LEARNING ENVIRONMENTS FOR STEM INTEGRATION

by

Michael W. Coots

A Thesis

Submitted to the Faculty of Purdue University

In Partial Fulfillment of the Requirements for the degree of

Master of Science

Department of Technology Leadership & Innovation

West Lafayette, Indiana

August 2021

THE PURDUE UNIVERSITY GRADUATE SCHOOL
STATEMENT OF COMMITTEE APPROVAL

Dr. Greg J. Strimel, Chair
Department of Technology Leadership & Innovation

Dr. Nathan J. Mentzer
Department of Technology Leadership & Innovation

Dr. Stephen J. Elliott
Department of Technology Leadership & Innovation

Approved by:
Dr. Nathan J. Mentzer

Dedicated to my family and friends for supporting me thus far

And my wife for giving the final push

ACKNOWLEDGMENTS

It has been a trek to reach this point, the journey has been arduous and long and I would never have made it without the support of people like my professors and family members.

I would like to express my deepest respect and gratitude to Dr. Greg Strimel for his patience and faith that I could complete this thesis. Dr. Strimel accepted the position of committee chair for my thesis at the beginning of my second year in the program. They would guide me through the entire process, from writing my research question through finishing edits. His support and advice have been an anchor during a very difficult time. Constantly, Dr. Strimel provided valuable feedback and encouragement, even when I was unsure of myself. I know I have not made his job any easier along the way, but his tenacity has always kept me going. I would still be lost in the writing if not for his guidance and persistence.

Truly I am blessed to have had two amazing advisors during my graduate education. I would like to also express my deepest respect and gratitude to Dr. Nathan Mentzer for believing that I had what it takes to complete the coursework for Technology Leadership and Innovation. Dr. Mentzer was my supervising professor during my student teaching, he was my supervisor during my work as a graduate assistant, and he was my advisor when I started graduate school. His professionalism and passion for Technology Education were always great motivators and his relentless work ethic was infectious. Dr. Mentzer allowed me to explore my interests, helped me with writing publications, and allowed me to continue teaching during my graduate education.

It has been my honor and privilege to attend Purdue University for both my undergraduate and graduate education. The faculty and staff of the Polytechnic Institute have helped me through some of the most difficult times in my life, providing me with opportunities to achieve both my academic and career goals. I would like to thank Dr. Strimel, Dr. Mentzer, and Dr. Minjung Ryu for agreeing to be the committee for my thesis and helping develop my research study. In addition, I would like to express gratitude to Dr. Elliot for stepping in and rounding out my defense committee when Dr. Ryu was no longer able to be part of my committee. I would also like to thank Stephanie Schmidt for always being there to help me with the necessary documentation for the Graduate School. Purdue was my home for nearly a decade, and I will always remember my time there fondly.

I would like to express my deepest love and gratitude to my family for their support, love, and endurance. As long and arduous as this path has been for me, so too has it been for my family. My parents have been with me since the journey began and they have eagerly waited for the resolution. Their support and at times tough love have helped me break through writer’s block and procrastination. I owe them more than I could ever repay for their patience, love, and support.

Finally, I need to thank my wife. We were married while I was trying to finish this research study. From the moment we met she has encouraged me, believing that I had the ability to finish this thesis. When I lost my way, she guided me back on task. I have always struggled with focus and determination; my wife has been my missing piece. Without her, I would not have been able to finish this study. Thank you, my love, my sun and moon, my every day.

TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

STEM education has been a topic of reform in education for many years and it has recently focused primarily on the education methodology called STEM integration. Universities and state departments of education have defined teacher education programs and STEM initiatives that explore the necessary ingredients for a curriculum using this methodology, but they do not provide explicit instructions for the design of the learning environment. The purpose of this study was to explore the question "What are the characteristics of high school learning environments that support integrated STEM instruction?"

This qualitative study used a postpositive lens and multiple-case study framework to distill the experiences and evidence gathered from four STEM certified high schools in the state of Indiana. This distillation resulted in three universal themes common to each school which were: the allocation of universally accessible free space for STEM integration, the importance for mobility of resources and students, and the need for supportive technological resources.

This study is applicable to both those who are educators working in STEM education and those researchers looking to understand the STEM integration paradigm or learning environment design. Educators can use this study to plan their own learning environments and researchers can use this study as a pilot to many other outlets in the topic of STEM integration.

CHAPTER 1. INTRODUCTION

1.1 Problem Introduction

Science, Technology, Engineering, and Mathematics (STEM) disciplines have been the central focus of educational reform, in the United States, for the past 50 years (National Commission on Excellence in Education, 1983). A recent trend in STEM education centers on the integration of curriculum and instruction to eliminate the silos of individual subjects. By doing so, educators could provide authentic and highly contextualized learning environments. In secondary schools, integration efforts take many forms. Educators are trained through various means in the hopes that it will increase their ability to teach 21st century competences and higher order thinking skills. These efforts may manifest greater retention and interest in STEM content areas and may increase the number of graduating students entering the STEM workforce. With this push to increase the effectiveness of STEM education through integration, teacher education programs at major universities are working to include integration methodology into teacher preparation programs (Ryu et al., 2018). Most of these efforts are focused on curriculum development and delivery, while little emphasis is placed on how to develop facilities or physical environments for a STEM integration. Each subject traditionally has its own learning environment, setup specifically to teach their content. Does this mean the integration of those STEM subjects require different learning environments? This non-emphasis on learning environments can be observed even in state policies on STEM education. For example, the state of Indiana has developed a framework for STEM school certification which evaluates school curricula and instructional practices. If an Indiana school meets the evaluation criteria, then it results in the school receiving a state level certification in STEM education. Yet, the Indiana STEM certification framework makes little reference to the physical learning environment beyond setting the expectation that it should resemble a job space (see Indiana's STEM Initiative Plan). Therefore, if the unwritten expectation is that the learning environment is left to the educators, then how do these educators design their learning environments in this era of integrated STEM education?

1.2 Research Question

The following research question guided this study:

> ***RQ: What are the characteristics of high school learning environments that support integrated STEM instruction?***

1.3 Significance

Today, there are increased societal and governmental pressures on teachers to innovate STEM education, one of those innovations is integration (Honey, Pearson, & Schweingruber, 2014). Therefore, this study sought to identify characteristics of a school learning environment that supports integrated STEM learning, by investing schools engaged in STEM integration practices. By sharing the findings from this investigations, other schools can replicate these practices and education researchers can explore the characteristics in more depth. Education is not one-dimensional; curriculum and content are not the only factors. Student context and the learning environment are also key factors to instructional practice and student learning (Daughtery, Klenke, & Neden, 2008). Efforts to implement STEM integration are often focused on pedagogy and curriculum development (Honey, Pearson, & Schweingruber, 2014) and these areas typically focus on providing authentic learning experiences for students. However, to be truly authentic, the physical environment in which this learning occurs should be important to understand. Facilities can be “make it or break it” for STEM initiatives but we may be unable to define those facilities without understanding the aspects of those spaces. Through extensive reading the researcher found a distinct lack of literature about the subject. This lack of definition was also found in the Implementation Matrix and application for STEM Certification by the Indiana Department of Education. The matrix and application include a section for the learning environment but did not provide actionable definitions. STEM integration can be seen as the removal of these disciplines from their silos, but STEM curriculum, methods, and certifications are still mostly siloed.

1.4 Scope

This study was designed to identify, based on the qualitative data collected from STEM certified schools, characteristics of an educational learning environment that can help facilitate student learning through integrated STEM curriculum. The participants of this study included teachers and administrators from STEM certified secondary schools in Indiana. Identified by the administrators at each school, these teachers and administrators are the leaders of the STEM initiatives in their respective schools. Participants have been asked to partake in interviews and give permission for after school observations of their educational spaces. Their experiences and perspectives can be critical toward understanding the attributes of their STEM classrooms. After data analysis, as a form of member checking, the participants were asked to review their respective case summary to validate the researcher's interpretation of the interview and observation process. The analysis of these data (interviews, observations, artifact analysis, and survey results) were used to identify the attributes of educational environments that support STEM integration.

1.5 Assumptions

During this study, several assumptions were made about the participating schools, the data collection and analysis, and the outcomes of the study:

- Participating schools' records of their application for Indiana STEM Certification are representative of this approach to STEM integration.
- Participating school representatives have thought carefully about the physical environment. They have adapted, or would like to adapt, their school's environment to be conducive to STEM integration.
- Artifact analysis of each participating school's certification application will provide information that can be used to inform the necessary interview questions and observation rubrics.
- Responses to the interview questions will be truthful and accurate instead of a façade to make them look good.

1.6 Limitations

This study has the following limitations:

- The number of schools in Indiana that are certified as STEM schools is small and they are generally congregated in the same region geographically. This may mean the data is not representative of all schools in the state.
- The nature of the qualitative case study is primarily to explore a phenomenon and the specifics of each case are not generalizable.
- The Indiana STEM Certification is a relatively new program, and most schools are still adjusting to the initiative to increase STEM emphasis and access.

<u>1.7 Delimitations</u>

There are several delimitations for this study:

- This study is focused on high schools in the State of Indiana that have been certified as a STEM School and that are a traditional school not a specialized school, such as vocational school. These specialized schools, like a vocational school, will not necessarily have all the STEM subject areas, let alone non-STEM subjects, that are part of the STEM integration concept.
- The validity of the study comes from the work done by the State of Indiana to develop a framework for certifying schools, which are the participants.

<u>1.8 Definitions</u>

- *Science, Technology, Engineering, and Mathematics (STEM) Integration*- an educational approach that combines the concepts and principles of STEM subjects (Wang et al., 2011). The goal of STEM integration is to increase STEM literacy, develop 21st century competencies, improve workforce readiness for STEM fields, and generate interest and engagement with students (Honey, Pearson, & Schweingruber, 2014).
- *STEM School Certification*- a current movement among individual state governments is to implement a certification for schools which are specifically engaging in progressive STEM education initiatives. A STEM certified school has been recognized by the state government as a school which is engaging in interdisciplinary literacy among STEM disciplines.
- *Learning Environment*- the environment in which learning occurs at school. This can include the classroom, hallways, laboratories, libraries, recreational spaces, etc.

- *Indiana STEM Implementation Matrix*- a hierarchy describing the implementation level of the STEM initiative plan. There are four levels outlined in the matrix and each one describes an increasingly more complex STEM education initiative.
- *STEM Immersion*- the prioritizing of STEM by incorporating STEM education at every level of schooling, engaging the local community and business, and adopting effective curriculum models.

1.9 Summary

Educational policies have been emphasizing STEM education since the federal report in 1983 called A Nation at Risk (National Commission on Excellence in Education, 1983). The current trend is a pedagogical method known as STEM integration, an educational method championed for its emphasis on 21st century competencies and STEM literacy. A question emerges from this educational method, “what does the classroom look like when engaging in this integration?” This study identifies the attributes of the educational space engaged in STEM integration. These attributes were derived from data collected from participating teachers and administrators of STEM Certified schools in the state of Indiana. This is qualitative study designed to understand this phenomenon in specific cases, as understanding the phenomenon is crucial to future research in this area which can eventually be generalizable.

CHAPTER 2. LITERATURE REVIEW

2.1 Purpose of Literature Review

Science, Technology, Engineering, and Mathematics (STEM) is a rich topic for research; being at the center of educational reform for the past 50 years, it has inspired many scholarly endeavors. To fully understand the context of the question, "What are the characteristics of high school learning environments that support integrated STEM instruction?", a synthesis of available literature is necessary. This chapter will cover the purpose of STEM integration and its implications for education, different approaches to integration, classroom management research, STEM labs and Makerspaces, and STEM schools. The purpose of this literature review is to develop an understanding of the problem space and define a context for this research study.

2.2 The Purpose of Integrating STEM?

Contemporary trends in STEM education have their roots of the events of the Cold War of the 20th century (Roy & Love, 2017). The launch of Sputnik by the Soviet Union focused the American people on the idea of being the first people on the moon. This drive was translated to the education system by emphasizing mathematics and science to close the gap between American students and those students of other countries (Roy & Love, 2017). Many educational movements of the late 20th century were focused on ensuring America's status as an international superpower. A reason it could fall from that status was an education system that would not prepare students for the advanced technical careers forming in the global industry (Roy & Love, 2017). As advancing STEM core values has continued into the 21st century, we also continue to search for the better ways to implement STEM content.

Many of the reforms, from the last century, proposed visions of science, mathematics, and technology being taught in unison (Roy & Love, 2017). This theory has evolved over the years, but it is currently called Integrative STEM, the purpose of which is to "intentionally teach content and practices of science and mathematics education concurrently with content and practices of technology/engineering" by the "application of technological/engineering design based pedagogical approaches" (Wells & Ernst, 2012). The purpose of integrating STEM subjects is also define by Wang et al.'s (2011) as "explicit and intentional blendings of science, technology, engineering, mathematics, and agriculture into a learning experience in order to deepen student understanding of each discipline, situate learning in socially and culturally relevant contexts, and increase interests in STEM careers." This intentional blending of content and practices has been the subject discussion amongst teachers and teacher educators (Ryu et al., 2018) and its application can take several forms.

2.3 STEM Integration Approach

Defining the purpose of STEM integration is only the first step, the next step is applying that purpose to a teaching practice. There are two major perspectives on what constitutes STEM integration. One perspective states that STEM integration refers to the use of the engineering design process to teach science and mathematics content and practices (Honey et al., 2014). The other perspective states that STEM integration is a specific instance of curriculum integration between, at least, two STEM content areas (Hurley, 2001). Understanding both perspectives and their approaches begins to define what might be the needs of the classroom.

2.3.1 Achieving Integration Through Engineering Design

Beginning with the Next Generation Science Standards (NGSS Lead States, 2013), a form of STEM integration has been developed around the inclusion of engineering principles and the design process (Honey, et al, 2014). From this perspective, science and mathematics are the core subjects that strengthened by the inclusion of technology and engineering. Technology, in this case, is often positioned as the tools and systems to facilitate learning, that is computers, software, etc. Engineering is not always seen as content knowledge but often a practice or method of applying science and mathematics to real-world problems. To have the skills necessary to apply content knowledge in real-world experiences, the engineering process provides authentic experiences that are transdisciplinary (Grubbs & Strimel, 2015). Advocates of this integration perspective believe that the integration of engineering and technology makes science and mathematics more relevant for students which in turn makes learning more meaningful (Moore et al., 2014).

This framework of integration has six major components, outlined by Moore, Stohlmann, Wang, Tank, Glancy, and Roehrig (2014) and synthesized by Guzey, Moore, and Harwell (2016). First, the integrated curriculum should include authentic real-world contexts for problems. Making problems more realistic by including current events and issues creates a more meaningful learning experience (Brophy, Klein, Portsmore, & Rogers, 2008; Carlson & Sullivan, 2004; Frykholm & Glasson, 2005; Kolodner et al., 2003; Strimel, 2014). Second, integration using a design challenge should educate students about engineering practices and the design process (Guzey, Moore, & Harwell, 2016). Third, failing and reflection are critical elements of both the design and the learning processes (Kolodner et al., 2003; Wendell & Rogers, 2013). Fourth, STEM integration lessons should include science and mathematics content that is appropriate for the intended grade level (Guzey, Moore, & Harwell, 2016). Fifth, the instructional method should be student-centered; project- and problem-based are proven methods for conceptual learning of science content (Hmelo, Holton, & Kolodner, 2000). Sixth, the design challenge should require students to develop their skills in teamwork and communication (Advancing Excellence, 2020).

In this approach to STEM integration, engineering and design are the methods of instruction for the science and mathematics content, technology is the tool and result of the design process. This approach, based on its framework, could be controversial amongst educators because the integration works in only one way. Mathematics and science use concepts and practices from engineering and technology but do not necessarily teach their content or standards. Using engineering this way could lead to a lack of authenticity and misrepresent the reality of engineering as a field (Strimel et al., 2020). In this approach integration is viewed from one perspective. This contrasts other approaches that offer integration from multiple perspectives.

2.3.2 Curriculum Integration

Curriculum integration, in terms of STEM content, is an approach that allows multiple perspectives about what constitutes integration. In 2001, author Hurley defined five different approaches to integration: sequenced (multiple subject areas taught sequentially), parallel (multiple subject areas taught simultaneously), partial (multiple subject areas partially taught together), enhanced (multiple subject areas taught as the major discipline(s) with other(s) included to support teaching the major discipline), and total (multiple subject areas taught together as multiple major disciplines). Hurley (2001) found that each approach had its own outcomes and, depending on which approach was used, the learning outcomes could be tailored by the educator.

Another framework was developed for the integration of multiple curricula by Jacobs (1989). They outlined six types of integration that ranged from low integration to high integration. These types were modeled as discipline based (separate subjects taught in separate classes), parallel disciplines (each discipline connected to the same theme or topic), multidisciplinary (some disciplines taught together), interdisciplinary units (deliberately making connections among disciplines), integrated day (taught disciplines under a theme or problem emerging from child's world), and complete program (totally integrated program, curriculum designed out of students' everyday lives) (Guzey, Moore, & Harwell, 2016).

Both the engineering design perspective and curriculum integration perspective on STEM integration have merit and are based in research, and though they are at odds, they both beg the same question: "Can they be taught in classroom designed for one specific content?" Neither perspective ties integration explicitly to the physical space of the classroom. Rather, both focus solely on the curriculum and/or the instructional practice for integration.

The researcher used the online Purdue Libraries search function, and various databases such as EBSCO Databases, Education Source, ProQuest Collection, etc., to find literature about the STEM integration methodologies and applications. Using various combinations of keywords, such as "STEM", "integration", "learning environment", "classrooms", "application", etc., the researcher was unable to find literature that discussed the characteristics of these STEM learning environments or how teachers can use their facilities to aid the integration of STEM disciplines. After extensive reading in the application of STEM integration, the researcher had found little mention of the learning environment for a perspective of the physical environment for this type of learning to occur. This can be challenging for educators attempting to start a STEM program or get their school certified as a STEM school.

2.4 STEM Education in Indiana

From an educator's perspective, STEM integration can be overwhelming, and many teachers may be left asking themselves where to start. Many teachers who are being asked to engage in this integration effort are unsure how their classroom should function (McGinnis, 2017).

To understand the current expectation of teachers engaging in STEM integration, a review of the standards for Indiana's STEM Certification program, the context for this study, was necessary.

2.4.1 Indiana's STEM Education Implementation

Indiana has adapted an implementation plan to form their own framework for STEM Education. In this framework, the term STEM Education is defined in the same manner as STEM integration.

> STEM education is an interdisciplinary literacy that seeks to integrate, in whole or in part, the four areas of science, technology, engineering, and mathematics into a comprehensive and coherent curriculum across content areas. STEM literacy includes, but does not simply mean, achieving independent literacy in these four strands; rather, STEM literacy focuses on relevant integration alongside independent literacy. (Indiana's STEM Initiative Plan, 2017, p. 5)

Indiana’s framework for STEM education does not explicitly define their approach to integration, rather they define each area of STEM education and then describe integration as an application of their framework. The approach outlined in the framework is closer to curriculum integration, due to its lack of emphasis on engineering design as a method of teaching science and mathematics content (Indiana's STEM Initiative Plan, 2017). The rhetoric in the document expounds on the importance of integrating across disciplines and developing a culture of interdisciplinary learning and thinking. Implementation of this approach is described more in the styles of Hurley (2001) and Jacobs (1989) as it is more about how the curricula are integrated and not about the use of design challenges.

Starting in elementary school, the Indiana Framework for STEM Education proposes that this integrated curriculum engages students in an exploration of the four disciplines. It cites integration as a method of meaningful learning which occurs during a real-world context and makes connections between prior understanding, new experiences, and new skills (Wang et al., 2011). The framework defines the level of integration in terms of STEM immersion and uses a "STEM Immersion Matrix" to detail the requirements and characteristics of each level (Indiana's STEM Initiative Plan, 2017).

2.4.2 STEM Immersion Matrix

The matrix used by the Indiana Department of Education is primarily based on an immersion matrix developed in Arizona. The Science Foundation of Arizona collaborated with local agencies to create the Immersion Guide and STEM Immersion Matrix for Schools and Districts. Indiana modified these documents to work within the Indiana education system and thereby created the framework for Indiana’s STEM Initiative Plan and STEM certification. The framework defines four levels of integration: Full Immersion, Partial Immersion, Minimum Immersion, and Supplemental. The levels are defined in a hierarchal order with Full Immersion as the top tier integration model. Opposite of that, the bottom tier model is labeled Supplemental because the STEM experiences offered are not part of the school curriculum but rather as optional extracurricular opportunities which occurs separate from the school day (Indiana's STEM Initiative Plan, 2017).

The top tier integration level, Full Immersion, is defined as entire schools or districts participating in the STEM initiatives (Indiana's STEM Initiative Plan, 2017). The educational space is supposed to resemble more of a work environment rather than a traditional classroom. Also, the classroom culture should be geared toward solving community problems. Although the framework includes a criterion for the classroom to resemble a work environment, they give more indication as to how this is to be accomplished. The requirements for meeting this criterion are not defined and the educators implementing the STEM program are left to their own devices to define how the learning environment will look. The curriculum, however, is supposed to be problem-based and bound by authentic experiences which are career oriented and interdisciplinary. Schools labeled as Full Immersion should have partnerships and opportunities with local businesses and STEM companies.

A step down in the integration hierarchy is the Partial Immersion level. This model is still non-traditional, but it is not necessarily a school wide initiative. Curriculum integration is primarily a means of enhancing educational experiences but in addition to current curriculum. These schools frequently engage in long term projects which are cross-disciplinary, however only a portion of the student body participates. Schools engaged in this level of integration often have partnerships with local businesses, as well.

The third tier, labeled Minimum Immersion, generally resembles a traditional school but with curriculum that uses problem-based units. These units are integrative but often used as capstone projects and means of assessment rather than general instructional tool.

The final tier is known as Supplemental due it being primarily an optional educational experience that is not defined by the school's curriculum. This type of integration often takes the form of an after-school program or club.

2.5 Exploring Current STEM Spaces

Indiana schools, applying for a STEM certification, may consider their facilities and what is possible in their educational learning environment. Deciding how they will integrate or what methodologies they will leverage will depend on the size of their facilities and the equipment available. There are several options for these schools to develop their space for integration. Oftentimes schools in the state of Indiana have a space designated for a Technology Education program which can be a starting point for integrated learning. However, these Technology

Education spaces are tailored to diverse courses, such as college readiness courses like Project Lead the Way (PLTW) or vocational courses like Construction systems, categorized as Technology Education by the state curriculum guides. Many schools continue traditional industrial arts courses and are equipped with that type of lab space, while others offer PLTW courses and are primarily computer lab spaces. There are several other STEM spaces in the realm of education that may hold the answer: Fab Labs, Makerspaces, and STEM Laboratories. Each of these STEM spaces focus on providing students with a place to "engage in formal and informal STEM learning experiences" (Roy & Love, 2017, p. 4). According to authors Roy and Love (2017), "the demand for STEM labs" (p. 4) is due the educational movements of the 20th century which "promoted the integration of STEM as opposed to teaching each content area in isolation" (p. 4). Massachusetts Institute of Technology (MIT) started the first Fab Lab in 2001, and by 2016 there were Fab Labs on every continent, except Antarctica (Roy & Love, 2017). The maker movement, which began in 2005, is attributed as the driving force behind the creation of makerspaces (Roy & Love, 2017). Since 2006, thousands of makers across North America have attended Maker Faires, and makerspaces have found their way into school libraries (Roy & Love, 2017). STEM Laboratories (Labs) are "collaborative spaces where the study of science, technology, engineering, and mathematics (in conjunction with other content areas) can be integrated through hands-on experiences in a pure laboratory or combined classroom/laboratory setting" (Roy & Love, 2017, p. 6-7). When considering a learning environment that is designed to facilitate STEM integration, these spaces provide a possible framework to reference.

2.5.1 Fab Lab

The first Fab Lab was an outreach venture by MIT, funded by a National Science Foundation grant in 2001 (Roy & Love, 2017), and it served two different purposes. The first was to explain the relationship between STEM content and fabrication; the second purpose was to provide technology to disadvantaged communities as a grassroots effort to empower them (Roy & Love, 2017). These spaces are a means of engaging in product design and development, moving ideas from concept to entrepreneurial opportunities (Roy & Love, 2017). These labs are part of global network under a specific charter and are open to the public. The Fab Foundation, the parent organization behind the Fab Lab network, explains on their webpage what Fab Labs are:

> A Fab Lab is comprised of off-the-shelf, industrial-grade fabrication and electronics tools, wrapped in open-source software and programs written by researchers at MIT's Center for Bits and Atoms. Originally designed for communities as prototyping platforms for local entrepreneurship, Fab Labs are increasingly being adopted by schools as platforms for project-based, hands-on STEM education. Users learn by designing and creating objects of personal interest or invention and innovation. In educational settings, rather than relying on a fixed curriculum, learning happens in an authentic, engaging, personal context, one in which students go through a cycle of imagination, design, prototyping, reflection, and iteration as they find solutions to challenges or bring their ideas to life (Fab Foundation, 2020).

The focus of the Fab lab is on product design and development, learning experiences are informal and not assessed (Dubriwny et al., 2016). Makerspaces are similar in this way to Fab Labs and are often considered a spin-off of the Fab Labs movement. However, Makerspaces are generally comprised of less expensive equipment and do not have a parent organization (Roy & Love, 2017).

2.5.2 Makerspaces

Similar to the Fab Lab, Makerspaces can be a place to provide the space and community for individuals interested in learning through making something. Though Makerspaces are generally less formal than the Fab Labs, they can provide a similar experience. Makerspaces are generally found in public facilities such as schools, universities, and community centers (Roy & Love, 2017). Both Fab Labs and Makerspaces are defined by their sense of community and the collaboration which results in both learning and innovations. While Makerspaces are often found in schools, they are an informal educational space and do not invoke a specific curriculum or content. Like the Fab Lab concept, authors Roy and Love (2017) explain that the physical space and equipment alone do not define the makerspace, rather it is the community or culture of collaboration and innovation that define the space.

2.5.3 STEM Laboratories

Finally, there is another option which is similar to the others but focuses on formal education rather than informal learning. STEM laboratories (labs) focus on the physical space but rely on the curriculum and pedagogical approaches of those educators using the facility to transform it into a learning environment (Roy & Love, 2017). These spaces are also known as collaborative spaces which encourage the learning of STEM disciplines through authentic experiences in a laboratory setting (Roy & Love, 2017). Being a space that invites STEM disciplines to engage in the learning process while providing an authentic physical space suggests that STEM labs are a possible model for schools engaging in STEM integration. Makerspaces and Fab Labs seem to focus primarily on the culture and experience of creating and innovating, whereas the educational experience is not explicit and therefore not formally assessable. If they were to be used in an academic classroom, as means to teach content, then they would start to become more of a STEM lab, where the educational experience is explicit and formally assessed.

2.5.4 Challenges of Current STEM Spaces

In their book Safer Makerspaces, Fab Labs, and STEM Labs, authors Roy and Love explain some of the challenges that schools face when implementing one these facilities (2017). The three general issues with these types of facilities, as listed by authors Roy and Love, are issues of safety, cost, and instructional training (2017). These spaces utilize hazardous tools, materials, and chemicals which means that safety is of great concern. This issue can increase when the facilities are open to the public, and it can be difficult to ensure all participants have the necessary safety training. Part of making the space safe can be spending enough money on safety equipment and insurance which can increase the cost of the facilities operating cost. The equipment and materials can often be cost prohibitive, as well. Finally, the instructors or lab operators should be prepared and trained to facilitate participants in multiple STEM fields. Finding individuals skilled enough in multiple content areas can be a major difficulty.

These three challenges can make implementation of these facilities difficult but not impossible; the major concern with these spaces can be that they are not backed by research in their contribution to formal STEM integration initiatives. There is some literature that explores the impact of these spaces on STEM learning, but they are often studies where participants are using the spaces as extracurricular experiences (Dubriwny et al., 2016). An example of this phenomena is the study conducted by Dubriwny and company (2016) which explored the impact of a local Fab Lab on the self-efficacy of students towards STEM education. In their study, they worked with a specific group of students who worked in the Fab Lab outside of normal class time. These types of studies can show these spaces are beneficial to student learning experiences, but they do not explain how they can be utilized in the school environment. If STEM integration is a pedagogical approach that educators are trying to implement, how do they utilize these examples of possible learning environments? How do they deal with the general issues outlined by authors Roy and Love? If Fab Labs, makerspaces, and STEM labs are only part of the solution, how are STEM integrators designing their learning environments?

2.6 Where does this Study Fit?

This literature review was started to develop a fundamental understanding of the context and theories of STEM integration and explore some current mainstream examples of the learning environment being leveraged to teach STEM integration principles. This helped to find the context for this study's research question and methodology. In the state of Indiana, which seems to have a progressive STEM education plan, there are several schools labeled as STEM certified schools by the Indiana Department of Education for their STEM initiatives and programs. These schools have been identified for their efforts to implement progressive STEM education initiatives, which are similar to STEM integration principles. When trying to identify what a learning environment would look like for STEM integration, it seemed reasonable that those educators and schools would be good examples to investigate. The mainstream STEM spaces, explored by authors Roy and Love (2017), provide a framework to contextualize the data from visiting the STEM schools. This study looks to provide real-world examples of learning environments which are used to teach STEM integration and identify the commonality that might exist between them. These schools are noted for their efforts in integration, so this study sought to investigate how their learning environments were designed?

CHAPTER 3. METHODOLOGY

This chapter explains the specific methods used in this study. First, this chapter will provide an overview of the case study framework leveraged for this research. Then there will be a discussion as to the specific theoretical lens and positionality of the researcher. Following that discussion, there will be a detailed review of the individual cases under investigation which will include the school demographics and participant information. Finally, at the end of chapter, there will be details about the data collection procedures, the role of the researcher, the trustworthiness of the data collection and analysis procedures, and the data analysis plan. To maintain alignment throughout the study, the following research question guided the development of this research methodology:

> ***Research Question: What are the characteristics of high school learning environments that support integrated STEM instruction?***

3.1 Qualitative Research

Qualitative research is an approach, often used in the social sciences, to scientifically explain a phenomenon by a means of systematic investigation (Mohler, 2017). The purpose of this research is to translate the knowledge and expertise of individuals, engaging in a phenomenon, into a detailed exploration of an identified case, which in the context of this research is a STEM certified school. More specifically, this study focuses on understanding how the learning environment in STEM certified schools is designed and implemented to support integrated STEM learning. A qualitative approach was selected because frameworks in this research-type use a small number of cases to explore many different sources of data, whereas quantitative frameworks use many cases to explore a select few variables (Creswell, 1998). Qualitative research is hallmarked by its purpose to understand the “how” and “what” of a specific phenomenon (Yin, 2003). Understanding the “what” is imperative to this study because the area of interest has not been thoroughly explored and the theories involved are unclear (Creswell, 1998). Quantitative studies require specific variables which are defined and measured by the research procedures (Creswell, 1998), however the limited literature and research in this area means that the variables are unknown. Qualitative studies can then be considered a good fit for exploring and describing phenomena, thereby defining possible variables which could be studied independently in future quantitative studies. To answer the guiding research question and explore the identified phenomenon, it is critical to begin by describing specific cases of schools engaging in STEM integration.

3.2 Case Study Framework

Describing specific instances of high schools engaging in STEM integration and their school environments could be conducted using a case study framework. Case studies are generally used to analyze specific, bounded instances of a phenomenon. This “method allows investigators to retain holistic and meaningful characteristics of real-life events” (Yin, 2003, p. 2) which help researchers describe complex social phenomena. Case study frameworks are generally selected because the context of the phenomenon is important (Yin, 2003). For this study, it was critical to fully describe the specific phenomena of a high school learning environment engaged in STEM integration, the specifics of the schools’ contexts, and their curriculum efforts and pedagogical approach to STEM integration. To explore this phenomenon, in a specific context, multiple cases of the phenomenon with similar bounds on the context were selected for this research study (i.e., STEM certified Schools in Indiana). This approach was selected because the results of this study will be more robust if they are derived from several cases that come from a similar context.

A framework for a multiple-case qualitative study has been developed for this research study. As seen in Figure 3.1, each case has its own context but also has a shared context and all cases will be analyzed using the same procedure under the holistic multiple-case study approach.

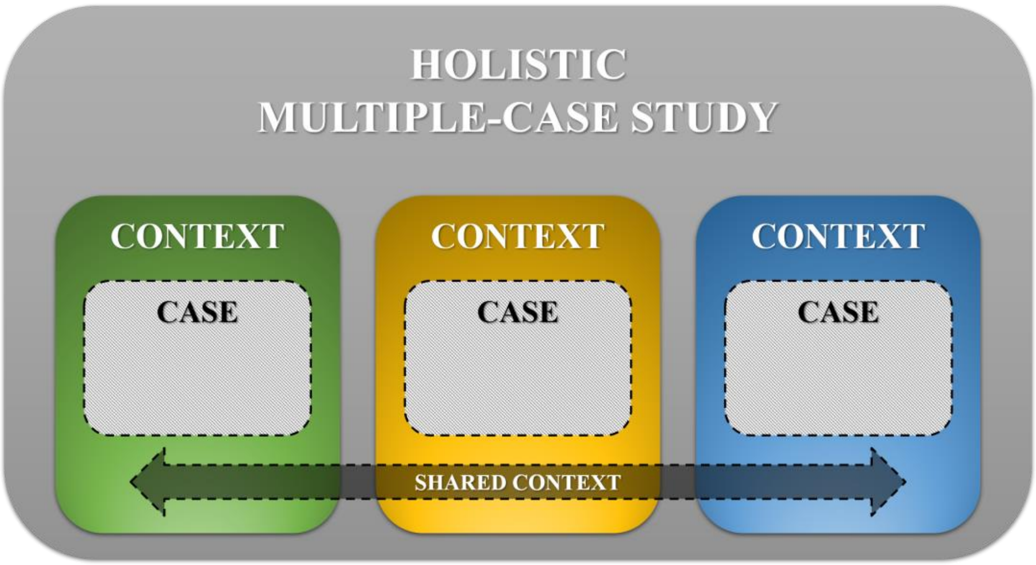

Figure 3.1 Multiple-case study framework (Yin, 2003, p. 40)

Following a "holistic" approach to the multiple-case structure, each case will follow the same general procedure and the data analysis will include data from each case (Yin, 2003). This was chosen because the goal of this study is not to contrast the unique phenomenon in each case, but rather to explore the unifying themes between each case. Multiple cases are often chosen to build unifying themes which can explain a more complex phenomenon (Shulman, 1992). This is also explained as "replication logic" (Yin, 2003, p. 47), which is defined as multiple cases being chosen to replicate the phenomenon. Collecting data from multiple sources builds support to the validity of the phenomenon and its worthiness for continued investigation (Yin, 2003). Multiple-case study of a single phenomenon also provides a robust understanding and supports conclusions based on the phenomenon.

Cases, also known as bounded systems, are bound by specific criteria, such as time and place (Creswell, 1998, p. 61). For this multiple-case study, time, place, and context bound each case. In this study, several cases of school environments were selected because their contexts were similar, and educators engaged in STEM integration are influencing how the school environment is developed. Each case was observed within the same time range, as they are all contemporary cases, and each case was from a different Indiana high school. Only schools who have applied and been certified by the state as a STEM school were selected for the cases. Each school has identified that they have been engaging in a form of STEM integration. This was the primary condition to bind each case; however, each school is unique and, therefore, a separate case. The shared context, of each case, as STEM certified schools was the portion of their context most relevant to this study. Each case, and the associated participants, are described in detail in a following section. Clearly identifying and describing each case helped define the reality of the phenomenon, or at least an approximate definition of this universal truth.

3.3 Theoretical Lens

This study and this framework were developed using a post-positive theoretical lens. An evolution of the positivist theory, post-positivism is the theory that espouses the beliefs of positivism but with the development that theory should be tested and verified (Hays & Singh, 2012). This theoretical lens approaches research from the perspective that truth and reality are objective, universal concepts. There is one truth about phenomena which can be observed or experienced directly by the researcher. Post-positivism takes this a step further with their belief that theory should be tested; universal truth exists but can only be approximated because it cannot be fully measured or understood. This theoretical lens posits that “knowledge is obtained through measurable experience with participants and may be applied across a population” (Hays & Singh, 2012, pg. 40). Experiences, from this lens, can be directly observed or measured (Hays & Singh, 2012).

The procedures for data collection in this study were developed under this lens, and through direct interviews and direct observation of the school environment, the universal truth of the phenomenon is revealed. A post-positive theoretical lens was chosen for this study due to the positionality of the researcher.

3.4 Researcher Positionality

Development of this research study was derived from the researchers experiences as a STEM educator and their education in preparation for that occupation. During the researcher’s education to be a STEM teacher, they took several classes that were designed to teach and promote STEM integrative approaches. This informed the researcher’s perspective as they started their experience as a STEM educator in an Indiana high school.

When the research began their first year of teaching as a STEM educator, the plan for their classroom was to develop a culture and curriculum where students would learn STEM subjects through an integrative approach. The researcher believed, based on the expectations of the school administrators and the standards of the STEM subjects, that classrooms and curriculum could serve as a place to initiate a STEM integration plan. Contrary to the researcher’s initial expectations regarding STEM integration, integration did not occur in their classroom or in any classroom at the school. This is where the researcher learned that to participate in an integrative curriculum, there are certain prerequisites that must be met.

First, integration does not usually happen naturally in the current grammar of education, as the status quo is siloed disciplines which act independently and out of context from one another. To facilitate integration, there should be active participation and accommodation made by multiple teachers in various subject areas. When one teacher is working alone, without support from their administration, their integration efforts may not bear fruit.

Intellectually, the researcher understood the requirements for curriculums and lesson plans based on STEM integration, but there was a missing element, the physical classroom environment, when they tried to engage in those integrative approaches. It was during a reflection on failure to integrate curriculum with other classes that the researcher first asked the question that would lead to this research study. If school desire to provide integrated STEM learning experiences, then what would the learning environment look like to support integration?

The researcher's disposition as a STEM educator and religious person lead them to the understanding that there was a universal truth to be found. Through continued education as a graduate student, the researcher came to understand this a post-positivist perspective. Due to this natural perspective, this study has leveraged a post-positive lens. While this is advantageous for this research study, the researcher's experience and education as a STEM educator may manifest some researcher bias. Understanding that bias and isolating it can help the researcher, a post-positivist researcher, to remain neutral and refrain from influencing the perception of reality.

3.4.1 Researcher Bias

As an educator in a STEM related field, the researcher has their own opinion of the how the school environment should be a designed. Using a post-positivist lens, however, stressed the importance of the researcher remaining neutral (Hays & Singh, 2012). To define the reality of the phenomenon it was critical that the researcher did not influence or manipulate the participants while exploring their experiences. It was also important that during the observations of the schools that the facts of the school environment were recorded accurately and separate from the researcher personal interpretations. Identifiable objectivity during the data collection process defined a portion of this study's validity. This objectivity was addressed in the role of the researcher during data collection and analysis.

3.4.2 Role of the Researcher

The role of the researcher in qualitative studies has been defined many ways; generally, there are five areas of consideration to help define this role. A researcher must 1) consider the voice of their participants, 2) their research team, 3) their subjectivity, 4) their reflexivity, and 5) their peer debriefing (Hays & Singh, 2012). In this study, the researcher has taken steps to address each of these areas. The considerations of the research team and reflexivity are addressed during meetings with advising professors and fellow researchers. By reflecting and soliciting feedback from multiple sources, the researcher strove to establish a sense of trustworthiness. Including member checking as a step in the data collection procedure, the researcher was also able to debrief with peers in the field of education. In addition, this member checking helped to ensure that the voice of the participants was accurately representative of their own perspectives. Subjectivity was addressed by the adoption of the post-positivist theoretical lens. As such, the researcher was able to maintain an objective, post-positivist lens throughout the study due these five areas of consideration.

3.5 Sampling Methods

Qualitative studies use several methods of sampling desired populations which focus on generating a sample size of information-rich cases. There are two aspects of sampling which need to be considered: the sample size and the sampling method.

The first aspect of sampling to consider for this qualitative case study is the sample size required to fully understand the phenomenon in question. Each approach in qualitative research has a suggested sample size to consider but the general guideline is to purposefully select a few cases to collect extensive detail about a specific phenomenon (Creswell, 2013). The case study approach generally looks at four to five cases per study, allowing the researcher to collect the necessary extensive details, identify themes, and conduct a cross-case analysis (Creswell, 2013).

The second aspect of sampling considered for this study is the method of selecting the sample set. To establish rigor in a qualitative study in education research, many researchers leverage a specific type of purposeful sample strategy (Hays & Singh, 2012). A purposeful sampling strategy is one that uses criteria to establish the specifics about cases which exhibit the phenomenon under study prior to selecting samples from the population (Hays & Singh, 2012). Under the umbrella of purposeful sampling strategies, there are three categories of sampling methods which contain several subcategories of specific sampling methods.

In the purposeful sampling category of Theory Development and Verification, two sampling strategies were selected for this research design. To identify cases of schools which exhibit the desired phenomenon, the method of criterion sampling was utilized. Criterion sampling is a method that selects cases based on predetermined criteria which are developed to highlight the phenomenon (Hays & Singh, 2012). This method was used to select the specific schools which are the cases of this study, each school had to meet specific criteria before being recruited for this study.

The second method of sampling leveraged for this study was snowball sampling. In this method, an individual is selected from the case based on their interaction with the phenomenon and then asked if they know other individuals who interact with phenomenon (Hays & Singh, 2012). This method was used in each case to identify individual participants as rich sources of information relevant to the phenomenon.

For this study, a selection of schools was determined by a list of STEM Certified Schools in Indiana of which only four high schools were identified. The researcher identified the high schools in Indiana that were traditional high schools and not specialized programs or buildings. Other schools on the list such as vocational schools, middle schools, and elementary schools were eliminated as they strive to provide different experiences than the high school framework. There were only four high schools on the list of certified schools at the time this study was conducted. Each school chosen had been certified by Department of Education in Indiana and met specific standards of integration according to the rubric, which defined their level of integration. The Indiana STEM Immersion Matrix provided the bounds of the case study. Using the criterion sampling strategy, only schools that had received their state STEM certification in Indiana met the criteria for this study. Using the snowballing sampling method outlined above, administrators or STEM program leaders, at each school, identified other educators, at those schools, who have knowledge about the phenomenon. All participants identified for this research signed a consent form, which includes an administrator from the school (see Appendix A). Each school was identified as an individual case and in those individual cases participants were identified. To fully explore the phenomenon and allow as many educators to participate as possible, the researcher has set the maximum number of participants at 40 individuals across all four cases.

3.5.1 School Demographics

The four high schools chosen as cases for this study are Indiana schools which have been certified as leaders in STEM education. Though each one is similar through the emphasis on STEM education, a unique context also defines the individual cases of each school. The context of each school is explained using demographics provided by the state of Indiana and information made public on the school's webpage.

3.5.1.1 School A

This school opened its doors in 2010 with its first cohort of students graduating four years later. A relatively new school in the state of Indiana, *School A* is part of a network of schools which started at the end of the 20th century. Being part of the network means they receive guidance and resources to implement the educational vision of the overseeing organization. This network now includes nearly 200 schools across the United States of America and Australia. Since the school opened, it has seen a trend of rising enrollment with a about 300 students enrolled this school year.

School A has demographics that were representative of the community in which it is situated. According to the United States census website, the ethnic demographics of the county mirrored the demographics of *School A*. The county census data for income and poverty were also similar, based on the school's report of students on free or reduced-price meals versus students who paid full price for meals. The following charts express the ethnographic breakdown of the *School A* population and the income and breakdown of enrollment by student socioeconomic status. According to these demographics from the Indiana Department of Education reports about *School A*, the majority of the population identifies ethnically as white and are able to pay full price for their meals at school. A small portion of the population identifies as an ethnicity different from the majority and are unable to pay full price for their meals ("DOE Compass: School Report", 2017).

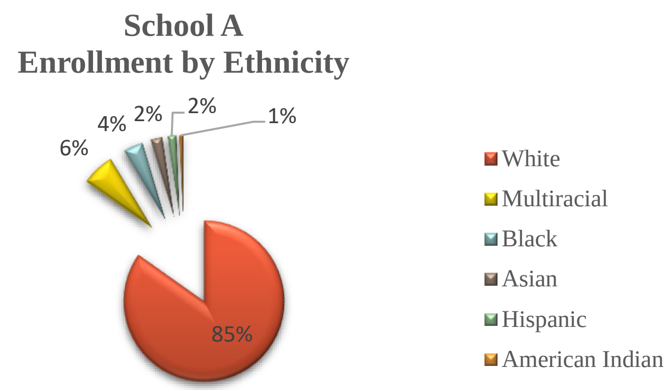

Figure 3.2 Enrollment of *School A* sorted by ethnicity.

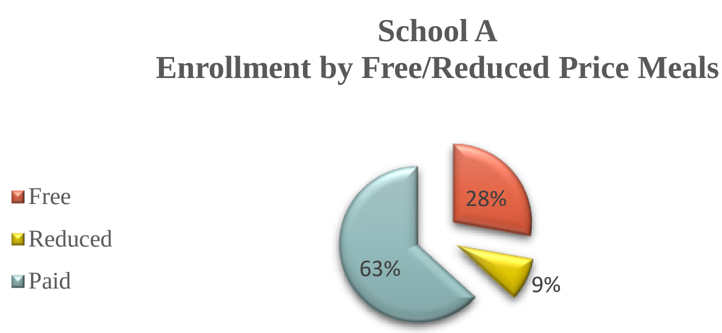

Figure 3.3 Enrollment of *School A* by price of meals for students.

In addition to understanding the student population and the community in which they are living, it was important to understand the demographics of the teachers who instruct them. From the same data set regarding the enrollment demographics for *School A*, the following chart illustrates the dispersion of experience among the teachers for this school. The majority of educators at this school have more than 20 years of experience in education.

Figure 3.4 *School A* teachers listed by years of experience.

3.5.1.2 School B

In 2005, *School B* was opened in central Indiana. This school was unique compared to the rest of the schools in the study due it only serving first-year high school students. *School B* is located in a central Indiana city serving a large portion of that community; approximately one thousand students are enrolled. A comparison of the community demographics to the school demographics suggest that the school represents a similar sampling to that of the community. The Figures 3.5 and 3.6 illustrate the ethnicity and socioeconomic status of the student body for *School B*. The ethnographic breakdown for this school shows the diversity of the population. Following that, the information regarding the pricing of meals demonstrates the socioeconomics of the student population, which was similar to the other schools.

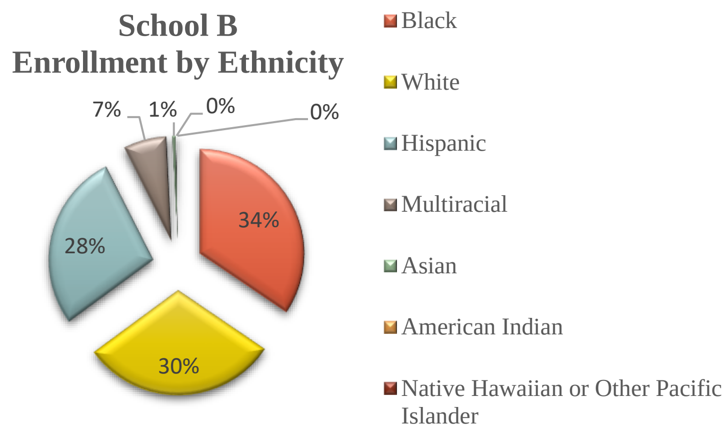

Figure 3.5 Enrollment of *School B* sorted by ethnicity.

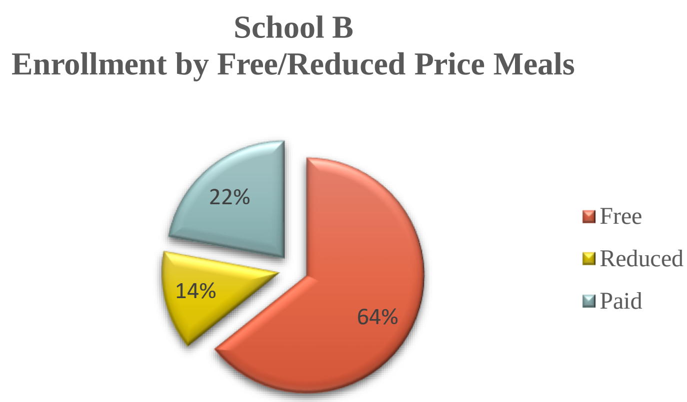

Figure 3.6 Enrollment of *School B* by price of meals for students.

School B hosts a large staff of educators to serve the large population of students. Figures 3.7 and 3.8 illustrate the demographics of these educators. The figures show the proportion of Black and Hispanic teachers to White teachers as well as the teachers' years of experience. The community in which the school is located is diverse, as is the teaching staff.

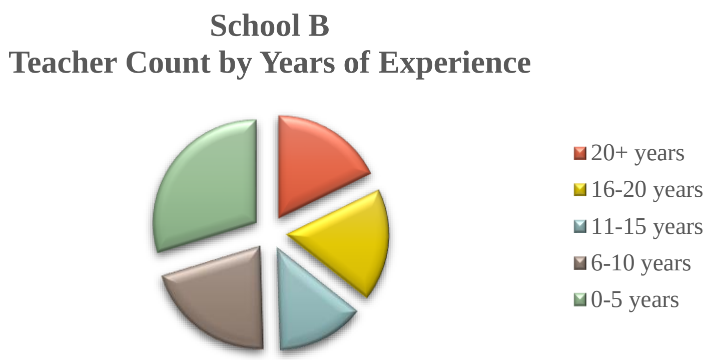

Figure 3.7 Teachers of *School B* sorted by years of experience.

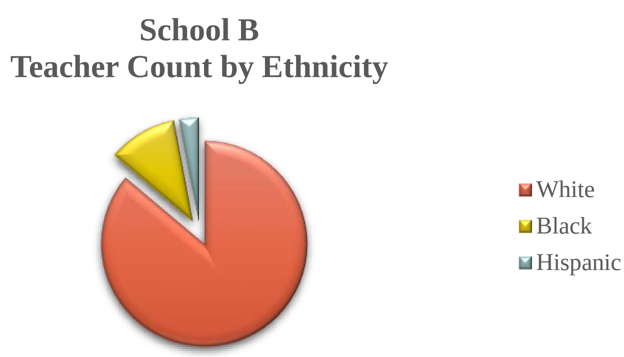

Figure 3.8 Teachers of *School B* sorted by ethnicity.

3.5.1.3 School C

In a relatively small town in north-central Indiana, the third school identified for this study hosts one of the largest student bodies in the entire state. The student population of *School C* is nearly 4,000. *School C* boasts many accolades, including a high graduation rate and success in academic programs. As seen in the Figures 3.10 and 3.11, most enrolled students at *School C* identify as White and pay full price for their meals.

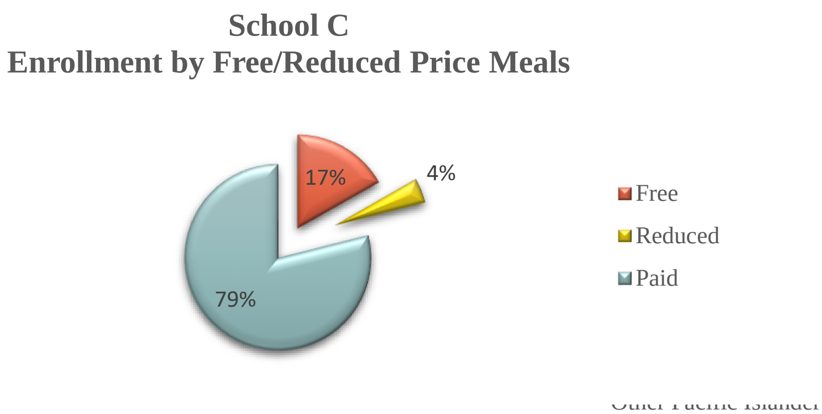

Figure 3.9 Enrollment for *School C* sorted by price of meals.

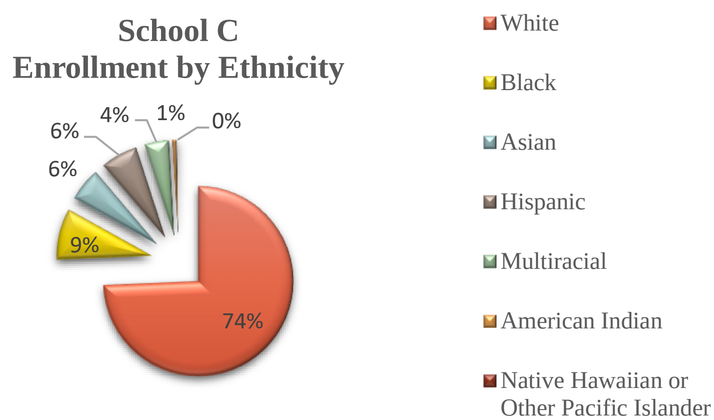

Figure 3.10 Enrollment of *School C* sorted by ethnicity.

With such a large student body to serve, *School C* employs nearly 200 teachers. Figures 3.11 and 3.12 illustrate the breakdown of the teacher staff by ethnicity and years of experience.

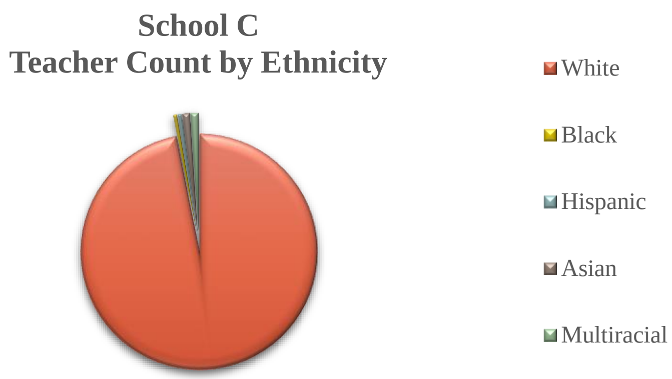

Figure 3.11 *School C* teachers sorted by ethnicity.

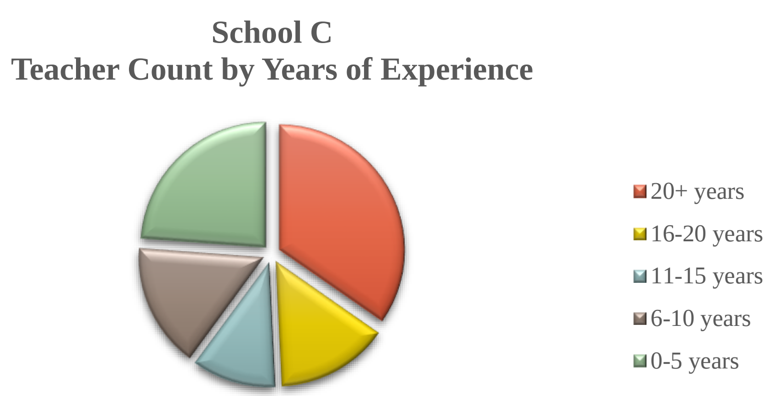

Figure 3.12 *School C* teachers sorted by years of experience.

3.5.1.4 School D

Since late 2010, *School D* has had its doors open to students. *School D* has operated in a modified commercial office space since its inception. When the school was in development, the commercial space was reconfigured, and the facilities modified to accommodate the learning process. In one of the largest cities in Indiana, *School D* caters to a diverse student population. Among the fewer than 300 enrolled students, there are several minority groups represented in the population. In this same group the number of students receiving free or reduced priced meals is about equal to the number of students paying the full price. The information about the teacher demographics for this school were not available.

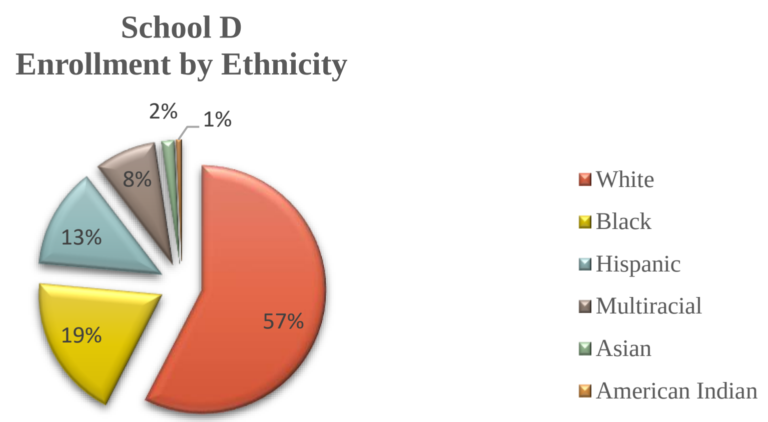

Figure 3.13 *School D* enrollment sorted by ethnicity.

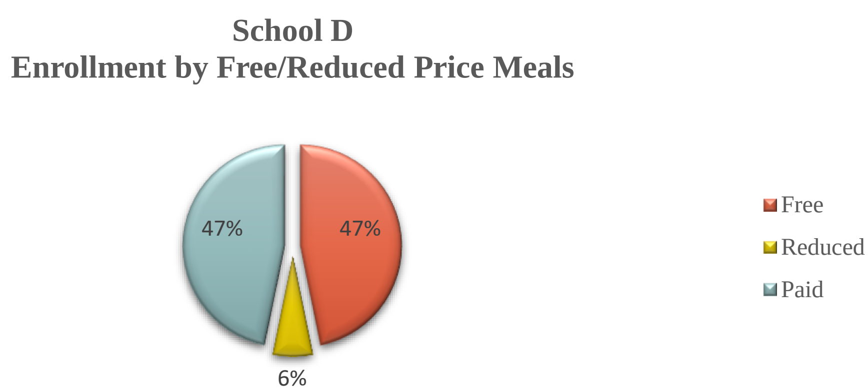

Figure 3.14 *School D* enrollment sorted by price of meals.

3.5.2 Summary

These schools each had a unique context, aside from their credential as being a STEM certified school in the state of Indiana, which might have influenced how the school environment was arranged and/or designed. Though each school transitioned a pre-existing building into the STEM school, they each became STEM schools in a different context. Understanding this context informed how the researcher asked the questions for the interview process and how the researcher processed observable facts during the observations of the schools.

3.6 Data Collection Procedure

After the framework and theoretical lens for this research study were developed, the procedure for recruiting participants and collecting data was generated. Participants were recruited using the sampling methods discussed in the previous section. The forms of data collected for this study were individual interviews and direct observations. Following the collection of these forms of data, the accuracy of the participants' experiences and understandings of the phenomenon was ensured by engaging participants in a strategy known as member checking. Figure 3.15 illustrates the process of developing the methodology for this study and the procedure to procure and understand collected data.

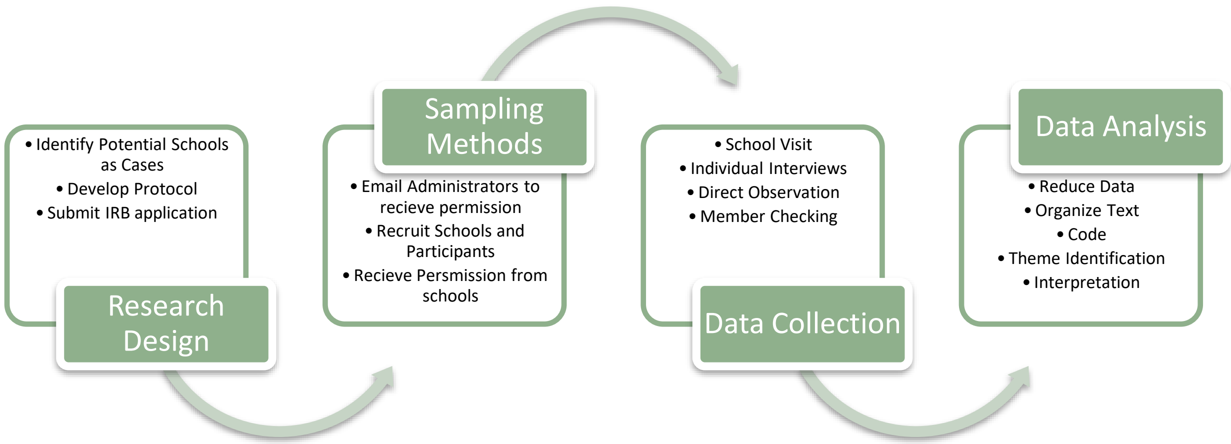

Figure 3.15 Process of creating methodology and collecting data.

Before data collection or school recruitment could start, the Institution Review Board (IRB) reviewed the research application and data collection protocol. Once approval came through from the IRB, the schools that fit the requirements for the study, were contacted and offered the opportunity to participate in this research. The case study framework leverages multiple sources of data to develop a rich description of the phenomenon. In this study, two recommended types of data forms, observations and interviews, were selected to define this phenomenon (Yin, 1998). Though there are set protocols, with guiding questions and procedures identified, qualitative research methods often evolve alongside data collection and data analysis (Creswell, 2013). After recruiting the schools and participating educators, a school visit was scheduled and planned. During each school visit, the researcher conducted interviews with participants and observations of the school environment, all of which occurred outside normal school times without the presence of students. For this study, the researcher was advised to reflect on the data collecting process after the first school visit and improve or evolve the protocol to tailor the methodology to phenomenon under consideration.

3.6.1 Interview Protocol

Collection of data began with individual interviews. Participating educators were asked to engage in a 30-minute interview with the researcher on site at their school. Interviews are considered one of the most commonly used data collection methods in qualitative research as they generally focus on a few opened questions over the course of a 30-minute to one-hour process (Hays & Singh, 2012). For this study, the interview questions and protocol followed a phenomenological approach defined by author Irving Seidman (2013). A phenomenological approach was chosen for the interviewing process because the emphasis is on the participants "lived experience," which might lead to data about how the school became setup for STEM integration through their certification efforts. The researcher specifically chose Seidman's third phenomenological theme, known as "lived experience as the foundation of 'phenomena,'" (p.17) which explains that for the interviewee to articulate their experience they must first exit their stream of action and reflect on the elements of the lived experience (Seidman, 2013). It is only through this reflective process that the interviewees "lived experiences" are understood as phenomena and take on meaning for the interviewer and interviewee (Seidman, 2013). The following were questions that guided the interview process and framed the interview protocol:

- What intentional changes were made to your school's facilities when it decided to transition to a fully integrated STEM certified school?
- How does the physical environment of your school influence the STEM integration efforts of your school's curriculum?
- Based on your expertise and experience, what are the specific attributes of the physical school environment necessary for STEM integration?

These questions inherently asked the interviewees to reflect on past events and translate them into rich accounts of their "lived experiences". This approach to interviewing fit well within the theoretical framework of this study. Seidman's (2013) third theme for interviewing emphasizes the importance of guided reflection and limited researcher input. From a post-positivist theoretical lens, it is important to bracket researcher bias and collect the objective truth from participants. The interviews conducted for this study were recorded and transcribed, participants were notified that the data collected would be kept confidential and after a set amount of time it would be destroyed. While the guiding questions stayed the same throughout the interviewing process, the protocol and follow-up questions evolved after each interview. Based on the relationship that developed between the researcher and the participant being interviewed, the questions were reworded or re-emphasized. Seidman (2013), in his book called *Interviewing as Qualitative Research*, notes that effective questioning reflects the relationship between the researching and participant. They also state that interview questions should not manipulate or influence the participant, as the purpose of the interview is to hear the story of the participant (Seidman, 2013).

3.6.2 Observation Protocol

In addition to the interviews being conducted at the schools, the researcher conducted observations of the school environment after the interviews were complete. Similar to interviews, observations are a hallmark of qualitative research as they establish a protocol for collecting these data which enables the researcher to focus their senses on a specific phenomenon (Creswell, 2013). During the observational process, the researcher recorded factual data about the school environment, research comments, and a reflective summary. Each portion of the observational field notes is a piece of the whole picture.

The factual data about the environment is known as the descriptive portion of the field notes (Hays & Singh, 2012) (See Figure 3.17). This section of the field notes details the specifics of the scenery and events, often leveraging photographs and sketches to depict what is directly observable (Hays & Singh, 2012). For this study, the observation protocol focused on the school environment and the detailed descriptions and sketches were supplemented by photographs.

Field Notes

Exploring Educational Spaces for STEM Integration

Date:
Time of Observation:
Location:
Observer:

Facts and Details in the Field Site	Observer Comments
[Describe physical setting] *[Describe spatial/relational arrangement of facility components]* *[Diagram and sketches of the physical setting]*	*[[Record sensory impressions]* *[Record notes about the interviewees' comments or interactions]*

Field Notes

Exploring Educational Spaces for STEM Integration

Reflective Summary: *[Reflect on your thoughts and feelings regarding the setting][Record new questions and ideas that impact the research design]*

Figure 3.16 Field notes protocol

Observer comments and the reflective summary are the subjective aspects of the observation protocol. Known as the reflective portion of the field notes, these notes are assumptions and ideas generated by the researcher during and after the observation activity (Hays & Singh, 2012). These reflective notes work toward understanding the phenomenon on several levels; helping the observer capture all the important factual data through intuition and reflexivity;

launching the data analysis and protocol evolution; and helping bracket the researcher's bias by identifying during the observation activity the researcher's opinions on the phenomenon.

Qualitative observations are often known as naturalistic observations because the principles that guide this data collection method allow the research to observe phenomena as directly as possible (Hays & Singh, 2012). The four principles of naturalist observations used to explore phenomenon include: noninterference by the researcher, observation of natural behavior and not staged behavior; observation used for exploration; and a thorough description of the observed setting. (Hays & Singh, 2012). These principles fit explicitly with the theoretical lens and case study frame selected for this study. To achieve the noninterference principle and satisfy the post-positivist belief in objectivity, the researcher was a non-participatory observer, or an outsider, taking field notes without interacting with the environment being observed (Creswell, 2013).

3.6.3 Member Checking Protocol

The final piece of the data collection puzzle is the member checking protocol, a key strategy to establish trustworthiness in a study and a way to enrich the data collected. This strategy allows the participants to bring their own voice into the data analysis. Member checking is the consultation of the participants after their interviews are transcribed and analyzed to establish if the findings fit their perspective and that they are represented clearly (Hays & Singh, 2012). This strategy is more than the participant double checking a transcription for accuracy, it is the insurance that the participant's voice and experience is accurately articulated (Hays & Singh, 2012).

This study attempted member checking after the interviews and observational data was organized and analyzed, which allowed the researcher to make sure the voice of the participant was preserved and accurately presented. To accomplish this, the participants were contacted a second time and asked to review the case summary of their school. Feedback from the participants about the case summary ensured that the voices of the participants were preserved and to enrich the case summary by expanding the input of the participants.

3.7 Data Analysis Methods

Analysis of the data began during the collection process; parts of the observation and the application of the member checking strategy were considered part of the data analysis. Collection and analysis occurred concurrently due the nature of qualitative research—during and after the observation activity the researcher reflected on the process and the new information gathered (Hays & Singh, 2012). The researcher began making connections and summarizing the findings to improve the next iteration of the observation protocol. By its very nature, qualitative studies do not have a set formula for analyzing data as each study develops a unique process. This does present a challenge for generalizability since the process cannot be replicated (Hays & Singh, 2012). However, there were common analysis processes that worked to generate the description of the phenomenon.

The first step in analyzing the qualitative data was to reduce the data collected by rereading the interviews and field notes at least six times. The researcher then spent time writing holistic summaries of each case. Next, the text from the interview transcription, field notes, and summaries were organized before being chunked into groups in a process known as coding. These groups were generated from either the data or the participants, but they were used to chunk data into groups that were identified as a theme, factor, item, or domain (Hays & Singh, 2012). Finally, the codes were used to identify specific themes that were either unique to the case or were common across the four cases. These themes generated the basis for the detailed description of the phenomenon and answered the research question.

3.8 Trustworthiness

Unlike in quantitative research that uses statistics and generalized processes to define the validity of the study, qualitative research defines the validity of a study through trustworthiness. This term means that specific criteria have been addressed through the research design and the application of qualitative principles to develop enough rigor that readers trust the information presented (Hays & Singh, 2012). Many criteria of trustworthiness have been identified by leading researchers in the field of qualitative research. For this study, three criteria were chosen to establish trustworthiness with the readers: credibility, transferability, and confirmability (Hays & Singh, 2012).

Credibility is defined by researchers as the alignment of the research design and the conclusions (Lincoln & Guba, 1985). Transferability is defined as the ability to repeat the procedure and gather valid data again, also known has generalizability of the research design (Hays & Singh, 2012). Confirmability is based on the neutrality of the researcher. In a post-positivist theoretical lens, the researcher makes efforts to bracket their objectivity which establishes the confirmability of the study (Hays & Singh, 2012).

To establish these criteria of trustworthiness in this study, several strategies were implemented. Confirmability was established through the application of the post-positivist lens and the role of the researcher as an outsider extracting the experiences and information from participants in both the interview and observation protocols. Credibility was established through the application of a structure framework and research design based on accepted methods of qualitative research. Transferability was established using the state certification as a means of bounding the case. The process of selecting schools and participants, collecting data, and member checking are repeatable processes that can be applied to new schools as they are certified.

3.9 Summary

This chapter has addressed the qualitative methodologies that are the foundation of this study and how a research design was developed from those theories. The research design was presented as a qualitative multiple-case study conducted with a post-positive lens. The chapter continued into the sampling method and the data collection procedure, before finishing with the data analysis and an explanation of the study's trustworthiness.

CHAPTER 4. RESULTS

4.1 Introduction to Results

Four schools were identified for this study, each one a high school in Indiana that was certified by the state as a STEM School. The researcher contacted an administrator from each school to inquire about a school visit and possible contacts for the STEM Initiatives. The researcher scheduled time for visits to each school and interviews with STEM educators at each school. At each school, the researcher took observational notes, and each interview was recorded. The researcher used these data sources to create preliminary case summaries for each school and then sent those case summaries to the interviewees, as form of member checking, to ensure the accuracy of the case summaries. This chapter includes the member checked case summaries for each school, the identified themes, and an explanation of the member checking experience.

4.1.1 School A

School A, as discussed earlier in chapter 3, was a relatively new school in the state of Indiana and listed a student population of about 300. With only a lobby and two hallways, the school stressed the importance of STEM education and their integration efforts to offset their lack of facility space. *School A* was physically connected to the district vocational school and occupies part of the building that was once part the adult education facility. This proximity to the vocational school provides the high school a unique relationship with the vocational school. Once students start their junior year, they are afforded the opportunity to take classes at the vocational school. With almost half the student population spending half the day in another part of the building, the student population becomes much more manageable, according to the administrator.

Collecting data at this school afforded the researcher the opportunity to explore a unique educational facility and its impact on the STEM education and integration efforts at that school. It was clear from the observation of the classrooms and the interview with the administrator, that the school was lacking some more traditional equipment and resources.

The first stop on the observational tour was the biology room. This room, and the other science rooms, lacked some amenities that are generally found in more traditional schools, such as sinks and vent hoods or water and gas lines. During the observation and interview process, the administrator was vocal about the lack of traditional equipment and how it is important to work toward having those items. During the interview the administrator stated:

> We're a STEM-certified school and our biology room doesn't have a sink. You know, and so it's, on the one hand, well, how-how does a school get STEM-certified if their biology room doesn't have a sink? We just work around, things like that. You know, and so, our hope is, although we've been STEM-certified for two years and we're still looking for some traction that way, but you know, hopefully, that'll give some push to saying here are some things that we need to make things better.

It became clear that the school was able to operationalize their resources and overcome their shortcomings. The administrator emphasized this idea by how the biology teacher uses the water spigot just outside the exterior exit in the rear of the room. While discussing the biology room, the administrator stated:

> Because there is no sink and so for biology [the teacher] has do a lot of things without water. There is a water faucet right outside that she can use but it makes things more difficult. Figure 4.1 highlights the biology room exterior exit to the water access.

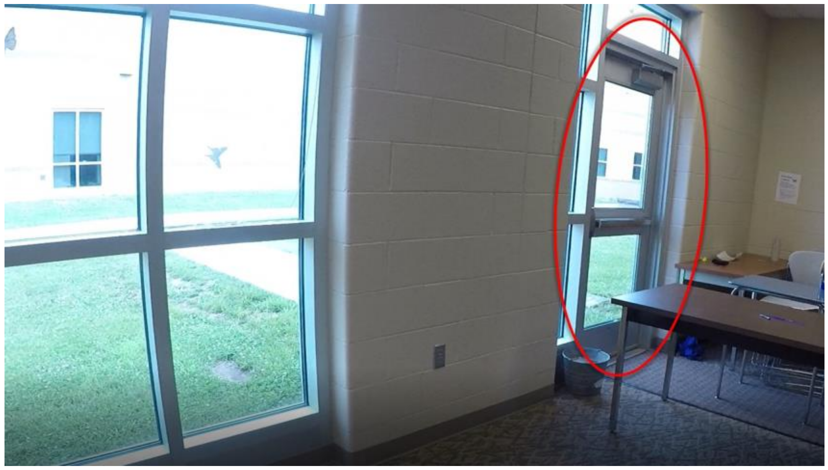

Figure 4.1 *School A* Biology Classroom: Exterior Wall with Exterior Exit to Water Spigot

Many teachers, in addition to the biology teacher, also operationalized their available resources by allocating space in the room for collaborative processes and teacher-student small group discussions. The biology room was divided into three main sections, a more traditional table and chairs in front of the Promethean board for direct instruction, larger round tables near the back for collaboration and teacher facilitated discussions, and workbenches at the back for hands on activities. The administrator described the Promethean board as a similar product to the commonly known Smart board, a multi-touch board and projector system designed for modern classroom spaces. During the observational tour of the biology room, the administrator spoke about the biology teachers use of the collaboration space. According to the administrator, this teacher uses the collaboration space for class projects, teacher-student small discussions, and student group work. While pointing out the space during the observation, the administrator stated that the biology teacher "has her tables up here in front of the board and more lab space in the back here." See Figure 4.2.

Figure 4.2 *School A* Biology Classroom: Entry and Interior Wall

In the image Figure 4.2 it can be seen that the biology room had several large cabinets on the interior wall, the same wall that has the two entrances. Circled in red in the Figure are the large cabinets which house equipment and resources. This room was originally two separate spaces, now as one large room it provides extra space for the workbenches and the round table for collaboration and teacher facillitation in small groups. *School A*'s administrator explained it this way:

> With the collaboration that she does, she got a round table…so she calls back groups or like roles, such as process observers. She will call back all process observers, or she will call back all facilitators.

Following, in Figure 4.3, is an image showing the large space designated for direct instruction and presentations.

Figure 4.3 *School A* Biology Classroom: Promethean board and Teacher Desk

Following the biology room, during the observational tour, was the physics room which was similarly divided into areas allocated for direct instruction and collaboration. The direct instructional area leveraged worktables in rows to simulate flat workbenches, and the walls were lined with cabinets to house equipment and materials. These cabinets were either permanent additions or mobile cabinets which are easily moved around the room to alter the space if needed. These mobile cabinets have been useful and versatile, but the administrator stated that their mobility was coincidence rather than intentional. During the observation, the administrator stated:

> It just sort of happened, [the teacher] in here scrounged those together. [The teacher] needed some place to put all the equipment. As you can see, [the teacher] doesn't have enough space for it all as is. Those cabinets are just full of equipment and resources.

Red circles in Figure 4.4 mark the mobile cabinets that contain equipment and resources. While discussing the physics room equipment, the administrator talked about the challenges of having a room with outlets only on the walls and not having direct access for students. The administrator stated:

> [The teacher] helped design a classroom at another school, where every table had a plugin. And then [the teacher] comes here where there is no electricity in the table, you have to plug into the wall.

This seemed to be a concern because the school was a one-to-one school, meaning every student had their own device, and the need for powering student devices and scientific equipment stressed classroom management and safety expectations. A work around was still in development for this concern, according to the administrator.

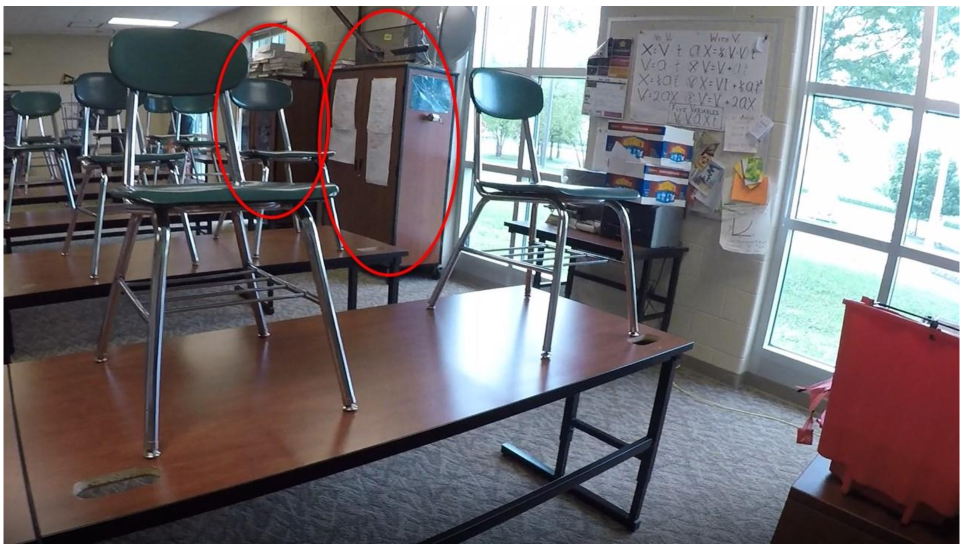

Figure 4.4 *School A* Physics Classroom: Rows of Tables and Mobile Cabinets

Figure 4.5 shows the Promethean board and the first row of tables, the teacher desk, and many class posters and notices. According to the administrator, “this is a lecture room that we turned into the physics room.” Like most of the classrooms in this school, this room was originally designed as a lecture room for an adult education center. This space was transformed into a classroom by allocating spaces for different education activities.

Figure 4.5 *School A* Physics Classroom: Promethean Board and Tables

The rear section of the classroom was allocated for group work and larger projects. In this space were round tables and larger workbenches, much like the biology room. In both the biology and physic classrooms, the teacher had designated areas for projects and collaboration marked by large tables and workbenches which were not aligned to a centered platform. The administrator stated during the observational tour of the facility that this area was distinct from the area used for direct instruction, and that the teachers are often engaging students as facilitators in the collaboration space rather than conducting direct instruction. This format, space for direct instruction and space allocated for collaboration, was also present in the technology education classroom,

Figure 4.6 *School A* Technology Education Classroom Division of Space

As seen in Figure 4.6, the technology education classroom was divided between a workspace for larger projects and a tabled space with Promethean board for direct instruction. Figure 4.7 shows tables on the direct instructional side of the classroom, which were similar to those in the physics and biology classrooms. The tables in the technology room were like the tables in the physics and biology classrooms due to their lack of power outlets. Conversely, the tables in the technology classroom were paired with padded chairs.

Figure 4.7 *School A* Technology Classroom: Direct Instructional Section

In Figure 4.7 the image also shows that the technology education classroom also has a Promethean board and whiteboard. Much like the physics and biology classrooms, the teacher desk is on this side of the room. The administrator explained that the technology classes, that used this classroom, did a “good amount of CAD drawing.” The classroom tables, as shown in Figure 4.8, faced CAD drawing posters, project examples, and classroom procedures. This is a stark difference to the physics and biology classrooms where the tables and chairs faced the teachers’ desk and Promethean board.

Figure 4.8 *School A* Technology Education CAD Examples and Class Procedures

This section of the classroom was also home to paper printers and multiple 3D printers. The administrator explained that the 3D printers were used by the technology class and by some of the other teachers when the need arose. During the observational tour, the administrator detailed the school plan to have multiple 3D printers in the makerspace, primarily for rapid prototype and project work. The administrator also explained that the use of 3D printers could progress the same way as computers in the school environment. The administrator further explained:

> You know, computers started as desktop installations but turned into laptops, which were kept in cabinets. Those cabinets were then wheeled around into the classrooms that needed them. Now, every student has their own laptop, I can see 3D printers eventually being wheeled into each classroom on carts. The cost and durability of the machines will eventually make it, so they are mobile tools.

As shown in Figure 4.9, the technology classroom had multiple 3D printers available to teachers and students. As detailed by the administrator, these machines were important to the larger projects conducted in the introductory level engineering and technology classes. Next to the 3D printers were two large, mobile cabinets, as seen in Figure 4.9. These cabinets housed materials and resources for the entire room but were mobile so as to move out of the way of larger projects.

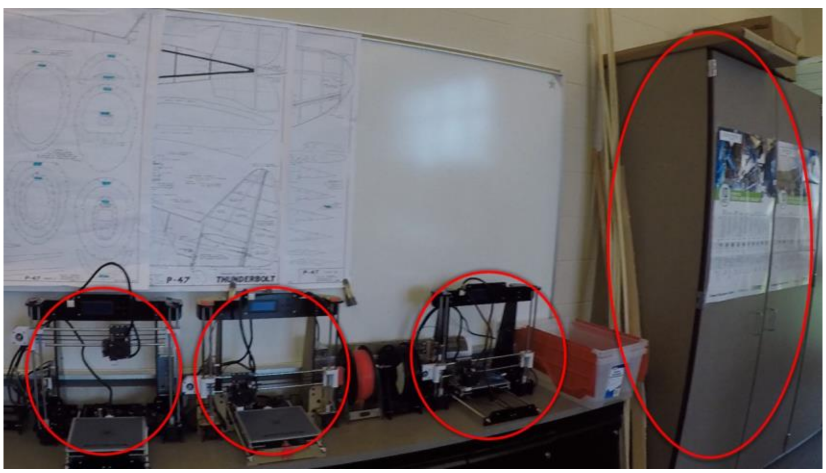

Figure 4.9 *School A* Technology Classroom: 3D Printers and Cabinets

In Figure 4.10, the larger projects were on display in the project workspace, the administrator explained that the teacher had two ongoing projects to which the students could contribute. The two large projects in question were a scale model of a World War II fighter plane, the P-47 Thunderbolt, and a historical architectural model. The administrator explained that the fighter plane was school mascot and a reference to the factory that produced all the Thunderbolts during the second world war, which was located less than a mile away. As shown in Figure 4.11, the plans for the scale model Thunderbolt airplane were posted on the wall next to the 3D printers. Figure 4.12 shows the current completed work on the scale model of the Thunderbolt fighter plane.

Figure 4.10 *School A* Technology Classroom: Ongoing Projects

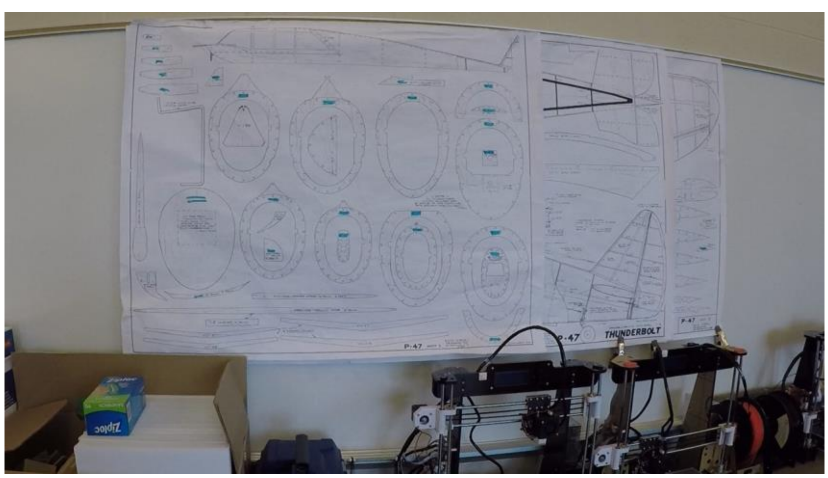

Figure 4.11 *School A* Technology Classroom: P-47 Thunderbolt Blueprints

Figure 4.12 *School A* Technology Classroom: Thunderbolt Scale Model

The 3D printers on this side of the technology classroom were also used to recreate specific pieces for the architectural model, which was also an ongoing project for the technology classes. The architectural model is a dollhouse recreation of Wes Peters' work in the local area. Wes Peters was a protégé of Frank Lloyd Wright, an architect that spent time designing homes and other buildings in a southwestern Indiana city. Figure 4.13 shows the current version of the dollhouse marked with a red circle. The administrator explained that the 3D printers were used to recreate the exterior textures and scale models.

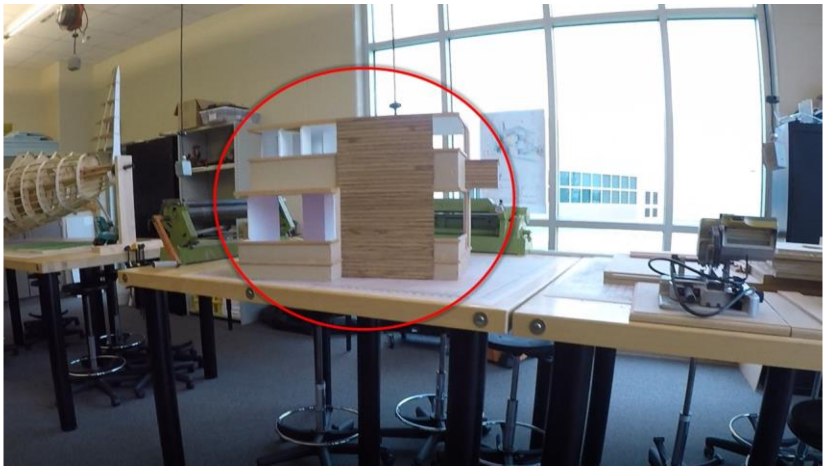

Figure 4.13 *School A* Technology Classroom: Dollhouse Model

According to the administrator, these two ongoing projects have integrated concepts and project work from other disciplines. Multiple teachers, from various subjects, have been involved with these projects. After exploring the technology classroom, the administrator showed the researcher the makerspace, which was still in development.

During the interview, the administrator stated that part of the plan to be a STEM-certified school was to eventually have a complete makerspace; at the time of the data collection, this makerspace was still in development. This makerspace was something that the administrator hoped would have an impact on their curriculum and could be something used by every class. The administrator stated:

> We also did talk about having a makerspace. I just met with two of our teachers, we're going to a conference later this week to talk about getting our makerspace up and running. So, I think just, you know, it's not a direct curriculum impact but we hope it will be though. You know, we're having a makerspace where all classes can go in. So that-that is a room that we've dedicated. We've taken a classroom and have dedicated it to being a makerspace.

During the observation of the developing makerspace, the administrator spoke about his intention for the space to be open to the entire school and the community. They spoke at length about its potential to take the integration efforts of the school to the next level. In this explanation, the principle compared the makerspace to a computer lab, a common space available to those teachers and students who need it to improve the learning experience. The room *School A* designated as a makerspace was still in development, but the administrator and his team of teachers still considered how to operationalize the space and equipment, adapt the space by understanding what they lacked and what was needed, ensure the space encouraged collaboration, and the space was mobile enough to accommodate teachers and students.

Figure 4.14 *School A* Makerspace Promethean Board, Computer Desks, and Granite-top Tables

Figure 4.14 shows a view of the school's fledgling makerspace. Just inside the classroom door a Promethean board, several computer desks, a shelving unit, and granite-top worktables can be seen. Figure 4.15 shows the room had a large amount of floor space to utilize and the whiteboard at the back is a great tool for collaboration. Unlike the other rooms observed, the layout of this educational space was being designed to be transient and flexible. This room was not divided into multiple sections, it was allocated entirely for project work and collaboration. The Promethean board, which aligned the previous classrooms, is not the center of attention in this space. As seen in Figures 4.14 and 4.15, the bulk of the room was kept clear, and equipment was stacked along the edges of the room. The principle explained that this room was intended to facilitate projects from any class, where a physical solution would improve the learning outcome.

Figure 4.15 *School A* Makerspace: Floor Space and Whiteboard

This large amount of floor space is available due the large cabinets on the interior wall and the use of folding chairs instead of more traditional permanent chairs. In Figure 4.16, the interior wall is lined with large cabinets, a shelving unit, and a file cabinet.

Figure 4.16 *School A* Makerspace: Cabinets, Chairs, and Shelving Units

During the observational tour of the makerspace, the administrator explained that the room would eventually include several 3D printers, a laminate cutter, and various other equipment.

4.1.1.1 School A Identified Themes

After reviewing the data collected from *School A*, two themes became evident in the way the classrooms were designed and how the teachers utilized them. From several conversations with the administrator, it was obvious that the school was intent on continual improvement and developing their school environment to better suit their needs. From “scrounging” for new furniture to working around missing amenities, the staff at *School A* was focused on improving the school environment. Their efforts manifested two themes for adapting a school environment to accommodate STEM integration: improving their collaboration efforts by allocating space for STEM activities and improving the mobility of the classroom.

School A showed an interest in adapting the school environment to improve their methods of teaching, while primarily practicing a project-based pedagogy. The educational staff, as explained by the administrator, achieves their current STEM integration efforts through collaboration and project-based pedagogical practices. The administrator explained that STEM principles and project-based learning were practiced in every content area. According to him:

> As far as STEM-integration, we are integrating, you know, even in history or in English or in Spanish, you know, pulling STEM topics into those classes. And so, you know, our English teacher can teach a topic through, you know, Shakespeare or can teach it through the lens of STEM. Or even while teaching Shakespeare, you know, looking at it through a lens of STEM.

When asked to explain how this was achieved, the administrator elaborated:

> Collaboration and that's something that by virtue of being a new tech school, we use project-based learning as our main, you know, framework for instruction. And so, that really helped us along the process of becoming a STEM-certified school, because a lot of those habits of collaborating, you know, students collaborating with each other, teachers collaborating with each other, those habits were already there. So, when there's strong collaboration between students and between teachers and within classes, then it made that integration a lot smoother for sure. I think for the fact that we were—they sort of mutually help each other that, you know, the fact that we're a PBL—centered school, I think helps us do STEM better, and the fact that we have a STEM focus, helps us do PBL better, I think they definitely work hand in hand.

In each classroom, the emphasis on collaboration, and making space for that collaboration in the project-based pedagogy was made evident in the layout of the classroom. The first theme identified in the data from *School A* is that space for collaboration is necessary if collaboration is stressed as method of STEM integration.

As exhibited in each classroom, from the observational tour, the teacher allocated space for project work and collaboration. These areas of the classrooms were distinctly different from the space allocated for direct instruction, the area designated for collaboration used different furniture types and a different focus. The direct instruction areas were aligned a centralized point, usually the Promethean board and the teacher desks, and were stocked with rows of long, rectangular tables, with space for one person per side, facing that centralized point. The collaborative section of the room focused on larger tables, with room for multiple people per side or round tables that turned the user's attention towards the center of the table. These collaborative spaces also housed the most of the classrooms' equipment and resources, from the interview and observation, it seemed that the majority of project work was conducted in these collaborative spaces. According to the administrator, the classrooms were intentionally arranged this way so that the teachers could have both sections of the class available to them. As a coincidence, this manifested another theme, mobility of the classroom environment.

The second theme of mobility focuses on the student mobility within the classroom, but it also covers the necessity for teachers to move their class to an appropriate room for specific projects. During the observational tour, the administrator explained that teachers would have the students move from one section of the classroom to the other and would often take the class to another room entirely if it would help the students understand the concept. Previously, the administrator has been quoted about the biology teacher having students move from the direct instruction side of the room to the collaboration side so that they could have a group discussion. Through conversation and the interview with the administrator, it became apparent that in order to achieve collaboration, and therefore STEM integration, teachers and students needed the ability to move to a location that would facilitate that collaboration and integration. The most prominent example at *School A*, for both themes, was the makerspace. As stated by the administrator, the makerspace was intended to be a common space designed to facilitate project-based learning, collaboration, and STEM integration. The makerspace also increases the importance of mobility for the classroom, teachers that want to collaborate and integrate must be willing to move from their classroom to the makerspace.

4.1.2 School B

With a large student body, *School B* hosted only first year high school students within its walls. Developed as a preparatory school, teachers and administrators work to ensure students have a foundation that allows them to succeed in high school. A portion of this student population was part of the Innovation academy, a specific curriculum which introduced students to various STEM fields and engage them in STEM integrated activities. The STEM academy at *School B* focused their STEM integration efforts into activities conducted during the homeroom period. These activities were conducted in rotations, of which there were four field trips, and other special events. The STEM rotations were nine-week activities held during the homeroom period every Wednesday and once per week students would work on an extended STEM project. *School B* also boasted an established makerspace in the Media Center.

Collecting data at *School B* afforded the researcher a prime opportunity to examine the STEM integration efforts of a large well-established school and explore how the school leverages the school environment to conduct STEM integration. Data was collected at *School B* during two interviews and a brief tour of the school makerspace, located in the Media Center.

The first interview was conducted with an administrator of the Innovation Academy. During the interview, the administrator answers to the interview questions focused around four key ideas; 1) how the school designates time during the school week for authentic STEM activities, 2) how the school was designed to ensure that the academies had space to do large projects, 3) how the resources like technology are essential to providing authentic experiences, and 4) how the culture of the academy should be in order to expose students to STEM experiences.

The administrator spoke, during the interview and after, about the Innovation academy's STEM rotations. They stated that one of the reasons STEM integration works at *School B* is the allocated time for those activities:

> One of the things that I think they knew would make it work here was at the start of the day, we've got what’s called an impact period. And it's 40 minutes and each team [academy] has a different theme that they try to go with. And so, us with STEM, we've got the ability to move from room to room.

This rotation time that was built into the schedule, according to the administrator, was a school wide policy but the Innovation academy leveraged it as time to integrate learning. They followed his statement with an explanation of why it worked at *School B.* The administrator said the reason the rotations work was due to their amount of allocated space:

> We can do rotations, we can utilize the cafeteria, we can utilize the gym. We’ve got an area called The International Commons in addition to science labs and in addition to classrooms. And we also have an outside courtyard so that enables us to any of the kind of presentations of things we do. We've got spots to do it in. Some of that I know was intentionally thought when this building was designed as a ninth-grade center.

The structure of the building was designed so that classrooms with academies were arranged near one-another and that there was available space to engage in larger activities. The administrator said the STEM integration activities in which they were engaging required larger spaces and more resources. One of the activities they spoke about was the coding activity for Spheros, a spherical robot used in the makerspace. They stated that the academy was accumulating items like these to use during their rotations:

> Some of the teachers that have been on this team for more than four years when it all started with STEM, they wrote a grant to get some supplies. And so, we've got these different rotations, so we essentially have kind of seven different rotations kind of in place and so one of them is Sphero's for instance. A grant was written for those in so over time, we just tried to accumulate things and one of our rotations is focuses on building, so we have all types of supplies we use for that. So, it just was over time as we got ideas.

Along with the technological and consumable resources, the administrator spoke about the use of physical resources. They said:

> One of the similar rotations we have, you watch like those CSI Miami shows, we have a teacher that's developed like a crime scene, and she has the different aspects of that. Every team has a science lab that they can use. So, our science teacher, the STEM rotation, she does she's able to utilize that kinda like an experimental type thing.

According to the administrator, the Innovation academy need to allocate space and resources to their STEM integration efforts comes from a culture of STEM education in the school district. During the interview, they explained that students were coming to *School B* interested in their STEM activities:

> The STEM activities and ideas are starting at the elementary school. And then the middle school does quite a bit, so when they come here, the kids pick a team they wanna be on. We've got a lot of kids on the Academy, cause our teams are called academies. We have a lot of visiting kids on the academy night that picks STEM because they've done it at the middle school. So, the flip side of it would be if they hadn't been exposed to it, would be like we'd-we'd have people coming up going, "What's STEM?" So, that that to me, kind of really is the answer to the question. It's our district, people say, "Hey, we're doing some activities. We're doing specific things that are elementary specific things at middle school, specific things here." Our district has what's called a traveling science teacher. And he's won a lot of national awards and to utilize his expertise he'll go building to building throughout the year and he does a lot of STEM activities. So, the kids are getting it pretty early on.

It was clear during the interview, and subsequent conversations; The administrator was invested in the Innovation academy's method of integration. That method, however, was not the only method being employed at *School B*.

Second to interview, and the guide for the observational tour of the Media Center and makerspace, was the School Media Specialist, who is referred to here after as the SMS. During their interview and tour of the Media Center makerspace, SMS focused on the following ideas: the need for a makerspace in a centralized common location like the Media Center, the importance of technological resources in STEM integrative activities, and the need to ensure STEM activities are accessible to every student.

During their interview, SMS conveyed the importance of having a space allocated to STEM activities that was available to every student. When asked what changes were made to the school to certify as a STEM school they said:

> We showed the state how we utilize the makerspace not just for student free time, but also within classes and then we brought students in that are doing things and we show them what the students are doing, like the coding programs that they are working on.

SMS was then asked why the makerspace was a focus of change for the school, they answered with:

> We have a maker space in the media center which is centrally located. There's a foundation in philosophy of libraries that it's access for all, access for everyone. So, all classes can use the makerspace, when students have free time, which is like homeroom, lunch time as well as after school, they're free to come down here. I do run the makerspace club; it meets every other week on Thursday. So, we have that available to students. So, that is something that some schools that I know of that have a like tech teacher run the makerspace, you still have to be enrolled in that class, you know what I'm saying? If you are not involved in that class, you're not gonna really see this stuff, you're not gonna really have any knowledge of that. So, having a makerspace in a library is really a good thing because it gets more traffic, and it gets noticed more.

According to SMS, the value of the makerspace as a tool for STEM integration, and the STEM initiative in general, was that it allowed all students with interest to explore STEM concepts. To ensure the space was engaging students in STEM concepts and activities, SMS believed in leveraging technological resources. They gave an example of a project for Martin Luther King Day:

> I've had kids like for Martin Luther King projects; we show this to the STEM group from the state. They coded this Spheros to write “I have a dream,” and the like that was tremendous because we wanted to paint it.

She went on to explain that the students programed spherical rolling robots to trace the letters, while covered in paint. In addition to the Sphero robots, the makerspace was stocked with Legos, Snap Circuits, Kinects, and various other kits to encourage what they called an entrepreneurial mind. As seen in Figure 4.17 and Figure 4.18, the resources which make the space a place to explore STEM concepts, according to the SMS, were readily available to students. These shelves were along the media center’s west wall, there was no doors or restrictions on these materials. SMS explained that students would often come to the media center to work with these resources or checkout kits to work on at home.

Figure 4.17 *School B* Makerspace: Lego and Kinects Kits

Figure 4.18 *School B* Makerspace: Snap Circuits and Assorted Materials

She insisted that the STEM integration efforts at the school were vastly improved by the resources offered in the makerspace. SMS stated that the makerspace was a type of scaffolding approach and students have used the kits before moving on to create their own products. According to her, the makerspace worked well with the Project Lead The Way (PLTW) classes offered to students. They said, when asked how the makerspace impacts STEM integration:

> The PLTW teachers have used my Legos, they've used my connect kits, they use my Spheros all the time. I know there are times when they're supposed to try to make it themselves and they're given like materials, and they have to try to come up with it. It's also super cool for them at some point to use the kit that's available and to just don't give them the directions, though, and show them the picture of the roller coaster and say well, here's something huge you can make. Because that really broadens their perspective. Then when students kinda go back and forth to like pipe cleaners and ping pong balls and stuff like that, to seeing the bits that are in like the kits that I have, to me, it allows them to fill in the how do we do this, ‘cause it gives them models to look at.

During the interview they stated why they advocates for the makerspace and its location in the media center:

> So, we were going in that sort of thing that I love about this is it brings in just natural concepts that they're not hearing in the classroom. But again, you think of that like engineering, entrepreneurial, kind of mind where they're curious about it, well, let's just go do it. So, for me, it's natural to have that stuff in the library because to me, where else do you find the answers to everything but a library. So, whether that's getting on a computer in a library or finding books in a library whatever, I think that that's just a natural place for a makerspace to be.

While touring the Media Center, which was a common area with a STEM focus, SMS pointed out the numerous rectangular tables and computer stations located next to the makerspace. This area had additional resources such as reference books, whiteboards, power outlets, and access to the makerspace. Shown in Figure 4.19 was the west side of the Media Center which houses the makerspace and its resources.

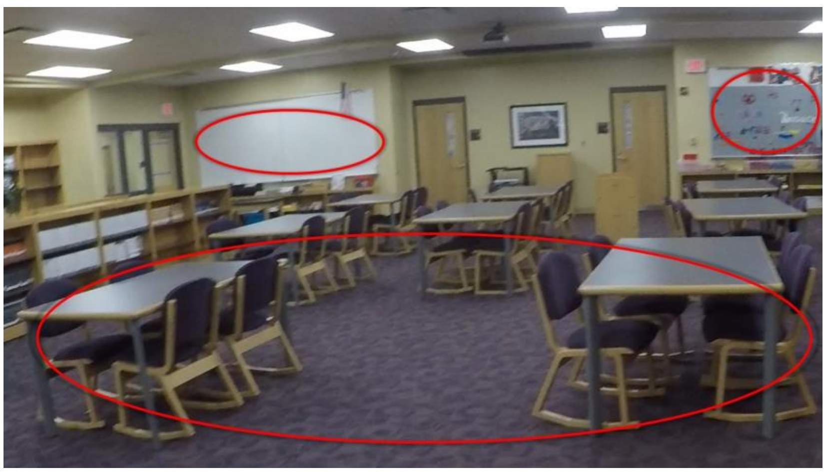

Figure 4.19 *School B* Media Center: Makerspace and Collaborative Space

SMS explained, during the tour, that it was important to have a large collaborative space next to the makerspace because it was part of the space's accessibility. Students required space to work when they came to the Media Center, both by themselves and with a class. According to her, the space has been beneficial to students in special aid math classes. During the interview they explained that the makerspace was a great resource for the special education students. They described their experience with the special education class in the makerspace:

> Special education classes have been coming down and using this. One of the things that we saw right away with classes that did come down is being very tactile with things. The kids their anxiety level just goes down tremendously and it's really awesome to watch. So, when I first saw that, when kids were coming in and using it like when classes were coming through, I said I need to talk with the special aid department head and I need to bring him in, which he did, and we said let's like talk about using this with special aid math. And what I've done with special aid math is I looked up like pixel art online, and then I bought tons of different colors of posted notes, and I'll give them the picture. Well, it's working on a graphic, you know what I'm saying? And they're doing spatial intelligence and spatial measuring. I have some emoji pictures and they would then take the posted notes and they have to on my whiteboard they recreate the picture that's just only 1/2 by 11, and they usually are able to do it and then afterwards like I'll point out to them well, do you realize it like if you think of this, let's say an X and Y axis and then they start like oh, okay, and then we talk about area like, you know, a posted says two by two, or two and half by whatever it is. So, like I try to show them the concepts they're learning in classroom. Again, there's real world issues here and there's real world things that they can see.

The accessibility that SMS was emphasizing was summed up by the summed up by what they called the “graffiti wall.” As seen in Figure 4.20 the far west wall of the makerspace had a board covered in Lego pads. This board was representative of all the entire makerspace as a space for STEM integration.

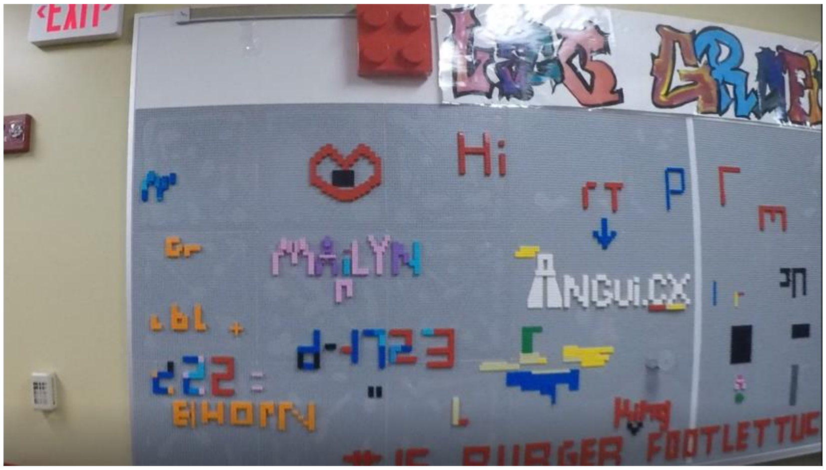

Figure 4.20 *School B* Makerspace: Graffiti Wall

She said this about the “graffiti wall:”

> I built the Lego graffiti wall because I was like how cool would it be that they can actually like make a graffiti wall versus just building from the table up. I have the Lego architecture kits and there's some kids who come in and they just want to sit with other kid and they wanna build that until they're done and then they have to disassemble it and then they can make something else. But a lot of them just wanna freebie, you know, and it's a lot of fun to see them just completely create like that, you know. It's really nice.

The board was collaborative and located in a common space, it provided students with resources to explore STEM concepts and engage them with those resources, and it was accessible to every student who came to the Media Center.

4.1.2.1 School B Identified Themes

Reflecting on the two interviews and the tour of the makerspace revealed three main themes for *School B*’s environment regarding STEM integration. Both SMS and the administrator stressed the importance of resources when engaging in STEM integration, of allocating space in which the integration activities could happen, and a culture of STEM accessibility.

Through the interviews and the observation of the makerspace, *School B* had many resources dedicated to the STEM initiative. Some of these resources included robots like the Sphero, maker kits like Snap Circuits and Legos, science kits, materials and kits for design projects, computers, and 3D printers. As explained in the case summary, both SMS and the administrator detailed examples of these resources being used to facilitate STEM integration. SMS said, during the interview, that the resource of the makerspace had be utilized by the Innovation academy for one of their STEM rotations. They stated:

> So, one of the rotations has often been coding. So, like I'll lend the Spheros out to one of the teachers who has worked with me a bunch so she knows how to code things and so they'll use the Sphero robots.

The administrator spoke of the science teacher who used science kits to create crime scenes in on the extra classrooms. From the interviews and the observation activity, the focus on resources reinforced their assertion that STEM integration was occurring in their collaborative project-based approach to education. This was further reinforced by the importance placed on allocating space in which the STEM activities occurred.

In the interview, the administrator spoke at length about the number of spaces used for their STEM rotations. They also explained that each academy had access to their own science lab, this meant that when the science lab was being used for a rotation activity it was not disturbed by other students in other academies. Other spaces, such as the gyms and cafeteria, were listed as usable spaces for STEM activities. SMS was emphatic that the makerspace was a necessary space for the integration efforts at *School B*, though they also stressed that it was open to all students. Whether it was part of the Innovation academy or makerspace, those individuals involved in the STEM initiative ensured that there was space available for STEM integration. This intentional allocation of space speaks to the culture of STEM education developed at the school.

From the Innovation academies rotations to the location of the makerspace in the Media Center, the culture of STEM education was prevalent at *School B*. Both The administrator and SMS spoke about the need for students to have access to STEM education and alluded the culture that develops as a result. The administrator commented on how the integration of STEM concepts in the elementary and middle schools has increased the number of students enrolling in the Innovation academy. They also stated that they thought that every student should be afforded the opportunity to engage in their integrative STEM activities. SMS spoke at length about the reasons for the makerspace being located in the Media Center and how that has provided opportunities in STEM education to more students. Specifically, they spoke about the students who come to the makerspace during their homeroom and the special needs students who use the makerspace to learn math concepts.

School B is a large school with a well-established STEM program. From the data collected during this research project, the STEM program seemed effective because their STEM initiative stressed three things. First, they stressed the importance of making resources available for STEM activities and then the importance of allocating space for the integration to happen as well as the importance of creating a culture of STEM education.

4.1.3 School C

School C has a student population of nearly 4,000, which is organized into several different academies. The STEM academy at *School C* has been certified by the state of Indiana as a STEM school. During data collection at this school, the primary focus were the areas designated for the STEM academy. The collection of data included an interview with the STEM academy leader and a tour of the academy's facilities, focusing on the areas engaging in the majority of the STEM integration efforts.

School C boasted a very large technology education wing, which was where most of the STEM academy classrooms were located. This wing included a large lab, many technology education classrooms, multiple classrooms for each other content area. The main school building had two floors and the entire back third of the building was dedicated to the STEM academy classrooms. The observational tour began in the large technology lab, which was divided into three main sections. The first section observed was the robotics lab, which has housed the First Robotics team from *School C* for nearly 20 years. As seen in Figure 4.21, this portion of the lab is dedicated to the robotics, the center of this area is a practice course for the First Robotics competition. In this section, there was space for constructing the robots, storing components, and storing previous entries. The STEM academy leader explained that although the space was allocated primarily for the robotics team, all the classes in the STEM academy had access to the space if needed for a class project. According to him, when teachers engage in STEM integration, they often take students to the lab during their class time. As seen in Figure 4.22, each bench has ample space around it to accommodate teams and project work, the tools and resources common to robotics projects are also stored in the toolboxes nearby.

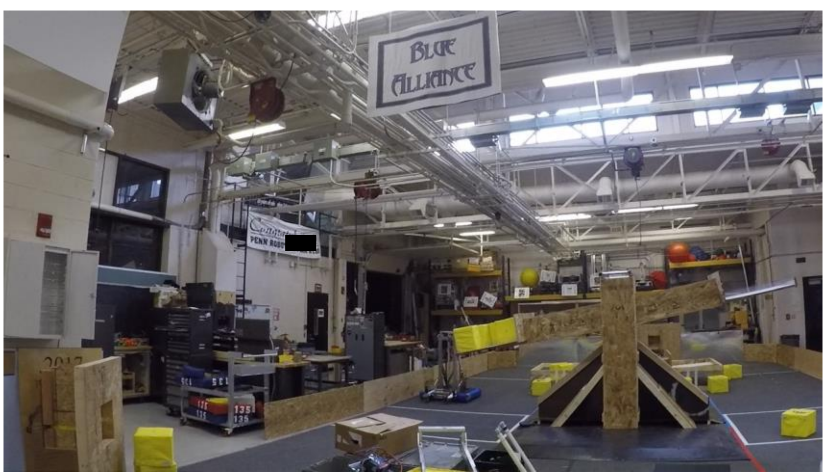

Figure 4.21 *School C* Technology Lab: First Robotics Lab and Arena

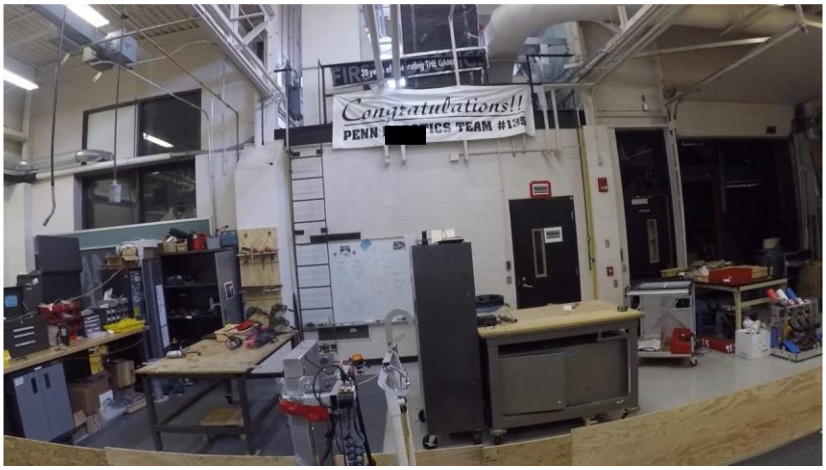

Figure 4.22 *School C* Technology Lab: Robotics Workbenches

The black door, located on the rear wall in Figure 4.23, opened to a storage space and ventilated workspace. In this room was a hood that served as a fumes hood for both the plasma cutter CNC machine and the paint booth. The large opening on the right side, of Figure 4.23, led to a storage area designated for First Robotics projects.

Figure 4.23 *School C* Technology Lab: Robotics Parts Storage

This storage area, for the robotics team, had a loft with more storage on the second level and accumulated parts from the many years that the program has been running. The STEM academy leader explained that the school only pays for the teachers. The students have raised an annual budget of nearly $70,000 for the programs. From this large budget, the program and technology department had accumulated a large assortment of parts and tools. The academy leader stated:

> Our school does not fund our program, at all, other than paying the coach, teacher, a stipend. Our students raise all the money, so they typically run about a $70,000 budget, which is high. Um, that's not required to run Firsts, by any means, but we build two robots every year, we pay for our students' hotels, sometimes their food, our mentors, travel, we cover everything. Our students raise all that money. So, we actually run this in class, as a class. We have two classes, there is an automation and robotics class where we run the actual robot piece through. Building the robot, learning about the pieces and the parts and how the automation works within that. And then we have an internship, which is kind of the business side of the team. That's where the funding comes from, the planning and the community outreach and partnerships and mentors. So, we actually run those as classes, so they can earn credit for it.

According to the STEM academy leader, *School C* has participated in the FIRST competition for the past 20 years, this commitment to the competition is reflected in their offering of robotics classes and collection of previous entries. *School C* has kept their robotics team entries from every year of the competition, in which they entered, over the past 20 years. Figure 4.24 shows the collection of previous entries, according to the academy leader these entries were saved for posterity, examples, and spare parts.

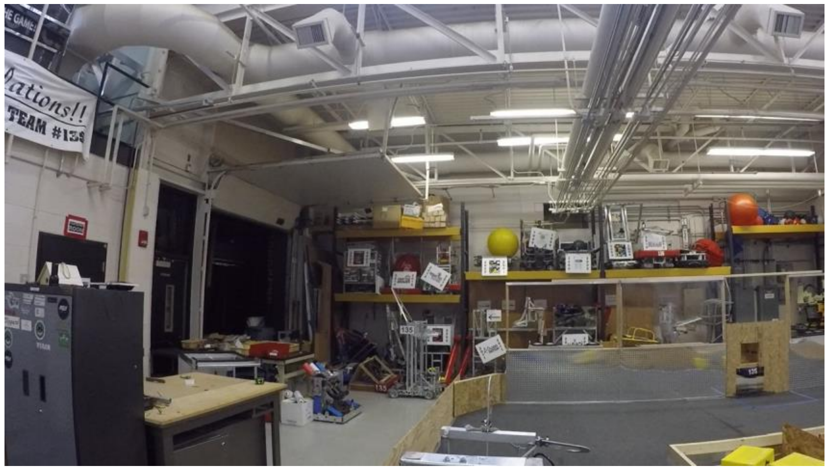

Figure 4.24 *School C* Technology Lab: First Robotics Collection

The next section of the technology lab was the center area of the entire lab space, with entrances to the manufacturing classroom and the main technology classroom. As seen in Figure 4.25, the layout of this center space was six tables arrayed in a three by two pattern. The STEM leader said this part of the lab was primarily used as a group work area for projects involving the robotics area or the manufacturing area.

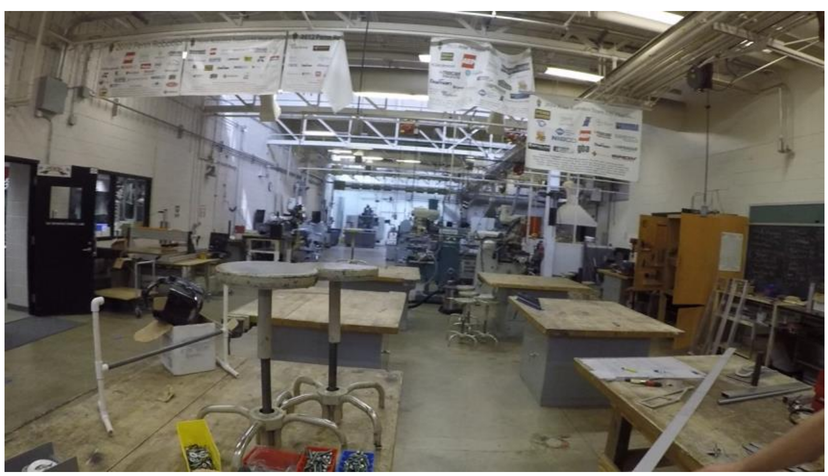

Figure 4.25 *School C* Technology Lab: Group Workspace

The tables, in Figure 4.25, had storage underneath and cabinets for Personal Protective Equipment (PPE) were attached to the wall on the right side of the image. According to the STEM academy leader, the entire lab was being rearranged to eliminate safety concerns. When discussing lab safety concerns, the STEM academy leader stated:

> A lot of that stuff was not built into this lab. We had grinders grinding towards electrically boxes, and we still do. So, we are in the process of rearranging the lab, so that we are in compliance with a lot of that stuff.

This was important to this center space because it was the main access point from the two classrooms. The STEM leader explained that this space was kept as a workspace and not a machining space due to safety concerns. They also stated that this was a beneficial because it allowed them to keep a necessary collaborative space.

The third, and final, portion of the lab was a manufacturing lab that was stocked with mills, lathes, and various other manufacturing machines. As seen in Figure 4.26, the manufacturing lab had many large machines, closest to the center section were the five manual vertical milling machines. Across the main walkway, on the left side of the image, was the first CNC milling machine for the lab.

Figure 4.26 *School C* Technology Lab: Vertical Milling Machines

The STEM leader explained that the first CNC milling machine brought to the lab was a vertical milling machine that was converted to a CNC machine. This machine did not have the capability of working with a computer to accept pre-compiled G-code, students and teachers had to manually enter code into the machine interface. This machine was the first step in an effort to evolve the manufacturing capabilities of the lab. According to the STEM leader, the STEM academy was pursuing a plan to bring more CNC machines into the lab space as a response to modern manufacturing needs.

Figure 4.27 *School C* Technology Lab: Old CNC Milling Machine

As stated by the STEM academy leader:

> The goal is to get more of the CNC stuff in, that's what the people want, that's modern manufacturing. I have this big dream, of high schools being training facilities for companies. You know, companies are starting to build these multi-million-dollar training facilities, because they are constantly having to train new workers. Why? Spend half that money on your local high schools, update their labs and give them new machines. And then they can teach their kids with it, and you can bring your guys in and train them, I mean it costs less money. And you get trained workers coming out with less time in training.

School C was converting their lab space to meet the needs of modern manufacturing, as seen in Figure 4.28, the multi-axis CNC milling machine added to the lab was a huge step, as explained by the STEM leader. The discussion of this machine illuminated that the lab was being rearranged to that all the CNC machines would be located around the multi-axis milling machine.

Figure 4.28 *School C* Technology Lab: New Multi-Axis CNC Milling Machine

In addition to the advanced manufacturing machines, located on this side of the lab, there was also a section dedicated to foundry processes. The STEM leader explained that the teachers at *School C* found community members who were experienced in foundry work to mentor interested students. In addition to mentors from the community, teachers have worked to learn and practice foundry processes. The foundry section and fume hood are seen in Figure 4.29, along with furnaces, anvils, and various foundry tools.

Figure 4.29 *School C* Technology Lab: Foundry

Next to the foundry area of the manufacturing lab was another storage area, similar to the robotics lab storage area on the opposite side of the building. As seen in Figure 4.30, this storage area contained a tremendous amount of metal stock.

Figure 4.30 *School C* Technology Lab: Metal Materials Storage

According to the STEM leader, the businesses in the community were really activity in supporting the school. They highlighted this point by explaining the completely full metal racks in the manufacturing storage area. They stated:

> [A local company] was our first sponsor for robotics. And over the past 20 years they will just call us up and say, "We got a load of more metal we need to get rid of, bring your trailer." And they will just load us up, and this is just full all the time.

The STEM leader continued to highlight community involvement throughout the lab space and the classroom. Everything from modified workbenches to repurposed classroom desks were connected to the community in some fashion, as stated by the STEM leader.

The next stop on the observational tour, of *School C*, was the main technology classroom, which ran parallel to the lab for about the same length. The STEM leader explained that the room had previously been three separate classrooms, a teacher prior to his arrival had the room modified to one large classroom space. This classroom, like the lab, was divided into three main sections. The portion of the classroom parallel to the manufacturing lab was allocated for direct instruction and individual computer work. Figure 4.31 shows the numerous desks and computers that made up this portion of the classroom. Most of the furniture in this classroom, as explained by the STEM leader, was obtained from the community. The tables and desks were originally modules but have been modified to their current form. This area was explained as the direct instruction side of the classroom, the layout of the desks was aligned on a central screen from which the teacher instructed.

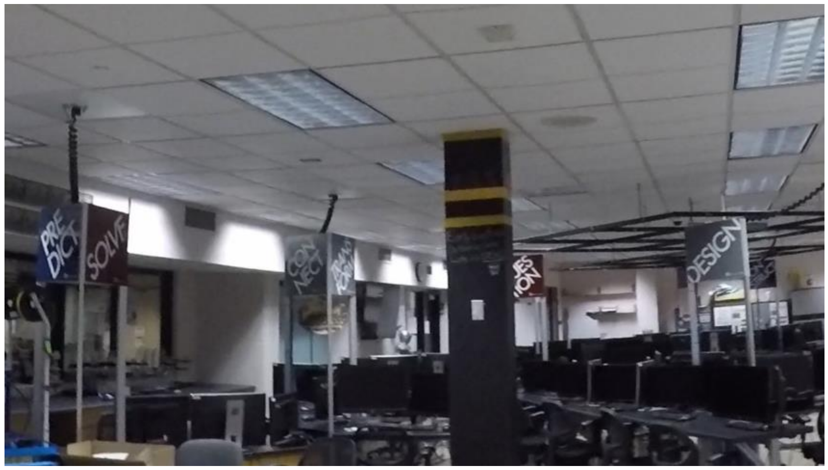

Figure 4.31 *School C* STEM Academy: Technology Classroom Direct Instruction Space

The next area in the classroom was described as the collaboration space, the STEM leader stated that this area was often used for small class discussions, small group work and less formal meetings. They explained, again, the connection to the community by detailing the acquisition of the furniture in this space. According to him, the seats and foot stools in this space were sold by a local company for a dollar a piece, this was due to a teacher in the school having connections to the company. The STEM academy leader also explained that this space was used during STEM integration activities for small group discussions.

Figure 4.32 *School C* STEM Academy: Technology Classroom Collaboration Space

The final section of the classroom was allocated to the robotics team and robotics classes. This space was distinct from the other parts of the classroom; it had worktables, tools, and parts for building robots. This part of the classroom was parallel to the robotics lab with a door between the two spaces. The STEM leader explained that multiple robotics classes were conducted in this space, those classes ranged from the introductory course on robotics to the First Robotics class. This was another area, identified by the STEM leader, which was used for STEM integration lessons.

Figure 4.33 *School C* STEM Academy: Technology Classroom Robotics Area

On the rear wall of the classroom, in the robotics section, the STEM leader highlighted the resource that they claimed was necessary for STEM integration. That resource, as seen in Figures 4.34 and 4.35, was revealed to be mobile cabinets and portable storage containers. In Figure 4.34 the mobile cabinet and portable containers were storing large quantities of Legos. According to the STEM academy leader, these Legos, and other resources kept in the similar cabinets, were moved to and from classrooms when needed.

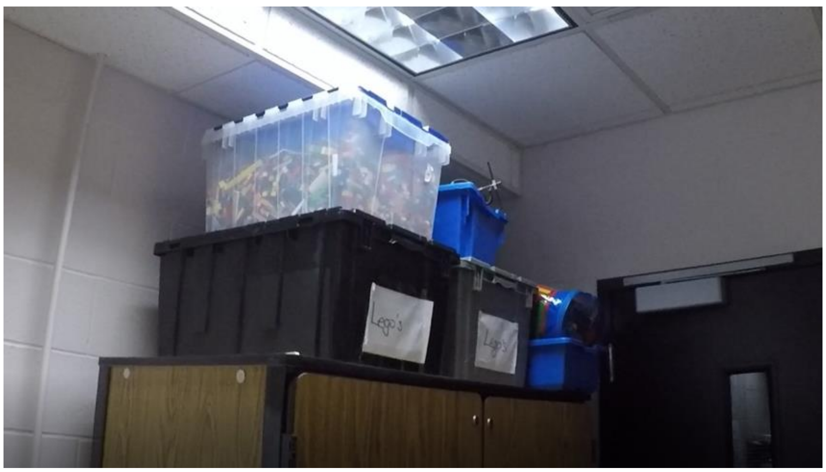

Figure 4.34 *School C* STEM Academy: Mobile Lego Cabinet and Tubs

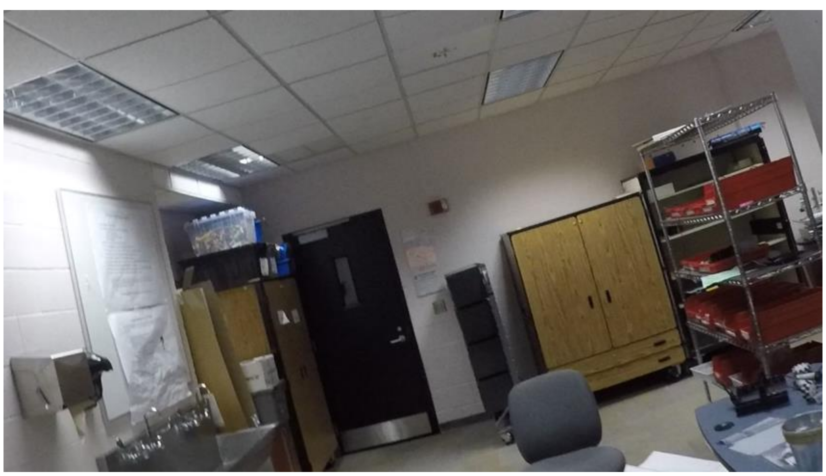

Figure 4.35 *School C* STEM Academy: Mobile Cabinets

There were two mobile cabinets in Figure 4.35, these were the only two cabinets stored in the classroom, five more mobile cabinets were stored in locked hallway adjacent to the classroom. During the observational tour, the researcher was led down this hallway to connect with the main hallway for the first floor of the STEM academy. In this hallway, parallel to the main technology classroom, was the construction classroom.

The construction classroom was divided into two sections, the first section was shown in Figure 4.36. This portion of the classroom was dedicated to direct instruction and computer work; as stated by the STEM leader, the students that take classes held in this room generally used the computers to learn about architectural drawings and 3D modeling software. According to the STEM leader, students taking a construction class, or an architectural class, start with the software Google SketchUp before learning Autodesk Revit. They also explained that many of their designs were able to be printed on the 3D printer located on the other side of the room. Some of the projects for those classes were also built to scale in the other section. As seen in Figure 4.36, this part of the room layout was aligned to a front and center display screen. This was a stark contrast to the other side of the room which was very much an open space with no alignment to a specific wall.

Figure 4.36 *School C* Construction Classroom: Direct Instructional Space

Figure 4.37 shows that the other half of the room was a spacious area for project work and demonstrations. The tables stacked in the left side of Figure 4.36, as stated by the STEM leader, were used for conference meetings, design reviews, and project work. In this space, students have created scale models of their buildings, built walls, and solved problems. One of the examples of STEM integration, provided by the STEM leader, was a project to optimize the office space for one of the school staff members. The staff member in question had restricted mobility and the students worked to make their workspace more accessible. In the project, the students leverage geometry principles and technology processes to solve the optimization problem.

Figure 4.37 *School C* Construction Classroom: Collaborative Workspace

This part of the room also had an extra-large whiteboard, plotter printers, 3D printers, and shelving for consumable materials and reference materials. The STEM leader explained that this space had also been used for STEM integrative projects, the project in the room was a collaborative project with an English class to promote a bicycle sharing company in the local area. Figure 4.38 shows the bicycle in question; according to the STEM leader, this project was an authentic marketing challenge led by both an English teacher and Technology teacher.

Figure 4.38 *School C* STEM Academy: Current Integrated Project

Figure 4.38 was a great example of the integration activities at *School C*, as explained by the STEM leader. According to him, it was very common for non-technology teachers to utilize the technology classrooms when integrative projects required collaborative space or special equipment. During the tour, observation of the of the other classrooms in the STEM academy showed rooms completely dedicated to the content. The science classrooms were lab spaces with workbenches arranged in rows aligned to a center presentation board and teacher desk. The math rooms and liberal arts rooms were primarily arranged in a direct instruction layout, with individual desks arranged in rows facing a presentation board and teacher desk. STEM integration at this school happened because teachers were willing to move resources and students to their optimal location for learning. As stated by the STEM academy leader:

> We're already in an academy, all those classes are together in an academy, we have similar PLCs, um, staff meetings, things like that are together. There's the STEM leader kind of helped make some of those connections, natural connections between the two. Um, physically, there's a little bit of distance between our Math, Science classes and our Engineering tech classes, but it's just right up the stairs. So, we make that trip back and forth. Um, we found teachers that were interested in pursuing connections and then they were, "Who cares if we have to walk across the building or whatever to make that connection." So, we've taken some of our Engineering tech students up to the Math, Science classes, we brought some

> Math, Science teachers down to Engineering classes. Um, like on a-a class period basis, not all the time. as far as some of the other physical items, we do have a manufacturing lab or metals lab and a construction wood lab. We have a lot of old machinery or had a lot of old machinery, and those are really only used-- by the engineering tech classes and, obviously, STEM integration is more than just the tech classes. Even still now, they're still not a ton of those that are used by other classes, but in the last five to 10 years with 3D printers, laser engravers, some of those smaller things that can be moved around and taken places, that has helped us open up or overcome some of those hurdles, 'cause we can take a small 3D printer on a cart and wheel it to another room and people can see it happening.

While STEM integration was not defined as using the latest and greatest gadgets, using technology and technology education principles was a foundation that *School C* has built their STEM integration efforts upon.

4.1.3.1 School C Identified Themes

Three themes presented while collecting and analyzing data from this school: the importance of allocating space for collaboration and STEM integration, mobility of resources and students, and the importance of community interaction in the classroom.

It all starts with having space which can be allocated for different learning activities. The academy leader explained that *School C* had the space to engage in STEM integration:

> We have a lot of space. Each teacher in the engineering tech courses has their own room, or we have enough space for everybody. We do some sharing of rooms based on the class, but we have the space. We have two different labs, one for manufacturing, one for construction, so that made it a little easier for us.

Though the school had the large amounts of space before their STEM certification, it was important to understand and utilize all the available space by allocating specific areas for collaboration and STEM integration activities. During the observational tour of the school's STEM academy, the academy leader spoke about teachers sharing classrooms and utilizing the space that best fit the class or project that they were facilitating. The STEM leader spoke about leverage the technology labs and classrooms as integration spaces for teachers that needed to use the space.

> We've taken some of our Engineering tech students up to the Math, Science classes, we brought some Math, Science teachers down to Engineering classes. Like on a class period basis, not all the time.

These classrooms are utilized because they often have common areas, larges areas for collaborative work, and/or individual worktables. Common collaborative space, allocated for use by the entire STEM academy, means that teachers and resources must be mobile.

The second theme is the importance of mobile resources and classroom space. As stated by the STEM leader, teachers from other disciplines move their classroom to spaces which facilitate their learning needs. This is not, however, the only mobility required for spaces being used for STEM integration. As highlighted in the case summary, certain resources for STEM integrative activities need to be mobile, as well. Space in the technology classrooms is allocated for collaborative work, but with so many students and classes, sometimes the resources need to be used in rooms other than the technology classroom. The STEM leader, while speaking about the mobile cabinets and containers, described previous integrative activities which required Legos and the math teacher leading the activity was able to move the necessary materials to the math classroom. Along with Legos and robotics kits, the STEM leader described cabinets and carts with portable computers, 3D printers, laser engravers, and the like. When large project space is not available, or not required, mobile resources bring the tools for integration to the classroom.

The third, and final theme, identified from *School C* was community interaction with the classroom space. STEM integration focuses on providing authentic experiences to students by challenging them with real world problems. When the community interests and problems were brought into the STEM academy, they were integrated into the learning environment. The integration highlighted in the case summary, the marketing project for a bicycle sharing program, is an example of the community providing problems for students to solve. This project was feasible for the STEM academy because the community had provided support for the STEM programs at *School C*. All the equipment, mentors, and resources provided by the community creates a culture of STEM principles and authentic experiences.

School C had many experiences to share in regard to STEM integration and their continued efforts to improve their facilities. The focus on providing allocated space for integration, providing mobile resources and alternative learning spaces, and their connection to the community enrich the STEM integration efforts at *School C*.

4.1.4 School D

A large city, in north-central Indiana, is home to *School D*; as stated in chapter 3, this school had a small student population of about 300 since late 2010. Prior to opening doors as a school, the building was used designed and used as an office space and warehouse. When *School D* took residence in the building, the office space was converted to classrooms and common areas, where as the warehouse was converted to the manufacturing lab. *School D*, as a high school, shared the building with their middle school counterpart; during data collection it became apparent that many STEM integration efforts were shared between the two schools. Data collected and analyzed for this research project only represents the high school facilities and staff, as per the stated scope of the research project.

The observational tour and interviews covered many aspects of the school facilities and school culture. First in the data collection efforts at *School D* was several interviews with four individuals involved with the STEM education efforts at this school. The individuals interviewed included the Director of Information Technology (referred to as the DIT), the Digital Learning

Manager (referred to as the DLM), the administrator, the physics and chemistry teacher (referred to as the science teacher), and the engineering technology teacher. First to be interviewed was the administrator, they were the guide for the observational tour.

The observational tour focused on three main areas used for STEM education and integration: the high school core classroom space, the manufacturing lab, and the PLTW classrooms. First stop on the observational tour was high school classroom space, which was arranged as a pod of classrooms surrounding a common area called a “flex space.” As seen in Figure 4.39, this common area was a large open space with large amounts of natural light and versatile furniture.

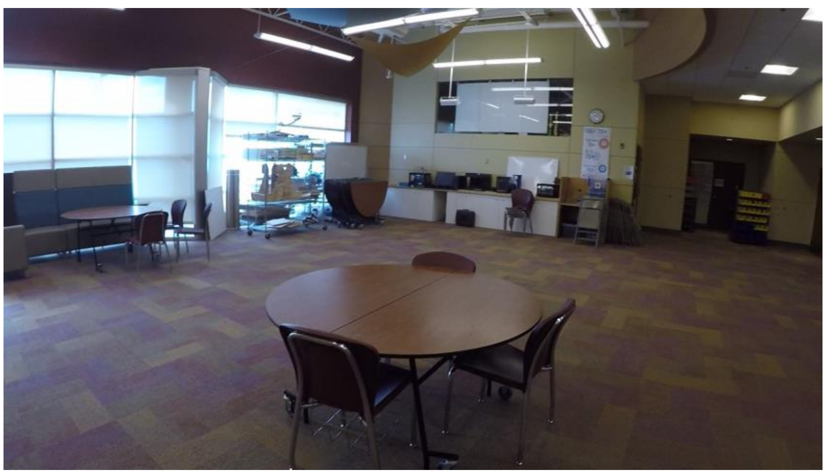

Figure 4.39 *School D*: High School Flex Space A

This area was accessible to several classrooms and was designed to be a project workspace and study area. According to the administrator:

> We have a shared area, of four or five classrooms. We are working on making this a makerspace. It’s in progress, but we have portable storage, you know, which we can move in and out of classrooms, we they need to be used and that kind of thing. Kids can come out here and work, trying to give the kids as much autonomy as possible, and the resources they need in the space.

As seen in Figure 4.40 the space had several folding, round tables that were outfitted with wheels to make them portable, in this space a few 3D printers were also available. The space shown in Figure 4.40 was another “flex space” for a separate pod of classrooms, the round tables were also used in this space. Visible in Figure 4.40 was more large windows for natural light and open wall space, at the far end of the room was also shelving units like the ones in the other “flex space.”

Figure 4.40 *School D*: High School Flex Room

The shelving units in both spaces were used to store projects and resources. In addition to the shelving units were large rolling cabinets. The administrator stated, in the quote above, that these portable storage units were used to transport resources in and out of classrooms. Figure 4.41 showed the cabinets next to the shelving unit in the first “flex space.” In Figure 4.40, at the bottom left of the image, another example of portable storage was seen in the “flex space,” these were laptop charging carts. These carts offer students storage for their laptops that also charges their devices.

Figure 4.41 *School D* Flex Space: Mobile Cabinets and Shelving Unit

As The administrator had previously stated, these “flex space” were designed to give students extra workspace, in addition to resources and project space. Part of that design was to give students a comfortable place to work and study. Both examples of the “flex spaces” had soft cushioned furniture, more practical for reading and writing rather than tables and benches for project work. Examples of these cushioned seats were seen in Figure 4.42 and Figure 4.43; each space had these study areas in addition to allocated space for collaborative projects.

Figure 4.42 *School D* Flex Space: Study Nook

Emphasizing the space as a multipurpose room, rather than a lab, was the beginning of creating a collaborative culture for the "flex space." Spending everyday with the space and understanding its purpose created a culture of collaboration and student autonomy. The administrator stated during the tour that the space was designed to allow students to take the lead in their learning experience. The "flex space" had plenty of wall space to include policies for the makerspace, school notices, and student work, exhibited in Figure 4.43.

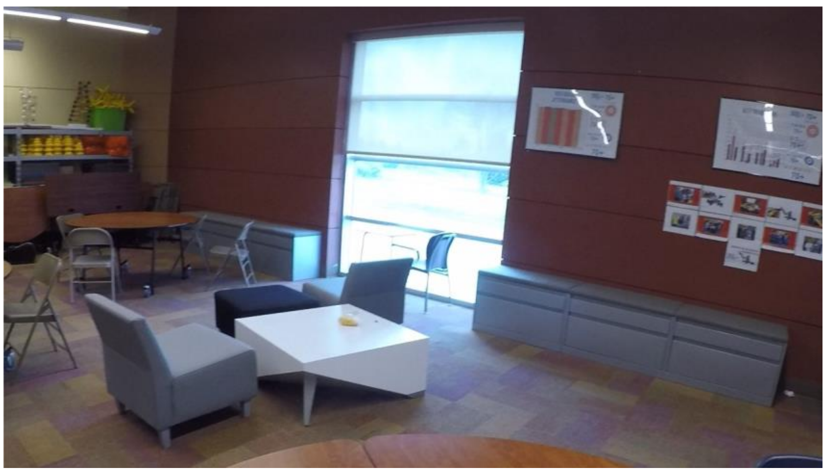

Figure 4.43 *School D* Flex Space: Cushioned Seats

Creating the culture of collaboration and comfortability with the "flex space" lead to students being comfortable with the tools and resources available in the space. As shown in Figure 4.44, the "flex space" had a maker section stocked with 3D printers and cabinets of tools. This was made available to the students to develop give the experience in rapid prototyping and creating physical solutions to test.

Figure 4.44 *School D* Flex Space: 3D Printers

An example of the integrative project work being completed in this space was stored on one of the shelving units in the "flex space." Figure 4.45 showed the ongoing project to design and build a table-top arcade cabinet. Students were using the materials and resources in the space to build the project, and the 3D printers were used to create custom parts.

Figure 4.45 *School D* Flex Space: Integrative Project for Arcade Cabinet

After exploring the “flex space,” and discussing with the administrator the purpose of the space; attention was drawn a unique feature of all the classrooms. As seen in Figure 4.46, classrooms with walls adjacent to the “flex space” were converted to garage doors. This gives teachers the option to expand the learning environment into the common area. According to the DIT, the retractable wall was not unique to the wall connecting classrooms to the “flex space.” The DIT stated during the interview:

> There's garage doors between many of the classrooms, which is unique to our building. I would say, cross-curricular, collaborative opportunities, "Hey, these two classes are studying something, working on some projects, boom, the garage doors can go up and we can, you know, collaborate and work together on something." Um, frees up some space, you know, just kind of changes that learning environment makes it a little more collaborative. Many of the garage door is also open into a flex area, that you'll see, where we can use that space just in creative ways, designing projects, collaborating with students across, you know, different classrooms, but also different grade levels, those kinds of things.

The administrator elaborated, during the observational tour, that garage doors were also put in place to allow to teachers to set boundaries for the students. When teachers need students to focus inside the classroom, while taking tests or listening to presentations the doors can be shut. The removable walls allow teachers to leverage the space as they see fit for the learning objective of the class.

Figure 4.46 *School D* Flex Space: Garage Door to Classroom

In addition to the makerspaces in the high school “flex spaces,” *School D* had a large manufacturing lab located in the former warehouse part of the building. Next on the observational tour was a quick look at this large lab space. This space was allocated, primarily, for vocational classes but it was available if integrative projects required more specialized equipment. While touring the lab space, the administrator explained that a number of projects from art and the humanities had been integrated with projects in the manufacturing classes. The welding class had been known to integrate art projects with their metal working in the lab.

Among the many machines in the manufacturing lab, *School D* boasted several industrial machines including a multi-axis CNC milling machine (Figure 4.47). The administrator explained during the interview that the machines in the manufacturing lab provided the students with many opportunities. They stated:

> The shop area with all of the heavy equipment, we have a Haas CNC setup. We have smaller CNC; we have 3D printing. We have laser engravers. We have a welding program. We have just lots of opportunities available to the students. Medical science, similar opportunities with CNA program and those kinds of things. So, there's lots of things that kids can take and, kind of, pursue, within the building.

Machines, like the CNC mill, were useful for students working towards vocational careers but they were also useful for large projects which required machined parts. Integrating the manufacturing class with the project-based collaboration of the rest of the school provides the students, from every class, real-world experience.

Figure 4.47 *School D* Manufacturing Lab: CNC Milling Machine

Other machines located in the manufacturing lab were four metal lathes, two vertical milling machines, a number of surface grinders, belt grinders, woodworking machines, drill presses and the like. In Figure 4.48 the machines are arranged in groups by the machine. Along the back wall, two vertical mills were placed opposite the large metal lathes, and on the end of the row of lathes and grinders was a smaller metal lathe that is centered in Figure 4.48.

Figure 4.48 *School D* Manufacturing Lab: Machine Layout

Figure 4.49 *School D* Manufacturing Lab: Vertical Milling Machines

To fully utilize the well-equipped manufacturing lab, the school had a well-stocked metals rack. As seen in Figure 4.50 the metals rack is almost entirely aluminum stock, a metal chosen because it is easier to machine and cheaper than steel alloys. Aluminum was also chosen because it is a versatile and lightweight material, perfect for small projects and novice machinist.

Figure 4.50 *School D* Manufacturing Lab: Metal Stock

Included in the metal inventory was a good deal of steel scrap and steel stock, one of the courses available to students was a welding class. The left side of Figure 4.50 shows the steel scrap bins, to the left of the bins were several larger pieces of steel stock. While the shop was primarily stocked with aluminum, the welding course necessitated an inventory of steel alloy.

Figure 4.51 *School D* Manufacturing Lab: Welding Stations

On the opposite side of the wall, where the metal was stored, was the fourteen welding booths utilized by students seeking a welding certificate. The welding stations were seen behind the metal stock wall in Figure 4.50 and the stations were fully seen in Figure 4.51, each station was separated by a painted cinderblock wall. In each station there was a metal work surface, fume collector, welding unit, and water container. This area of the shop also had PPE available for students on the tables to the right of the welding stations in Figure 4.51. Students who worked towards a welding certificate also required experience with cutting torches. The eight torch stations were visible in Figure 4.52, each station included a metal workspace, gas tank, and cutting torch.

Figure 4.52 *School D* Manufacturing Lab: Metal Cutting Stations

After exiting the manufacturing lab, the administrator led the way to the PLTW classrooms, located at the front of the building. As it was the middle of the school day, no images were taken of the PLTW classrooms for this research project. Walking to the PLTW classrooms, the administrator explained that the school offered students pathways for both college and vocational careers. While the manufacturing lab was primarily a vocational space, it was also used by the PLTW classes, and those teachers engaged in large scale integration projects. The PLTW classrooms had similar features to the classrooms in the high school core area, the lab space and classroom space were separated by a garage door and both areas had access via garage door to the main hallway and common space. While interviewing the engineering technology teacher, one of the engineering teachers that uses the PLTW classrooms, they spoke about the fluidity of the space and the teacher intent to continue to improve the learning environment. The engineering technology teacher stated:

> My classroom, which is kind of a computer lab plus a shop area, it used to be like, kind of two separate places crammed into a smaller area and, they moved it up to the front of the building and separated the two rooms but there's like a garage door in between. So, we have, kind of the instructional area and then the hands-on area. The school had vocational pathways and college pathways if you will, like, as one big room. That's kind of a cool thing 'cause my engineering class can CAD something out and walk over to the other side of the room, laser-cut or 3D-print it, put it together, you know, in their shop tables and everything. So, it's kind of a two-part classroom, which really helps out.
>
> We're actually just this week thinking about what's gonna happen over the summer as far as like changing layouts and stuff. I mean we're always trying new things. I share my classroom with one of the other teachers that does advance manufacturing and principles of engineering and that kind of thing. And so, we both have that engineering side, but we teach different classes. So, a lot of times he's in the shop area when I'm in the computer lab area and then we switch. So, we try to come up with ideas together, and we're gonna take away rows that we have with the computer lab. And try to do like kind of groups, like little islands clusters of desks. So, we'll do that over the summer. We're gonna completely rearrange the shop, the big shop at the end of the building, just to make it more efficient. So, we're constantly just kind of tweaking what we have already and making it a better.

This idea of continual improvement in the school environment and learning strategies was echoed in the other three interviews, as well. When speaking about the science classrooms, the science teacher stated:

> There are things missing in the science labs here that I've had in other traditional schools that I would love to have the money to be able to put into place equipment-wise, infrastructure-wise. We're using pretty low-tech

> heating sources here because the building wasn't designed in a way to put in natural gas lines and things like that. So, that would be in my area, in the chemistry area, in particular, just having the ability to really significantly boost up the equipment and the design of our science labs. Also, to make it a little bit more station-oriented where there was, you know, a sink in every station, and equipment for every station. And again, just because the school's new and we're slowly accumulating things, setting up a lab. In my chemistry, we're doing a NASA-related project in that class, and they're breaking down into groups and trying to figure out how do they get rid of the carbon dioxide in the International Space Station that's building up with people breathing, and another group's figuring out how do they store all the gas-related fuels because gas takes up a lot more space than liquids and learning about cryogenics. And so, they're attacking different ones, but we're setting up a lab to demonstrate loss of bone density for astronauts. And I've got seven flasks that will work for this lab, and I've got five clamps that will work for this lab. And so, it's just over time trying to add the material. So, to me, if I had an unlimited budget, I would just pour a ton of money into getting the equipment and the infrastructure in the science lab, so that we could really expand the depth of the projects that we do.

The DIT summed up this common idea of continual improvement by stating during the interview:

> The interesting part that I've noticed, and especially thinking about it now, is the one thing that keeps us going is we're actually never satisfied. We keep setting a bar, and then we keep moving the bar higher and higher. We've never gotten to a point and said, "All right, we're done." So, I don't think it'll ever stop evolving. And maybe that's the trick is, it never stops evolving.

4.1.4.1 School D Identified Themes

Several themes presented during the analysis of the data from *School D*, each one was connected to the overall school culture of STEM integration and collaboration. The four themes present in the data were the necessity of the “flex space” as a common area allocated for collaboration and integration, the adaptability of classrooms and resources, time to collaborate with other teachers, and the application of supportive technologies.

During the interview with the DIT and the administrator, both explained that the classrooms were designed with the garage doors to facilitate “cross-curricular,” or integration, opportunities. The DIT stated:

> There's garage doors between many of the classrooms, which is unique to our building, I would say. Cross-curricular, collaborative opportunities, "Hey, these two classes are studying something, working on some projects, boom, the garage doors can go up and we can collaborate and work together on something."

This theme of collaboration also presented in the design of the school's "flex space" and design of the PLTW classrooms. Collaboration and integration were major focuses during the design of the high school, the core high school classrooms surrounding the "flex space" all have access to the common area via garage doors. The focus on collaboration extended even into the selection of furniture for the "flex space," each common area in the high school had several folding round tables. As shown in Figure 4.53, the tables were portable and collapsible, a consideration that highlights the second theme.

Figure 4.53 *School D* Folding Portable tables

The versatile nature of the folding tables was also present in the mobile laptop charging carts and mobile storage cabinets. As The administrator was quoted in the case summary, the cabinets and laptop charging carts were selected because they could transport resource in and out of classrooms or around the common area to arrange the common space as the teachers saw fit. As seen in Figure 4.54 and Figure 4.55, the mobile cabinets were kept in the common for use by the students and teachers.

Figure 4.54 *School D* Mobile Cabinets

Figure 4.55 *School D* Mobile Laptop Charging Cart

Adaptability, of the classroom and resources, as a theme manifested from the high value placed on the being able to move resources to and from classrooms and the "flex space," but also moving students to areas best for the learning activity. This adaptability was considered in the design of the PLTW classrooms; the engineering teachers, as quoted by the engineering technology teacher in the case summary, use the computer space and the lab space fluidly. A large component of both the theme for collaboration and adaptability were the garage doors installed as tractable walls in most of the classrooms.

Leveraging the adaptability of the school resources and utilizing the collaborative spaces would not be effective without the third theme, allocated time to collaborate. During the interview, the administrator explained how this collaboration was achieved the formation of teams and scheduled time for those teams:

> It's super collaborative with the teams and there's a lot of different teams within the building curriculum, content area teams, grade level teams that meet every single day to discuss student issues and curriculum and ideas and that kind of thing, you know, "This failed, this doesn't work. I'm struggling in this way; how can you help me?" And there are always people rallying around each other to have those conversations.

He continued to explain that this made a huge difference during his experience as a teacher the previous year. The administrator continued:

> That's was probably, in my mind being a classroom teacher for the last two years, the biggest difference. For me, being a new teacher in this building, there was an hour every single day of the school year for me to sit down with the other teachers in my grade level. I was as an eighth-grade science teacher. And every day the eighth-grade teachers would sit down and discuss curriculum goals, student needs, and issues.

The science teacher echoed this sentiment, they described how being on a team and have allocated time to collaborate provides opportunities to integrate. During the interview they stated:

> We do teams, I'm on the 11th and 12th grade team and we meet daily as teaching staff to talk about what we're doing in our different classes to see if there's overlaps and things we can coordinate on. I think that it helps,

> especially as a project-based school, find out if there's something I'm doing as a project in my class that might tap into something that they're doing in a different class.

He continued, during the interview, to provide an example of a project that was accomplished due to the allocated collaboration time. they detailed his experience as:

> So, in our team this year, last semester, we did a health and nutrition unit project where all the different subject areas, kind of attacked that approach. And so, like in the non-STEM areas, like in history, they talked about welfare systems and the development of welfare systems in countries but then, in the math and science areas for science, we study the nutritional aspects of foods and water. If you're on a budget kind of a little bit of the bioethics of most of the cheap food that people can afford aren't healthy food. So, we talk a little bit about that as well, and we'd actually did quite a few labs on just identifying the caloric content of different kinds of foods. Then, in the math department, they did more of kind of almost connecting those two with, "Okay, you are on a budget. This is all you have. You need to, based on what you learn in chemistry, come up with a diet that's gonna be sustainable, economically, and also healthy for your body." Challenge them to do, you know, look for discounts or for coupons, and figure out a way that they could spend that money on food that would be good for them and still stay within their budget. So, it's kind of a real-life application, mathematical application that connected all three elements together.

During the interview, the science teacher also stated that the collaboration and integration could extend outside the content teams to include the engineering and technology classes. They described an integration effort between himself and the engineering technology teacher:

> You can't sacrifice content in all the areas in order to have that depth sometimes, but in the science fields, we have a little more flexibility. So, right now, in my physics class, they're studying music and sound waves and they're designing their own music instruments. Then, they have to analyze the physics behind it, what are the harmonics, can they create beats, can they create different frequencies and doing the math behind their design. I had some kids down here and, actually, the engineering technology teacher's engineering lab this morning put together CAD diagrams for their instruments and laser-cutting some of the pieces. Then, some of them are gonna be, I think, 3D-printing some of the pieces for their instruments. So, that's a bit of an integration between my physics class and then the

> engineering world with the engineering technology teacher. Because the school has that focus, I think, all of us feel the freedom to try new things and it's not always gonna work the first time through, you're gonna have to figure out the hiccups and the weaknesses, but there's not a real fear of failure 'cause we're being challenged and encouraged to experiment and you know, learn ourselves as teachers which kind of projects are gonna help the kids learn.

Allocated time for every teacher to collaborate and develop integrative opportunities further explains the culture of STEM integration present in *School D*. As the DIT eloquently stated it:

> So, I think there's a lot of things in things in this building that I don't think we take for granted, but it's just it's part of the culture. I mean, it's just our mantras, it's what we do, it's why we are here.

The final theme identified from the data was the necessity of supportive technologies. During the interviews, multiple comments were made about the importance of leverage computers to improve the learning experience. The DIT explained why a fully functional laptop was preferable over a Chromebook:

> I'd say the device is number one. I mean, having a laptop in every student's hands. That's one of the biggest catches that a lot of schools make is they go for Chromebooks and stuff like that, or just iPads in all the schools. The problem is those are not creation devices, they're consumption devices. So, you're giving them basically electronic book. And they can't do much more than that. They can't expand. They can't try new pieces of software. They can't plug scientific tools into their laptop and monitor changes over time. They can't do any of those things unless they actually have a full computer that can actually install other software on it. So, we have teachers that want to do all of their stuff in project-based, which is required in the STEM fields. We can't just learn from a textbook. We got to actually implement those skills in some way.

He explains that the laptops allow teachers to expand the students learning experience and engage skills in a practical application. The engineering technology teacher elaborated on the need for laptops, saying it went beyond the physical computer to the supportive software that the administrator helps them integrate into their classrooms.

> Definitely, you need to embrace technology. I don't mean just computers in general like doing it one to one, but I mean the administrator' purpose here is to find new ways to integrate technology and I mean that's super important 'cause he's out there on the hunt, looking for things that we can use in our classroom while we're busy with the classroom.

He continued to say:

> So, we got that kind of extra set of ears to the ground. But I think that's super important, he's just always looking to see like what's new and how can we use it, and not just for the sake of something new but for the sake of making things better. The kids are gonna use technology anyway, so, we need it constantly being moving on that front. Uh, the other thing is, hands on equipment. So, in my particular case, its tools, you know, and engineering equipment, it maybe VEX Robotics, it maybe Lego Robotics, it maybe, little LED kits, or origami even. But just materials and the tools to make everything hands on.

Many critics of integrating technology into the classroom state that technology becomes the focus, and the content is lost. The administrator both raised and answered this question during the interview, according to him:

> And I think there's still value. I mean, it's definitely a blended learning environment where the technology is not replaced. I just had a conversation with a teacher yesterday, technology is not replacing a teacher and never will. Good teaching is good teaching is good teaching, bad teaching and bad teaching is bad teaching. And I think the technology is just an accelerator and a supporter of either of those two things. If you're a poor teacher, you're going to stick out in a bad way more quickly when you introduce technology into the classroom. And if you're a Rockstar teacher, I think you can raise that bar even higher becoming more effective and efficient in what you're doing.

The importance of supportive technology in the classroom, for *School D*, was to facilitate their STEM integration efforts. Technologies, like 3D printers and simulation software, allow teachers to connect their content to the principles and concepts of other STEM fields. This technology also allowed them to engage students in authentic STEM experience.

Each of these themes were derived from the constant that *School D* had a culture of STEM integration. To quote the DIT, again, “it's just our mantras, it's what we do, it’s why we are here.”

4.2 Identified Themes

Each case, summarized above, presented themes when analyzed on a case-by-case basis. Reflecting on those cases from a holistic perspective revealed that while some themes were unique to each school, there were several themes across all four cases. These cross-case themes demonstrate potential attributes that are necessary for STEM integration. Three of the numerous themes listed in the case summaries were present in all four cases identified for this research study. Those themes were the allocation of specific collaborative space for STEM integration, the mobility of resources and students, and finally the importance of supportive technology resources.

The first theme, allocation of specific collaborative space, was the most prevalent theme identified in each case. *School C* was the only school that did not have a space labeled as a makerspace, but it did allocate space for the STEM academy to use when the integrative projects required larger a collaborative space. *School C* did not have a makerspace due to its extensive technology lab and classroom space that perform the function as a makerspace. The other schools also have technology classrooms but the vast amount of space at *School C* made an additional allocated space unnecessary. The data from each school showed that the makerspaces and the *School C* lab were intentionally designed to accommodate STEM integration practices. The makerspaces and labs were outfitted with furniture perfect for collaboration, such as round tables and workbenches or portable furniture. *School C* had several spaces that fit this bill, in their lab they had square workbenches and stools, in their main technology classroom they had a less formal sitting area for meetings and discussions, and in the classroom used for primarily for their architecture class they had tables that stacked so the main floor space was open. *School A*'s allocated space in their classrooms and makerspace had workbenches and round tables. The makerspace at *School B* had many tables and chairs with space to collaborate. Finally, *School D* invested in folding, round, portable tables to facilitate collaboration in their makerspace. The mobility of the round tables from *School D* also highlight the second theme, mobility of resources and students.

The second theme presented in each school through the collection of data, the interviews at each school specifically mentioned the importance of being able to move their resources and students. The administrator at *School A* spoke about teachers moving students from the areas arranged for direct instruction to areas in the classroom designed for collaboration. They also spoke about teachers moving students from one classroom to another when integrating and his plan to have teachers utilizing their makerspace by taking students to the room like computer labs of the past. The administrator and SMS from *School B* explained that students were able to move to spaces allocated for integration. They also spoke of taking their resources to classrooms or having teachers sign out technologies used in the integrative lessons. The STEM academy leader at *School C* said that science and math teachers had often taken their students to the technology classroom and labs to access resources for integration. They also stressed the benefits of have mobile cabinets and carts stocked with technologies and resources for STEM activities. The example they gave was of the Lego cabinet being taken to the second floor for integrative math lessons. The administrator, of *School D*, spoke about mobility in the context of students and resources, during the tour of the makerspace they pointed out that the furniture and storage were chosen because they were mobile and that it increased the versatility of the space and the utility of the resources.

They also highlighted that the classrooms were designed with garage doors as retractable walls to allow the learning space to be mobile. All the schools presented evidence that it was important that there should be space allocated to STEM activities and integration, but it was also clear that these spaces were different than the traditional classroom. Due to the allocated space being a common area shared by the school, it was a separate room from the rest and therefore teachers and students need to be able to move to the space. The separation of the allocated space also meant that the resources stored within needed to be able to move around the school building. These resources were often described as technologies used to facilitate STEM integrative lessons.

Finally, these resources used to facilitate STEM integration was the third theme present in each case. These resources were described as tools for creation, consumable materials, or technologies used to teach specific concepts. All four schools included and used 3D printers, computers with 3D modeling software, and common power tools; these technologies are important to facilitate design projects. *School A* had multiple 3D printers, and they were stocking their makerspace with common power tools; the school was also a one-to-one school where every student had access to a fully functional laptop. *School B* had these resources available in their technology classrooms and the makerspace was stocked with additional equipment for building circuits and robots. *School C* had multiple 3D printers available for integrative lessons, several computer labs, and a fully functional lab space. *School D* had 3D printers and tools in their "flex space" which functioned like a makerspace. Every student at this school also had access to their own laptops with 3D modeling software.

These three themes highlight the common answer found by each school to facilitate their STEM initiatives. The trial and error that led each school to these common themes can be a starting point for schools attempting to engage in STEM integration.

4.3 Member Checking

Trustworthiness in qualitative researcher is developed by utilizing several approaches, one of which is adhering to a member checking protocol. This protocol was meant to preserve the voice of the participants and ensure their ideas were accurately portrayed. To achieve this the researcher attempted to contact the participants of the data collection so that they could review the case summaries of their individual schools. Of the eight teachers and administrators that participated in this research study, three responded and provided feedback on the case summaries. Those three represented three of the four cases in this study. The process of member checking was a negotiation and discussion to confirm and revise the details and summary of their case, this helps the participant and researcher find a common understanding about each case. Each participant that responded confirmed their case with the researcher.

CHAPTER 5. CONCLUSION

5.1 Conclusions, Discussions, and Recommendations

Educational initiatives, for the past 50 years, have focused on improving the opportunities and curriculums for STEM subjects (National Commission on Excellence in Education, 1983). This study was proposed and completed to explore the intersection of STEM integration and school design, specifically the school environment. This chapter will cover the researcher's conclusions from the study, a discussion of the results, and the researcher's recommendations for educational practices and research opportunities.

5.2 Conclusion of Study

Each previous chapter outlined a step in this study that has led to an answer to the following question:

Research Question: What are the characteristics of high school learning environments that support integrated STEM instruction?

The exploration of this question took the form of a literature review and multi-case study. In the literature review, the researcher developed a context for the research study by exploring how STEM integration was practiced, how schools are identified as STEM schools, and what are current trends in designing STEM spaces. Schools were then identified for the multi-case study and data collected from each. Separate case summaries were written for each school and themes identified from those cases.

From the data collected several themes emerged and three were universal to all four cases. Those themes, detailed in section 4.2, were the allocation of universally accessible free space for

STEM integration, the importance for mobility of resources and students, and the need for supportive technological resources. Each school had evidence attributed to these themes and participants attributed their success with STEM integration, in some part, to the practices from which these themes were derived.

Though each school exhibited these universal themes it remains unclear if these schools are using their learning environments in the most effective way possible. These universal themes seem to answer the question for schools engaged in integration, at the moment, but it may look different as more research is conducted and more guidance is provided by educational authorities, like the Indiana Department of Education. As the research and guidance for STEM integration learning environments develops, the characteristics will most likely change.

5.3 Discussion of Results

The discussion of results for this study was divided into two sections, the first covers the universal themes and the second section refers to elements that the researcher did not find during the study.

5.3.1 Discussion of Themes

Resources used by these schools varied in amount and complexity but the technologies common to every school were robots, 3D printers, computers, and various production tools. These technologies were versatile and facilitated STEM integration with their application in lessons. Examples of these types of lessons were using 3D printers and production equipment during an English project on marketing or using robotics to teach mathematic principles. Opportunities for integration were seen in the access to resource technologies like computers, 3D printers, and other products that encourage rapid prototyping or creation. Machines like CNC routers, woodworking power tools, and hand tools that promoted a learning environment that was both authentic and adaptable. Robots are used to teach science concepts and math concepts while leveraging principles of technology and engineering. 3D printers allow teachers to do more design projects because they can rapidly prototype student solutions. Computers can be used to access scientific simulations, teach math, or integrate reading and writing. In reviewing the literature about STEM integration, one of the core tenets of the method is giving students an authentic experience. When designing a product, or solution to a problem, students need the ability to physically prototype and test their ideas so that the experience can be wholly authentic. These experiences build on each other and create a body of knowledge and experience that cannot be acquired without the physical experience. To have these experiences, schools need the space to utilize the equipment and space for students to store their projects.

The allocation of space was important because a hallmark of integration is the use of authentic experiences which can take more time and space than a traditional classroom can afford. Each school has space designated for the STEM experiences, a place for the production equipment and space for student work to be done and stored. Many of the authentic experiences that students engage in, with STEM integration, take multiple class days or even multiple class weeks and that means students need a place to store their work in progress. While they are working on these projects, students need a space to engage in the design process, as well as the production process. The schools in this study had areas that promoted collaboration through the inclusion of large tables or workbenches, whiteboards, conference tables, presentation equipment, and ample seating. The design process is diversity in its execution, so the learning environments are also diverse in how the space is allocated. In *School C*, the area designated for STEM integration included whiteboards, tables, chairs, desks, coaches, screens, workbenches, and a laboratory space. Spaces like this allow students to utilize the space most applicable to their immediate need by relocating between stages of the design process. This mobility was also a theme seen throughout the various case studies.

The mobility of resources and students allows for these authentic experiences to happen in the appropriate spaces and be accessible to a greater number of students. Depending on the activity or experience that the educator is offering, either the students or materials will move. Some resources, like laptops and robot kits, can be transported to different classrooms or spaces to create a temporary STEM learning environment. Mobility as a theme, however, is seen more as the movement of students from one space to another. This movement can be seen when students need to engage in brainstorming or decision making so they move to the whiteboards, but another group needs to test an idea, so they are working in the lab portion of the learning environment.

The environment designed for STEM integration is not a traditional classroom, design for one subject. Just like the premise of STEM integration, the learning environment that is design for this method of teaching is diverse and interconnected. The learning environment is large with space allocated for various authentic experiences and the ability for students to move between these spaces. STEM integration is the intentional blending of subjects to provide a more comprehensive and authentic learning experience, the environment should mirror that intentionality. Students should have access to the technology and equipment that will provide that authenticity. They should have an ample amount of space and the type of space needed for their experiences. To engage with and utilize the learning environment fully, students should have the mobility to move through the space and find the best fit for their learning experience.

5.3.2 Discussion of Missing Elements

Though each school had a defined collaboration space, each school defined and utilized their collaboration space differently. No two schools implemented this idea the same way. Each collaboration space also felt like an added space, or separate pieces to each STEM classroom. If the integration of STEM is meant to remove the boundaries between subject areas and blend them in a common space, the use of a specifical separate space seems counter-productive. Each teacher needs to make the choice to actively reserve and utilize the space instead of it being a seamless transition that is part of the learning environment. When this space is tacked onto the expectations of the teachers, which teachers are going to use this space? How many teachers remember the space is available and make use of it when it is separated from their natural learning environment?

The lack of commonality between the schools and their learning environments seems to be correlated to the lack of guidance provided by the certification materials and initiative plans. During the collection of data, the planning of the learning environment did not seem to be a priority for most of the schools. The commonality among the schools was finding ways to define and spin their current facilities to fit the limited criteria provided in the certification material. If the schools are not planning their learning environments around the integration model but instead planning their integration around their facilities, then integration efforts could be limited.

The lack of learning environment planning could be also attributed to the lack of facility planning guides. More research would need to be conducted before a reliable and valid planning guide could be developed but a simple process for schools attempting to prepare their learning environments for STEM integration could look like the following:

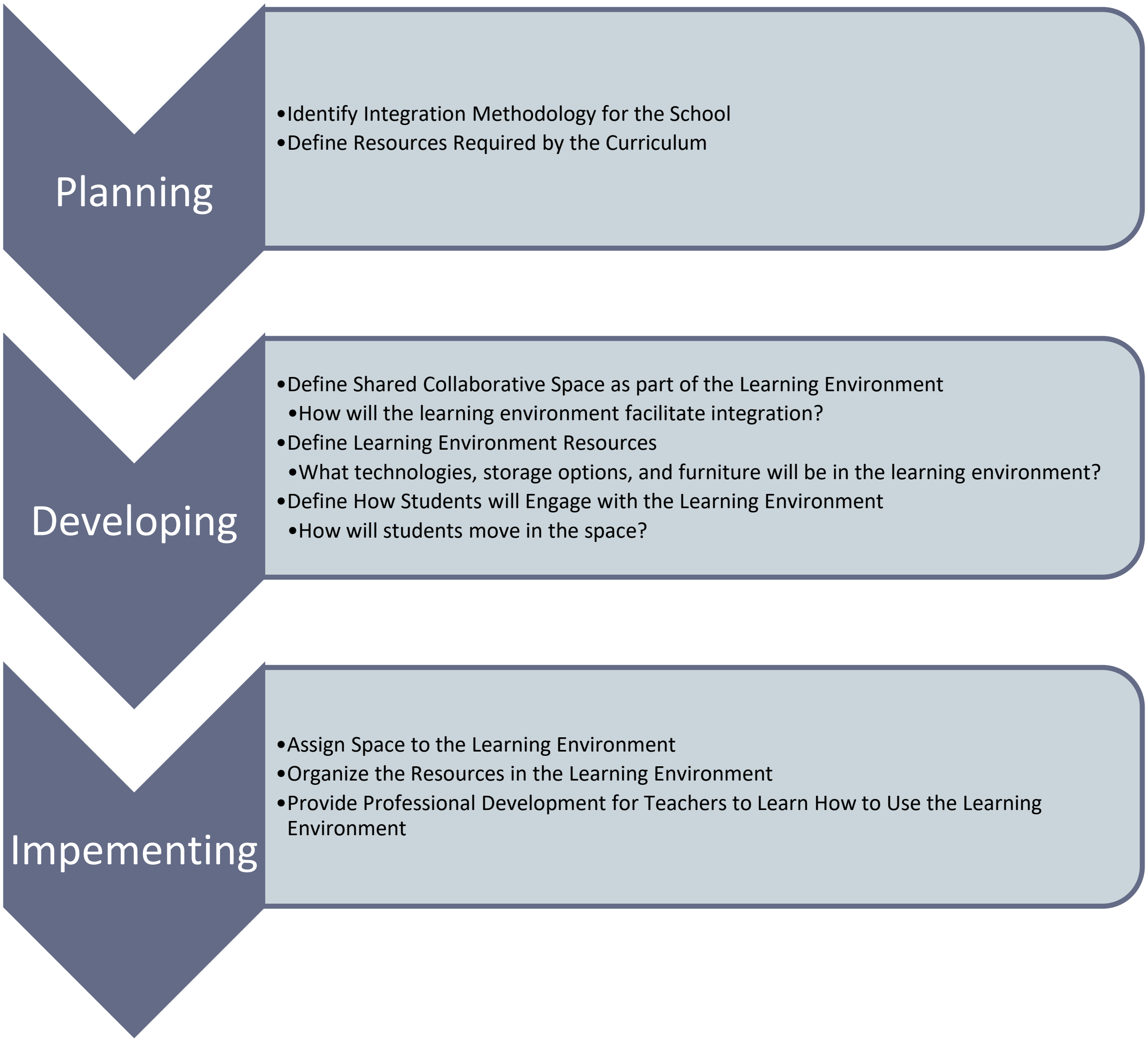

Figure 5.1 Proposed Facilities Planning Flowchart for STEM Integration

5.4 Recommendations

Themes from this study provide an insight into how STEM certified high schools design their learning environments for STEM integration. It was seen in the analysis of the data that these schools focused on three main themes when designing their space; the allocation of space, the mobility afforded students, and the resources made available to students. The significance of these universal themes has application from both an educational practice perspective and from a research perspective.

5.4.1 Recommendations for Educational Practice

Educators, seeking to develop their own STEM integration initiatives or learning environments, can take the themes identified in this paper and apply them to their efforts. Applications for educational practice, from this study, range from a preliminary understanding of STEM learning environment design to budget proposals for new equipment and facilities. Educators who are building a STEM program or attempting to initiate new STEM curriculums may need justification for their grant writing, curriculum proposals, or budget proposals.

Having a case study that identifies state certified STEM schools and their learning environments provides a model from which to begin building. Those educators can use this study to show how schools operate and identify areas of interest for learning environment design. This study does not provide specific information about the types of machines or software needed, or the specific square-footage of the learning environment. This study does provide a generalized list of key areas of concern and justification for each area.

When exploring options for a new STEM initiative it can be beneficial to understand the practices of those schools already recognized for their STEM programs. Grant writing requires an understanding of the amount or scope of materials needed, this study does not provide a breakdown of expenditures, but it does provide demographics of each school and a detailed case summary of each school. From this study, a grant writer could extrapolate the number of computers, desks, tables, classrooms, and other various equipment needed to start a program.

Educators, working or developing a STEM integration program at their school, could use this study to understand the scope of the learning environment needed for STEM integration. Each school, in this study, had their own emphasis for their STEM program and each emphasis resulted in a slightly different solution. Three universal themes were drawn from their cases, but those themes were not always applied the same way. This means that educators designing their own programs can see how these schools applied these themes and draw their own conclusions based on their needs and available resources.

5.4.2 Recommendations for Research

Researchers, conducting research projects in the area of STEM integration or learning environment design, will find significance in this research study. This study can be applied to research as identification of STEM certified schools in the state of Indiana. Researchers developing studies to look into STEM schools or their learning environments can find a list of certified schools and a case summary for each school in this study. Researchers could utilize the case summaries to identify a specific school to study or which type of STEM schools they would like to work with in their research.

This study can be used to identify variables of learning environment for future research. Research could be conducted into the significance of each theme in the development of a learning environment or the difference between these STEM integration learning environments and traditional learning environments. Researchers could develop a study to find the specific resources or equipment needed to engage in STEM integration or they could look into workflow models of the learning environments.

This study could be used to justify research into the significance of students having access to a STEM integration learning environment over a traditional learning environment. Does access to this identified learning environment affect student educational goals or student edification? This study can be a pilot for many different research opportunities in the area of learning environment design.

REFERENCES

Advancing Excellence in P-12 Engineering Education & American Society of Engineering Education (2020). *A Framework for P-12 engineering learning: A defined and cohesive educational foundation for P-12 engineering*. American Society of Engineering Education. https://doi.org/10.18260/1-100-1153-1

Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in K–12 classrooms. *Journal of Engineering Education*, , 369–387.

Carlson, L., & Sullivan, J. (2004). Exploiting design to inspire interest in engineering across the K–16 engineering curriculum. *International Journal of Engineering Education*, *20*(3), 372–380.

Creswell, J. W. (1998). *Qualitative inquiry & research design: Choosing among five approaches*. Thousand Oaks, CA: Sage Publications, Inc.

Creswell, J. W. (2013). *Qualitative inquiry & research design: Choosing among five approaches*. Thousand Oaks, CA: Sage Publications, Inc.

Dalton, D. C. & Hunt, T. C. (1979). Thomas Jefferson's theories on education as revealed through a textual reading of several of his letters. *Journal of Thought, 14*(4), 263-271.

Daughtery, M. K., Klenke, A. M., & Neden, M. (2008). Creating standards-based technology education facilities. *The Technology Teacher*, 19-26.

Dubriwny, N., Pritchett, N., Hardesty, M., & Hellman, C. M. (2016). Impact of fab lab Tulsa on student self-efficacy toward stem education. *Journal Of STEM Education: Innovations & Research*, *17*(2), 21-25.

Fab Foundation. (n.d.) *Getting started with fab labs*. https://fabfoundation.org/getting-started/

Frykholm, J. & Glasson, G. (2005). Connecting science and mathematics instruction: Pedagogical context knowledge for teachers. *School Science and Mathematics, 105*(3), 127–141.

Grubbs, M. & Strimel, G. (2015). Engineering design: The great integrator. *Journal of STEM Teacher Education, 50*(1), 77-90.

Guzey, S., Moore, T., & Harwell, M. (2016). Building up stem: An analysis of teacher-developed engineering design-based stem integration curricular materials. *Journal of Pre-College Engineering Education Research (J-PEER), 6*(1).

Hays, D. G. & Singh, A. A. (2012). *Qualitative inquiry in clinical and educational settings*. New York, NY: The Guilford Press.

Hmelo, C., Douglas, H., & Kolodner, J. (2000). Designing to learn complex systems. *Journal of the Learning Sciences, 9*(3), 247–298.

Honey, M., and Kanter, D. (2013). *Design, make, play: Growing the next generation of STEM innovators*. New York, NY: Routledge. Doi: 10.4324/9780203108352

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

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

IDOE: Compass. (2017). Demographic data on Indiana schools and corporations displayed in charts and tables. *School and corporation reports*. Retrieved from https://compass.doe.in.gov/search.aspx?q=

Indiana Department of Education. Indiana's Science, Technology, Engineering, and Mathematics (STEM) Initiative Plan. (2017). Retrieved from https://www.doe.in.gov/ccr/indiana-stem-education-science-technology-engineering-and-mathematics

Jacobs, H. H. (1989). Design options for an integrated curriculum. *Interdisciplinary curriculum: Design and implementation* (pp.13–25)*.* Alexandria, VA: ASCD Publications.

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., Putnam, S., & Ryan, M. (2003). Problem-based learning meets case based reasoning in the middle schools science classroom: Putting learning by design into practice. *Journal of the Learning Sciences, 12*(4), 495–547.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic Inquiry.* Newbury Park, CA: Sage Publications.

Lincoln, Y. S., & Guba, E. G. (1986). But is it rigorous? Trustworthiness and authenticity in naturalistic evaluation. *New directions for evaluation, 1986*(30), 73-84. doi: 10.1002/ev.1427

McGinnis, P. (2017). STEM integration: A tall order. *Science Scope, 41*(1), 1.

Moore, T. J., Stohlmann, M. S., Wang, H.-H., Tank, K. M., Glancy, A. W., & Roehrig, G. H. (2014). Implementation and integration of engineering in K–12 STEM education. *Engineering in precollege settings: Research into practice* (pp. 35–60). West Lafayette, IN: Purdue University Press.

National Academy of Engineering and National Research Council. (2014). *STEM Integration in K–12 Education: Status, prospects, and an agenda for research.* Washington, DC: The National Academies Press.

National Research Council. (2000). *How people learn: Brain, mind, experience, and school: Expanded edition.* Washington, DC: The National Academies Press.

National Research Council. (2009). *Engineering in K–12 Education: Understanding the status and improving the prospects.* Washington, DC: The National Academies Press.

National Research Council. (2011). *Successful K–12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics.* Washington, DC: The National Academies Press.

National Research Council. (2012). *A framework for K–12scienceeducation: Practices, crosscutting concepts, and core ideas.* Washington, DC: The National Academies Press.

National Research Council. (2013). *Monitoring progress toward successful K–12 STEM education: A nation advancing?* Washington, DC: The National Academies Press.

National Science and Technology Council. (2013). Federal science, technology, engineering, and mathematics (STEM) education 5-year strategic plan. Retrieved from www.whitehouse.gov/sites/default/files/microsites/ostp/stem_stratplan_2013.pdf

NGSS Lead States. (2013). Next generation science standards: For states, by states. Retrieved from https:// www.nextgenscience.org/search-standards.

Patton, K. G. (2004). *Comparative case studies of teacher change within the context of reform-based physical education teacher development*. Retrieved September 4, 2012 from ProQuest Dissertations and Theses Database (3152733).

Ravitch, D. (2013). *Reign of Error: The hoax of the privatization movement and the danger to America's public schools*. New York: Alfred A. Knopf.

Roy, K. R. & Love, T. S. (2017). *Safer makerspaces, fab labs, and stem labs: a collaborative guide*. Vernon, CT: National Safety Consultants LLC

Ryu, M., Mentzer, N., & Knobloch, N. (2018*). Preservice teachers' experiences of STEM integration: Challenges and implications for integrated STEM teacher preparation*. International Journal of Technology and Design Education, 29(3), 493-512.

Seidman, I. (2013). *Interviewing as qualitative research: A guide for researchers in education & the social sciences* (4th ed.). New York: Teachers College Press.

Shulman, L.S. (1992). *Case methods in teacher education.* New York, NY: Teachers College Press.

Strimel, G. J. (2014). Shale gas extraction: Drilling into current issues and making STEM connections. *Technology & Engineering Teacher*, *73*(5), 16-24.

Strimel, G., Huffman, T., Grubbs, M., Kim, E., & Gurganus, J. (2020). Establishing a content taxonomy for the coherent study of engineering in P-12 schools. Journal of Pre-College Engineering Education Research (J-PEER), *10*(1), https://doi.org/10.7771/2157-9288.1232

United States Census Bureau. (2017). Demographic data from identifiable areas of the United States displayed in tables as statistics. *Quick Facts*. Retrieved from https://www.census.gov/quickfacts/fact/table/US/PST045217

U.S. Department of Education (2009). Duncan endorses efforts to improve STEM education. Retrieved from www.tinyurl.com/ndzycc9

. National Commission on Excellence in Education. (1983). A nation at risk: The imperative for educational reform: A report to the nation and the Secretary of Education, United States Department of Education. Washington, D.C.

Wells, J.G. & Ernst, J.V. (2012). *Integrative STEM education*. Blacksburg, VA: Virginia Tech: Invent the Future, School of Education.

Wendell, B., & Rogers, C. (2013). Engineering design-based science, science content performance, and science attitudes in elementary school. *Journal of Engineering Education, 102*(4), 513–540.

Wang, H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research, 1*(2), 1-13.

Yin, R. K. (2003). *Case study research: Design and methods* (3rd ed.). Thousand Oaks, CA: Sage Publications, Inc.

APPENDIX A

Purdue IRB Protocol #: 1801020150 - Expires on: 01-MAR-2019

PARTICIPANT CONSENT FORM
Exploring Educational Spaces for STEM Integration
Principal Investigator- Greg Strimel, Ph.D.
Co-Investigator- Michael Coots
Technology Leadership and Innovation
Purdue University

What is the purpose of this study?

The purpose of this research study is to explain how the physical school environment impacts the integration of STEM disciplines. You are being asked to participate because you have been identified as a STEM educator in an Indiana STEM certified school, and as such have first-hand knowledge about the application of STEM integration and the aspects of the school environment.

What will I do if I choose to be in this study?

By participating in this study, you will be asked to participate in two interviews and lead the researcher around the school to facilitate the researcher's observations of the school environment outside of student class time. Once the initial interview data are analyzed, you will be contacted for a brief second interview to check the accuracy of the interview interpretations. Minimum amount of participation will be one 30-minute interview conducted face-to-face and one 30-minute interview conducted by phone. Maximum participation will be the two 30-minute interviews and a 30-minute observation tour of the school facilities. The research team for this study will be audio recording the interviews and taking photographs of the facilities (at the participants discretion) during the observation.

How long will I be in the study?

Participation in this study will be a minimum of 60 minutes over the course of two interviews.

What are the possible risks or discomforts?

There is a potential risk of compromised confidentiality. However, established measures will be conducted to help mitigate this risk. All participant data will be de-identified and stored the local disk of a password protected computer located on Purdue University's campus. Aside from the risk of compromised confidentiality, your participation in this study will expose you to no risk greater than your day-to-day activities and conversations.

Are there any potential benefits?

There are no direct benefits from this research, but your contribution could be the foundation of a future publication meant to provide guidance to educators engaging in STEM education integration.

Will I receive payment or other incentive?

This research study does not offer any type of reimbursement.

Will information about me and my participation be kept confidential?

The project's research records may be reviewed by the Principal Investigator Greg Strimel, Ph.D., and Co-Investigator Michael Coots and by departments at Purdue University responsible for regulatory and research oversight. Participant data, consent forms, and school permission forms will be de-identified and kept confidential during publication of the study's results. Participant and school data will not be included in the publication of the research findings. This information will be stored on the local disk of a password protected computer on Purdue University's campus for three years after the study is reviewed and accepted as a graduation require for the researcher, at which point all the pertinent data, audio recordings/transcriptions and photographs, and forms will be destroyed. Findings maybe cited in future publications but identifying information, participant data, and research materials will not be accessible.

What are my rights if I take part in this study?

Your participation in this study is voluntary. You may choose not to participate or, if you agree to participate, you can withdraw your participation at any time without penalty or loss of benefits to which you are otherwise entitled. Participation in this study can be withdrawn at any point before publication of the results. Participation or non-participation will not affect your employment status, none of your identifiable data will be directly shared with your employer.

Who can I contact if I have questions about the study?

If you have questions, comments or concerns about this research project, you can talk to one of the researchers. Please contact Greg Strimel, Ph.D. (gstrimel@purdue.edu, Purdue Polytechnic Institute, 765.494.7989), and Michael Coots (coots@purdue.edu, Purdue Polytechnic Institute, 910.545.7794) through email.

If you have questions about your rights while taking part in the study or have concerns about the treatment of research participants, please call the Human Research Protection Program at (765) 494-5942, email (irb@purdue.edu)or write to:

Human Research Protection Program - Purdue University
Ernest C. Young Hall, Room 1032
155 S. Grant St.,
West Lafayette, IN 47907-2114

Documentation of Informed Consent

Please check the boxes for the activities you agree to:

- ☐ Two Interviews
- ☐ Observation Facilitation
- ☐ Photographs of School facilities taken by the research team

I have had the opportunity to read this consent form and have the research study explained. I have had the opportunity to ask questions about the research study, and my questions have been answered. I am prepared to participate in the research study described above. I will be offered a copy of this consent form after I sign it.

____ ________________________

Participant's Signature Date

IRB No.________________ Page 2

____

Participant's Name

____ _____________________________

Researcher's Signature Date