good for them to maintain their independence, but it reduces the benefits of integrated STEM instruction. The students may see overlap between the classes, but did they see the connections clearly?

The teachers were able to see that the collaboration was more than mapping out an instructional schedule and creating groups. In an ideal situation, the teachers could spend time visiting each other's classroom. This might provide insight for finding the clear connections between the two classes. Many teacher schedules do not allow time for these observations. But, if the time became available, it would be beneficial for identifying explicit connections between the disciplines. NAS (2014) says a goal for teachers should be to build pedagogical knowledge. The teachers are new to integrated STEM instruction and they need to identify, through planning, the differences in instructional strategies that are needed in this unique environment. In order to reach the full potential of integrated STEM education, the teachers need to identify successful approaches through planning.

6.1.4 Implications

The teachers in this study were able to successfully implement an integrated STEM unit. There were benefits of collaborating to implement the unit but further quantitative research is needed to identify the impact on student learning, student motivation, and teacher self-efficacy. The teachers perceived that increases were visible in each of these areas but there is no empirical evidence to support that claim. It would also be beneficial to further study the collaboration between two teachers. There is a need to identify ways to collaborate in a school setting where student schedules do not align between two teachers.

6.2 Conclusion

The collaboration had benefits and challenges for these teachers. The teachers were able to collaborate to successfully implement the unit. The collaboration did impact their willingness to continue to provide integrated STEM instruction. The relief of pressure of having to face the challenges was a benefit to these teachers. They were able to share the challenges with each other. This sharing allowed Mrs. Jane to feel unconfident in teaching engineering but able to explore the content without feeling overwhelmed.

Mrs. Lew taking the lead. Mrs. Lew was able to focus her time on the math and engineering aspects while Mrs. Jane addressed the science content. The concluding factor is that the teachers are enthusiastically willing to attempt the unit again. They are also willing to introduce new units in the future. The teachers are working to expand the collaborative efforts to include the social studies teacher.

The planning methods utilized to implement this integrated STEM unit provide an example from which to learn. The teachers were uncertain about the type of planning they should do. They learned that they needed additional time to plan and needed to plan to be intentional about the meaningful connections between the content.

6.3 Final Remarks

STEM literacy is an important characteristic for students to succeed after they graduate from education institutions in the United States (NAS, 2007). It will be difficult for students to succeed in the coming STEM jobs without being STEM literate. The ability to solve problems and understand procedures is essential. Bybee (2010) says students need these skills to address the global challenges that are facing our society. The research in integrated STEM education can help further this agenda. The researchers can identify characteristics of the teachers who successfully implement integrated STEM curriculum.

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APPENDICES

APPENDIX A

Interview Questions

1. Tell me about you plans for the heat unit in terms of how the two classes will be connected.
    a. Why did you choose to teach the unit together?
    b. How will content be connected between the classes?
    c. How will you expect this to help the student learning?

2. How did you plan this collaboration?
    a. What are the benefits you are looking for in the collaboration?
    b.
3. Tell me about your comfort level with teaching an integrated STEM unit?

4. How do you believe the collaboration will impact your teaching of an integrated STEM unit?
    a. To what extend do you plan to collaborate?
    b. What planning methods were utilized for this unit?

5. How do you plan to incorporate the engineering design aspects of the unit?
    a. Why are you conducting the unit in this way?

6. What impact do you believe the collaboration will have on the teaching of the engineering design concepts?

7. Do you plan to teach aspects of each others content?

8. Will you plan to implement another integrated STEM unit in the future?

9. Will you plan to implement another integrated STEM unit collaboratively?

10. How would you describe your role as a teacher in an integrated STEM classroom?

APPENDIX B

Journal Questions

1. What topic was covered today in class?
2. How competent were you with the content?
3. Would you feel comfortable conducting a similar lesson again?
4. Did the collaboration have any impact on today's lesson?
5. How is the collaborative relationship?