ABSTRACT

A Design-Based Research Study of School-Based Makerspaces in the Discipline of Mathematics

Kurt Salisbury, Ph.D.

Mentor: Trena L. Wilkerson, Ph.D.

The Maker Movement is a trend that has gained momentum in education which places students at the center of learning where they become creators or makers of things in a makerspace. While educational leaders see the potential for the Maker Movement to support learning, researchers have called for an increased focus on exploring students' learning through making, particularly concerning the learning of specific content or disciplines. The purpose of this study was to explore the mathematics learning or mathematical proficiency of students when mathematics was taught in an educational makerspace. The study was conducted through design-based research to determine what strands of mathematical proficiency were evident as part of a makerspace experience. The participants of the study were two seventh-grade mathematics teachers and their students in four seventh-grade mathematics classes. As part of the design-based research (DBR), the researcher and the teachers partnered together to develop a pilot study and two makerspace experiences following educational making principles in the form of Resnick's 4P's – projects, peers, passion, and play- that targeted students' mathematical proficiency.

The researcher collected observation data, student artifacts in the form of student creations and written reflections, and interviews with the practitioner, which informed the study. The data were coded into the five strands of mathematical proficiency as defined by the National Research Council ([NRC], 2001). Furthermore, the data went through axial coding to determine if any other relevant themes emerged. Results from this study revealed all five strands of mathematical proficiency were evident in the observations, student artifacts, and teacher interviews collected by the researcher when students engaged in educational making. Additionally, two other themes emerged, including exploring mathematics beyond the intended learning goal and the importance of developing makerspace experiences that release content learning in conjunction with the educational making. The researcher provided implications and recommendations based on these results along with potential future areas of research.

A Design-Based Research Study of School-Based Makerspaces in the Discipline of Mathematics

by

Kurt Salisbury, B.A., M.S.Ed.

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Approved by the Dissertation Committee

Trena L. Wilkerson, Ph.D., Chairperson

Kevin R. Magill, Ph.D.

T. Philip Nichols, Ph.D.

Dorina Mitrea, Ph.D.

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J. Larry Lyon, Ph.D., Dean

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CHAPTER ONE

Introduction

“It has been the risk-takers, the doers, the makers of things … who have carried us up the long, rugged path towards prosperity and freedom” (Phillips, 2009, para. 8). President Barak Obama spoke these words in his 2009 inaugural address, emphasizing the importance of building a nation of makers. In recent years, school districts across the country have focused their attention on the Maker Movement and makerspaces because of their hands-on nature and learner-centered environments (Barton et al., 2017; Cohen et al., 2017; Dougherty et al., 2016; Halverson & Peppler, 2018; Martin, 2015; Nichols & Lui, 2019; Waldrip & Brahms, 2016). This movement is centered on ideas of open exploration, personal interest, and tinkering founded on a belief in innovation. Furthermore, it is rooted in a culture of creativity, risk-taking and making in which people develop projects through a series of iterations free from any consequence of failure. The Maker Movement is now assimilating into school-based settings, creating a dedicated space that promotes the freedom to explore, take risks, and create. It brings about a natural interest in learning that combines constructivist traditions with new technology (Hatch, 2014; Martinez & Stager, 2013). While educational leaders see the potential for makerspaces to enhance the educational experience of students through this focus on creation, there is still need for research which evaluates how to apply this potential to content-specific learning outcomes (Halverson & Peppler, 2018; Kim et al., 2018).

The Maker Movement in Schools

The Maker Movement began as a development in informal learning spaces such as libraries, museums, and community centers in which individuals would explore personal interests often with the use of new technologies such as 3-D printers, laser cutters, and computers (Dougherty, 2013). These new technologies helped foster the growth of the Maker Movement as projects that were once difficult to create could now be easily rendered. It is a return to the do-it-yourself (DIY) ethos in which physical and digital tools are blended to allow for personal creation as part of a broader "maker" community (Hatch, 2014).

K-12 schools have latched on to the movement to reinvigorate science, technology, engineering, and mathematics curricula (Martin & Dixon, 2016). Others view the Maker Movement as shifting instruction from teacher-driven to student-centered learning as well as a means to teach 21st century skills like creativity and innovation (Martinez & Stager, 2013; Wagner, 2012). Dougherty (2013), the founder of Maker Media Inc., envisions this call for making to transform education in opposition to what he calls the "rigid academic system" that is shortchanging the vast majority of students through inflexible academic structures. These structures include high stakes testing that limit creative thinking and innovation.

The movement has manifested itself into the creation of sites of innovation, or makerspaces, where individuals engage in practices of the Maker Movement in the form of passion projects. While the Maker Movement and its purpose are still being researched, the popularity of the movement is undeniable. Sheridan et al. (2014) reported "makerspaces and the collaborative design and making activities they support have generated interest in diverse educational realms" (p. 506). In 2006, there were less than 100 makerspaces worldwide, by 2016, approximately 1,400, and this number continues to grow as makerspaces continue to integrate into K-12 education (Lou & Peek, 2016). This growth in popularity has stemmed from the interest in making as a way to encourage 21st century skills through a blending of technology, hands-on learning, and collaboration and has drawn the attention of education leaders (Hatch, 2014; Kim et al., 2018). However, the lingering question remains: What learning occurs in an educational makerspace (Halverson & Peppeler, 2018; Waldrip & Brahms, 2016)?

Mathematics in Schools

Through collaboration and the development of creative projects, mathematics instruction can potentially benefit from the types of experiences associated with educational makerspaces; however, mathematical instruction is not always presented in this manner. Boaler (2016) stated, "The majority of mathematical questions that are used in math classrooms and home are narrow and procedural and require students to perform a calculation" (p. 180). In a technology age, in which procedures can be easily calculated on any number of devices, it can be argued that teaching problem-solving should be prioritized over rote mathematics (Foster, 2018). Unfortunately, in an educational system that prioritizes high stakes testing, teachers are often pressured to teach to the test (Taubman, 2009). In mathematics placing a high value on test scores often means an over-emphasis on procedural fluency and calculator steps as a quick path to success (Musoleno & White, 2010; Resnick & Schantz, 2017). In fact, research in mathematics has shown that three-fourths of mathematics assignments tend to have low cognitive demand, over-emphasize procedural skill and provide little opportunity for students to communicate mathematical thinking (Dysarz, 2018). In these types of mathematics classrooms only one type of learner, one strong in recall and computation, is served while those with other learning styles are discounted (Boaler, 2016). Furthermore, there is a call by the National Council of Teachers of Mathematics to broaden the purpose of school mathematics to focus on the positive mathematical identities of students (National Council of Teachers of Mathematics, 2020). When students have a positive mathematical identity, they see mathematics as a worthwhile endeavor that connects to other parts of their life which offers the opportunity for curiosity and creativity.

When integrated into curriculum, a makerspace experience provides opportunities for teachers to present problem-solving tasks through principles of educational making that, when integrated with mathematics content, have the potential to promote productive struggle, are accessible to a wide range of learners, encourage collaboration, and facilitate mathematical discourse (Piggott, 2018). These types of mathematical tasks also help students to develop thinking and reasoning which allow students to build meaningful conceptual understanding rather than simply baseline knowledge of a topic (Day, 2015). In fact, several studies have stated the potential of educational making in the form of collaboration, projects, and tinkering which can promote problem-solving (Martin, 2015). In this convergence of mathematical tasks and makerspaces, teachers can facilitate learning that blends the potential of making with pedagogical practices of collaboration and creation that benefit student understanding.

Theoretical Framework

The Maker Movement in education is viewed by some as a means to reimagine constructivist learning theory in which students develop knowledge through the process of creation. Constructivist theory states people construct knowledge and meaning through experiences, which in a school-based setting allows students to be active participants in learning (Cobb et al., 1998; Jia, 2000). The process of creation in educational making presents the opportunity for students to explore a variety of topics, collaborate with others on solutions, and innovate or develop new ideas (Kurti et al., 2014). Through its connection to the constructivist tradition of learner construction knowledge, theory on makerspaces is informed by the work of scholars such as Jean Piaget and Seymour Papert. Piaget (1951) believed knowledge is not transmitted but rather constructed through experience. Papert expanded on the work of Piaget and is considered the father of the Maker Movement (Martinez & Stager, 2013). Papert's (1993) theory on learning is often described as "constructionism" in which he takes constructivist theory one step further towards the action of creation. While constructivist theory holds learning takes place in the mind, constructionism is the belief that learning is more meaningful when students engage in the maker process of creation (Kafai & Resnick, 1996). The Maker Movement is an educational approach where teachers invite learners to participate as producers of knowledge through creation which places making as a tool for constructivism in education (Dougherty et al., 2016).

To leverage the theory of the Maker Movement into the classroom, Resnick (2017), a pupil of Papert, developed the Four Ps (4Ps) of educational making. The 4Ps—projects, peers, passions, and play—act as guiding principles for implementation of making in school-based settings. The center of the Maker Movement is creation through projects. Peers embody the shareable and social theory of constructivism. Passions allow for personal meaning in learning. And finally, play is the opportunity for students to learn through "tinkering" or "experimentation" (Resnick, 2017).

As students engage in educational making through principles such as Resnick's (2017) 4Ps, they have the opportunity to direct aspects of their education through the process of creation. However, in school-based-settings, teachers are concerned with what content standards students learn in academic subjects such as mathematics (Dougherty et al., 2016; Resnick, 2017). This tension of freedom in educational making and the goals of content specific instruction leads to the need of a further understanding of what students learn through making (Halverson & Peppler, 2018). In the case of a subject such as mathematics, there is a need to define what it means to learn mathematics successfully in a school-based setting.

As part of a nationwide research study on mathematics instruction, the National Research Council ([NRC], 2001) examined mathematics instruction with the specific purpose of defining successful mathematics instruction and learning. The resulting study led to framing the understanding of mathematics or mathematics learning as mathematical proficiency as a way to make sense of this complex issue. "Recognizing that no term captures completely all aspects of expertise, competence, knowledge, and facility in mathematics, we have chosen *mathematical proficiency* to capture what we think it means for anyone to learn mathematics successfully" (NRC, 2001, p. 5). The five strands of mathematical proficiency as defined by the NRC are shown in Figure 1.

The five strands of mathematical proficiency – conceptual understanding, procedural fluency, adaptive reasoning, strategic competence, productive disposition - provide a framework for understanding what students learn and what they can do with that knowledge (Schoenfeld, 2007). Conceptual understanding refers to the integrated of functional grasp of mathematical ideas. Procedural fluency is defined as the skill in fulfilling procedures flexibly, accurately, efficiently, and appropriately. Strategic competence is the ability to formulate, represent, and solve mathematical problems. Adaptive reasoning is the capacity for logical thought, reflection, explanation, and justification. Finally, productive disposition is the inclination to see mathematics as sensible, useful, and worthwhile, coupled with a belief in diligence and one's own efficacy (NRC, 2001). Together these five strands provide an understanding of mathematics learning in the form of mathematical proficiency.

- Conceptual understanding
- Procedural fluency
- Strategic competence
- Adaptive reasoning
- Productive disposition

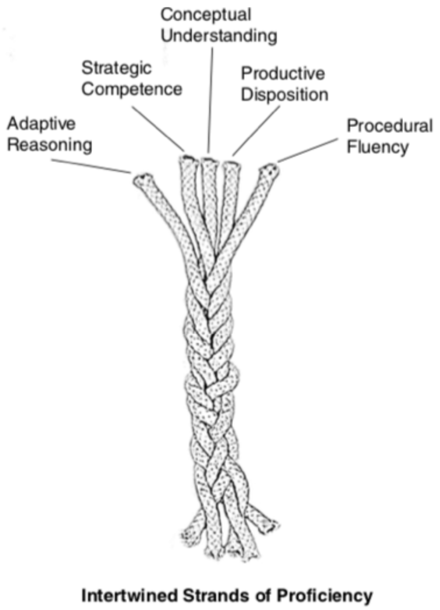


Figure 1. Five strands of mathematical proficiency (In *Adding It Up: Helping Children Learn Mathematics*, by National Research Council, 2001, p. 5. Copyright by National Academies Press. Fair use.)

It is also imperative to consider that these five strands are woven together. Mathematical proficiency cannot be divided into individual components that are learned in silos without addressing the others. Rather, mathematical proficiency is the synthesis of all five strands into the singular notion of effective mathematics learning. “Mathematical proficiency is not a one-dimensional trait, and it cannot be achieved by focusing on just one or two of these strands” (NRC., 2001, p. 116). Through the implementation of the five strands, researchers have explored the effectiveness of teacher instruction and what types of mathematical learning has taken place in the study of mathematics lessons (Groth, 2017; Langa & Setati, 2007; Pothen & Murata, 2006; Samuelsson, 2010; Suh, 2007). The five strands of mathematical proficiency provide a basis for understanding the mathematics learning of students when they engage in an educational makerspace.

Problem Statement

Educational leaders have become interested in the Maker Movement to reimagine education through the integration of hands-on learning traditions with new technologies. While this movement has spawned a myriad of “how to” books for the creation of makerspaces in schools (Fleming, 2015; Hatch, 2014; Honey & Kanter, 2013; Martinez & Stager, 2013), there is little empirical research that explores the development and implementation of makerspaces situated in school-based settings in connection with specific educational content learning (Halverson & Peppler, 2018). For example, in Felming’s (2015) *Worlds of Making*, she prioritizes establishing communities of making in schools and potential ideas for tools or supplies but offers little in the way of what students learn outside of discussing educational making as a means to support student centered learning. This is an issue as educational makerspaces continue to grow in popularity (Lou & Peek, 2016; MakerSpace, 2019) schools latch on to educational making for the purpose of blending technology and hands-on learning, fostering constructivism, and allowing students to direct aspects of their education (Dougherty et al., 2016; Hira & Hynes, 2018; Kim et al., 2018; Resnick, 2017), yet we are unsure what people learn when they engage in making (Halverson & Peppler, 2018). Without exploring school-based educational makerspace experiences, how do schools deliver on these promises? As a means of addressing this issue, the development and implementation of educational makerspace experiences by practitioners (e.g., teachers) that target students' mathematical proficiency could potentially provide some understanding of makerspaces in a school-based setting. While there have been studies conducted to explore makerspaces in non-traditional settings, to the understanding of the researcher, few, if any studies exist that explore content specific, in particular mathematics, learning of students when engaging in an educational makerspace.

Purpose of the Study

The purpose of this study was to explore the mathematical proficiency of students when mathematics was taught in an educational makerspace through the implementation of design research. Applying Resnick's (2017) makerspace principles in the form of projects, passion, peers, and play, practitioners partnered with the researcher to construct lesson makerspace experiences in which students were afforded the freedom to collaborate, experiment, and create to transform learning into a visible form while teachers provided guidance through the experience. Following students through a variety of makerspace lesson iterations, the researcher explored the types of mathematical learning generated by organizing the data using the five strands of mathematical proficiency framework (NRC, 2001). The five strands of conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition when viewed together provided a comprehensive view of students' mathematical understanding of a given topic (Groth, 2017; NRC, 2001). In particular, the study focused on the presence of the five strands as an indication of student mathematical proficiency and not the depth of any one individual strand. This framework in the form of the five strands of mathematical proficiency allowed the qualitative data from the study to give an in-depth understanding of the potential for educational makerspaces to impact student learning in the mathematics classroom (Creswell, 2014).

The study took place at one school site over the course of nine months where the researcher had an already established relationship with the teachers who took part in the study. The participants were two seventh grade math teachers or practitioners who had previous experience teaching in the school-based makerspace and eighty-seven seventh grade students. However, after the first makerspace experience the study was narrowed to one teacher and forty-one seventh grade students due to new site restrictions as a response to the COVID-19 pandemic. To explore student mathematical proficiency in an educational makerspace, the researcher sought to answer the following questions:

1. What happens when an educational makerspace experience is developed to facilitate mathematical proficiency?

This question was used to explore the development and implementation of educational makerspace experiences through applying Resnick's (2017) 4Ps of education making to address mathematics learning in the form of the five strands of mathematical proficiency.

2. What strands of mathematical proficiency are evident when facilitating an educational makerspaces experience?

This question related to the potential an education makerspace has on impacting student mathematics learning through the five strands of mathematical proficiency. As there exists little empirical research on educational makerspaces (Halverson & Peppler, 2018), exploring the mathematical proficiency of students had the potential to give an indication of student mathematics learning in school-based makerspace.

Significance

With this study, the researcher builds on the growing literature on educational makerspaces and their potential to transform the way one approaches teaching and learning (Kurti et al., 2014). Educational makerspaces combined with the making culture have positioned educators to transform some of the traditional rote activities found in classrooms into a new approach of learning by doing, steeped in the progressive education reform movement (Nichols & Lui, 2019). The majority of makerspace studies speak to the possibilities of making to improve education, but there is a need for research on makerspaces in what students learn from making (Halverson & Peppler, 2018; Hira & Hynes, 2018; Kim et al., 2018). By examining mathematics learning in the form of the five strands of mathematical proficiency in a school-based makerspace, this study contributes to the dialogue of understanding the potential in educational making and theory on makerspaces. To the researcher's knowledge, this is one of the first studies to explore mathematics content specific learning in a school makerspace based on *Adding it Up: Helping Children Learn Mathematics* (NRC, 2001), where the NRC identified the five strands of mathematical proficiency which indicate mathematical understanding.

Another important contribution from this study was the potential process of creating an educational makerspace experience that is content specific through partnering with practitioners in a design-based research tradition. Through the implementation of Resnick's (2017) principles, this researcher aimed to contribute to the practice of educational making in the form of curriculum integration, which, in the context of this study has the potential to support mathematics instruction. Often due to the pressure of high stakes testing, mathematics instruction is routinely oriented in a procedural only basis (Boaler, 2016; Foster, 2018). This creates the view of mathematics as isolated problems solved by one type of procedure causing students to only be exposed to a baseline level of mathematics and courses in which high value is placed on the ability to memorize and perform calculations quickly (Boaler, 2015; Pilgrim & Dick, 2017). This study's results give the opportunity to help forward the conversation about the Maker Movement in school-based settings and evaluate the potential for makerspaces in the teaching and learning of mathematics through the lens of the five strands of mathematical proficiency.

Limitations of the Study

While the study provided a rich description of the participants experience with educational making in a school-based makerspace, it does have several limitations. In particular, the number of participants was one limitation of the study. Qualitative research often results in fewer participants as it seeks to better understand the complex social phenomenon being studied (Creswell, 2018). Therefore, only two teachers and four classes of seventh-grade students took part in the study which limited the captured makerspace experiences by the participants. The collection of a variety of sources of qualitative data in the form of student work, observations, and teacher interviews was conducted to help address this limitation.

Second, the researcher had a previously established relationship with both practitioners in the study. The researcher served as an instructional coach and assistant principal at one point for both teachers. Thus, the responses by the teachers and the willingness to participate in the study may have been influenced by power dynamics that exists between administrators and teachers. However, the teachers in the study had participated in other research projects in past and provided input in both the design and implementation of the makerspace experiences as part of the design-based research conducted in this study. Both of the teachers had also taught lessons in the makerspace before so teaching using constructivist practices were not uncommon to them.

Finally, there were several delimitations for this study which were implemented by the researcher to help define the scope and purpose of the study. One delimitation was the site itself in that it had to be a site with an existing makerspace. As such, the teachers had some prior experience teaching in the space. Sites without a designated makerspace were not considered for the study. Another delimitation was the mathematical content. It was necessary to bound the study to one grade level in order to be able to have defined mathematical content learning goals to determine the mathematical proficiency of the student participants. These delimitations were important to focus the study and apply the appropriate theoretical framework.

Conclusion

The Maker Movement remains an emergent field in education with the need for more research in examining what individuals learn through making (Halverson & Peppler, 2018). Studies suggest there is potential in making to blend hands-on traditions with new technologies when it is integrated into schools and curriculum (Barton et al., 2017; Dougherty et al, 2016; Fleming, 2015). However, there is a need for further research related to educational making in the area of content specific learning in mathematics (Waldrip & Brahms, 2016). The goal of this study was to address these gaps in the literature in relation to educational making in the content specific area of mathematics through DBR.

CHAPTER TWO

Review of the Literature

The purpose of this chapter is to unpack the growing trend of the Maker Movement, educational makerspaces, and their potential for classroom application. The researcher describes mathematical proficiency as it relates to student understanding of mathematics as defined in *Adding It Up: How Children Learn Mathematics* (NRC, 2001). By detailing the strands of mathematical proficiency, the researcher clarifies the student learning outcomes being explored. Finally, the researcher summarizes the current state of research on the Maker Movement and in doing so details where this study fits in the growing work on educational makerspaces.

The Maker Movement

The Maker Movement is built on the power or philosophy of learning by doing. This movement promotes a culture of creativity, risk-taking, and innovation or “making” (Halverson & Peppler, 2018; Martinez & Stager, 2013; Fleming, 2015). Making is viewed as a way for people to come together in a learning community where individuals can share knowledge, passions, and creations (Kim et al., 2018). The locations of these community gatherings, be it physical or digital (e.g., online community such as the Massachusetts Institute of Technology’s scratch programming website), is referred to as a makerspace, and the individual participants are often referred to as “makers.” Through engaging in a makerspace, makers not only share ideas and passions, but they also participate in creative learning experiences that have the potential to transform people from consumers of knowledge into creators (Resnick, 2017).

While this movement does not have a defined beginning, there were several key contributors that fostered the modern emergence of the movement to become the trend that it is today. The first being the publication of *Make* magazine, the bimonthly magazine for DIY makers was published from 2005 until 2019. The founder of Maker Media Inc., Dale Dougherty, started *Make* as a way to spread the DIY philosophy and the magazine targeted people who enjoyed making things as a hobby (Dougherty et al., 2016). The message for *Make* and Maker Media was simple: Think creatively about hardware and repurpose old parts into something new (Corcoran, 2019). Dougherty (2013) was the first person to popularize the phrase "Maker Movement" as a term to refer to this type of open creation or as he calls it "experimental play" (p. 7). Through experimental play makers learn the orientation of being a maker, which is referred to as the "maker ethos" or "maker mindset." These phrases adhere to the overarching theme of the Maker Movement, which is one of creativity through design, play, and innovation through the process of making (Nichols & Lui, 2019).

Another important contributor to the spread of the Maker Movement was the advent of Maker Faire (Dougherty, 2013). Stemming from *Make*, Maker Faire is an event for makers to share their DIY projects and inventions with other makers. The first Maker Faire was held in 2006 and has led to Maker Faires all over the world. This showcase has allowed makers to connect in a physical sense and has fostered the growth of the Maker Movement by creating a community where makers bring their projects and innovations out of their homes and shops to be shared with others. The Maker Movement gained even more notoriety when former President Obama held the first ever Maker Faire at the White House (2014) as part of a National Week of Making. As part of the event, Obama declared, "I am calling on people across the country to join us in sparking creativity and encouraging invention to their communities" (para. 4). In his speech, Obama calls for innovation. He calls for the country to embrace this movement as a means of advancement. This potential for innovation is why the Maker Movement has come to be seen as a new type of learning phenomenon assimilating itself into schools to allow students to engage in creative learning experiences (Kim et al., 2018; Martinez & Stager, 2013: Resnick, 2017). To further understand the Maker Movement, it is important to explore the roots of the movement and the underlying philosophies that have led to this popular educational trend.

Maker Movement Philosophy

While the advent of making in education is considered a newer phenomenon, the ideas behind the movement can be linked to past philosophies and theories (Labaree, 2005). Educational theorists have been advocating for student experiences and creation of knowledge as a means for students to engage with learning for over 100 years. One of the most logical places to begin to understand the educational maker philosophy is with the work of John Dewey and other like-minded progressives. While it is difficult to define "educational progressivism" as a singular philosophy or movement (Labaree, 2005), the work of progressive educators during the late 19th and early 20th-century laid the foundation for the Maker Movement (Martinez & Stager, 2013).

Dewey (1902), the father of American progressive education, believed children had to participate actively in their own learning in order to experience the world and curriculum with tools. In 1926 Dewey wrote, “Tools are the expression of the man/environment interaction; by their means and consequences of action are adapted to each other” (as cited in Hausman & Douglas, 1999, p. 101). While Dewey meant that “tools” could be anything, his idea of active interaction of students with tools is at the heart of the Maker Movement. A makerspace provides students the opportunity to work with tools and digital technology that may not be possible elsewhere (Martinez & Stager, 2013). It gives students a place to understand how these tools and technology can play a role in their education and their future.

Dewey (1902) also detailed the importance of experience in a child’s education. The experience of a student is a driving force behind the Maker Movement. A makerspace is an area where students can go and have the experience of creating something. Through creation students have the opportunity to learn, explore, and tinker. It is a challenge though to blend the creation that takes place in a makerspace with the prescribed curriculum. It is an idea that Dewey believed to hold value in education. Dewey addressed the issue of experience with curriculum when he stated, “Hence, the facts and truths that enter into the child’s present experience, and those contained in the subject-matter of studies, are the initial and final terms of one reality” (p. 12). Part of the lure of the makerspace in education is the belief that it has potential to provide a space for the marriage of the two—experience and curriculum—to occur. It is an extension of learning through a disciplinary lens, whether it be science, math, history, or any subject in which students apply disciplinary knowledge to solve a problem or create a product (Bolkan, 2018). Dewey’s progressive theories of education planted the seeds for the Maker Movement to grow.

Piaget (1951), Swiss physiologist and epistemologist, clarified the teachings of Dewey and others to develop his theory of constructivism. Constructivist theory holds students are no longer just passive recipients of knowledge but are a part of the process of learning (Jia, 2010). Students must build on previous experience to understand or make sense of the curriculum. Piaget (1951) argued, "Each time one prematurely teaches a child something he could have discovered himself, that child is kept from inventing it and consequently from understanding it completely" (p. 51). The power of discovery or creation of knowledge is embedded throughout the Maker Movement (Papert, 1993). Through moving students from consumers of knowledge to creators by making, students build understanding of content that expands on student prior knowledge. It is the opportunity to create and tinker in a makerspace which leads to an opportunity for discovery (Hatch, 2014).

Another important contributor to the constructivist philosophy of education was the Russian psychologist Vygotsky (David, 2014; Moll, 2015; Turuk, 2008). His contributions to constructivism which have been applied to the Maker Movement is in the role of social interaction as a process of cognitive development (Moll, 2015). Vygotsky details three major themes of constructivism in the form of social interaction, zone of proximal development, and the more knowledgeable other (David, 2014). As part of his philosophy, Vygotsky (1978) viewed social interaction as the beginnings of cognitive functions. People construct knowledge through dependent interactions with others (Turuk, 2008). Therefore, if knowledge is dependent on social interaction there is a more knowledgeable other that has a higher understanding in relation to the concept being learned. When the dependent learner finds themselves in between what they can do and what they cannot, they enter the zone of proximal development in which the construction of knowledge can occur through social interaction (Moll, 2015). The role of social interaction and the transmission of knowledge is part of the maker ethos which is considered the rebirth of constructivism in education (Donaldson, 2014).

Both the educational theories of progressivism and constructivism place student experience and student creation or discovery of knowledge as important parts of curriculum. The connections between progressivism and constructivism helped Papert (1993), who is considered the father of the Maker Movement, develop his ideas on the educational making philosophy and the importance of student creation in schools (Stager & Martinez, 2013). His vision of constructivism is often referred to as constructionism as he adds the aspect of learning through engaging in the construction of meaningful products to the constructivist ethos of students creating knowledge (Kafai & Resnick, 1996). "The Maker Movement in education is built upon the foundation of constructionism, which is the philosophy of hands-on learning through building things. Constructionism, in turn, is the application of constructivist learning principles to a hands-on learning environment" (Kurti et al., 2014, p. 8). The Maker Movement is a tool of the constructivist philosophy of learning through the environment, social interactions, and creation that students experience when they engage in making.

Fifty years ago, Papert made the argument for a type of maker lab for students in which they could engage, interact, and create (Papert & Solomon, 1971). In the paper, Papert and Solomon (1971) wrote at the Massachusetts Institute of Technology, they discussed their vision for a place where students can create and invent. Papert and Solomon describe their vision of a school computation laboratory when they state, "The laboratory will have a supply of motors, solenoids, relays, sense devices of various kids, etc. Using them, the students will be able to invent and build an endless variety of cybernetic systems" (p. 39). Papert created his laboratory as a space where student experience, application of tools, agency, and discovery could take place. This vision is aligned with the theories of Dewey (1902), Vygotsky (1978), and Piaget (1951) in the form of social construction of knowledge through student experience. It is what the modern makerspace has the potential to become.

Papert further believed making is the means to realize the progressive educational ideas of Dewey and others (Kafia & Resnick, 1996). The Maker Movement creates unique learning experiences which is at the heart of the progressive movement in education. Papert (1996) stated,

> It is 100 years since John Dewey began arguing for the kind of change that would move schools away from authoritarian classrooms with abstract notions to environments in which learning is achieved through experimentation, practice and exposure to the real world. (p. 7c)

Dewey (1902) and Papert's (1993) visions of a different type of classroom experience have the potential to be realized through the Maker Movement. It is a vision of student creation in informal environments that has the potential to support learning outside of traditional education. Papert (1993) argued,

> Traditional education codifies what it thinks citizens need to know and sets out to feed children this "fish." Constructionism is built on the assumption that children will do best by finding ("fishing") for themselves the specific knowledge they need; organized or informal education can help most by making sure they are supported morally, psychologically, materially, and intellectually in their efforts. (p. 139)

When engaged in this type of learning students are supported to construct knowledge that has the potential to be more meaningful than rote facts transmitted to students. However, can the promise of the Maker Movement as indicated by Papert be realized in schools?

The Maker Movement leans on educational theories of progressivism and constructivism and applies them to educational settings. It is this new type of learning environment in which the philosophies of Dewey (1902), Piaget (1951), Vygotsky (1978), and Papert (1993) can be applied to a modern education setting. While these theories help shape the philosophy that underpin the Maker Movement, there needs to be further exploration of making in school-based settings. In the next section, the researcher details the properties of the Maker Movement as it applied to schools, provides a framework for assimilating making into the classroom, and how it could potentially fit with mathematics curriculum.

Educational Makerspaces

The Maker Movement is the promise of a community-based experience in which participants create projects, share knowledge, and learn through social interaction (Dougherty, 2013). The location of these experiences or makerspaces, as they are often referred, comes in a variety of forms. A makerspace is a place of people coming together for the purpose of creative production in the form of projects in which there is a blend of physical and digital technologies, both old and new, in which knowledge is accessible to all through social interaction and a share sense of community (Dougherty, 2013; Gershenfeld, 2007; Peppler & Bender, 2013). An educational makerspace is a makerspace located inside a K-16 setting or other type of educational institution with the purpose of facilitating a type of learning experience in which students are afforded the freedom to be makers. Fleming (2015), an educator and leader of the Maker Movement, defines a school-based makerspace as “a place where young people have an opportunity to explore their own interest; learn to use tools and materials, both physical and virtual;

and develop creative projects" (p. 5). Fleming's definition provides context for how a school-based makerspace was viewed in the current study. A school-based makerspace or educational makerspace is a place where students can create projects through the use of a variety of tools in an open-learning environment centered on social interaction.

When teachers integrate the use of makerspaces into their curriculum, they create a place for students to develop creative projects to explore content. Martinez and Stager (2013) describe it as, "When exciting new technologies combine with hands-on traditions, your classroom becomes a makerspace where learning soars" (p. 3). This open-learning environment or educational makerspaces presents a myriad of learning opportunities where students are empowered to become partners with each other or teachers in learning (Kim et al, 2018). It is in this type of setting that this researcher aims to explore the learning of mathematics when students engage in the creation of projects.

As described earlier, an educational makerspace is a place of creation that blends hands-on learning with new technologies where students work together to create a project. To further define educational makerspaces, Resnick (2017), a scholar at the Massachusetts Institute of Technology and student of Papert, developed a framework for educational makerspaces which he calls the "4Ps" of making. The 4Ps stand for projects, passion, peers, and play (Resnick, 2017). This framework acts as a guide for educators in implementing the Maker Movement into an educational setting. Projects are part of the belief in making that students need to be active in the creative process. The opportunity to create something through the completion of a project is a hallmark of the Maker Movement. Resnick argued students not only learn by doing, but are engaged in designing, building, and creating when in a makerspace. Through individualizing instruction in a makerspace, students can discover their passion. Resnick calls for teaching to not only be structured with “low floors” or low-entry points for all students and “high ceilings” in which students can extend their understanding, but also with “wide walls.” By wide walls, Resnick means that students should be free to have multiple pathways to learning. There should not be a singular course to lesson objectives, but rather a multitude of possible solutions to educational tasks presented to students. Learning from others and sharing knowledge is an important part of making. By allowing students to share their expertise with their peers’ teachers can create a learning community where are all students are valued. Finally, play is part of the process of making. Resnick calls for educators to bring play or the ability to explore through tinkering into the classroom. Tinkering is the general pedagogy and approach to making in the classroom (Resnick & Rosenbaum, 2013).

Resnick’s (2017) framework is closely aligned to another type of approach to making in the classroom labeled as, “Makification” (Cohen et al., 2017, p. 3). Makification is described as, “a framework for leveraging the Maker Movement into formal education” (p. 3). The creators of this framework built on the work of other researchers who studied educational makerspaces and the constructivist philosophy of education. Cohen et al. (2017) frame educational making into four principals detailed as creation, iteration, sharing, and autonomy. These align with Resnick’s (2017) framework in that creation is described as making of a new product in the form of a type of project. In the *Maker Movement Manifesto*, Hatch (2014) lists making or creating as the first principal, both frameworks begin with the tenant of making. Iteration, the second part of “Makification,” is akin to play, in which students are free to tinker and experiment with design through a process of trial and error. Sharing parallels with peers as much of the Maker Movement is centered around the collaboration of ideas. Finally, as Resnick (2017) describes it, autonomy is where students have the opportunity to explore personal motivations or passions. These two frames—being nearly identical—set out to accomplish the same goal in bringing the power of the Maker Movement into the classroom. In this study, the researcher implemented Resnick's framework as the guiding principles of educational making but also drew from "Makification" as a secondary set of guidelines.

While the combination of these four properties of educational makerspaces is a varied approach to applying the process of creation to the classroom, the individual components have been studied as a means of improving mathematics instruction and learning outcomes. For example, projects and project-based learning (PBL) have been an educational mindset that have origins in the progressive movement of John Dewey and his pupil William Heard Kilpatrick, who in the beginning part of the 21st century called for students to engage in projects that connected learning to social and physical environments (Pecore, 2015). According to S. Bell (2010), "PBL is an approach to instruction that teaches curriculum concepts through a project" (p. 41). More recent studies in relation to project-based learning have shown PBL has the potential to increase student engagement, foster a constructivist learning environment, improve student ability to apply mathematical concepts, and prepare students to be 21st century learners (Boaler, 1999; Han et al., 2015; Savery & Duffy,1996). The National Council of Teachers of Mathematics (NCTM) have also published a guide to facilitating PBL in the mathematics classroom as a means of inquiry-based learning where students are given a project at the beginning of a unit of study, and the culmination of the course work is a completed project including traditional practice problems and quizzes interwoven (Lee, 2018). PBL and educational making both subscribe to the power of creation as a tool of constructivism for students to develop knowledge.

PBL has much in common with educational making, however, PBL may or may not include all the principles of educational makerspaces. The Buick Institute for Education (2019) defines PBL as ". . . a teaching method in which students learn by actively engaging in real-world and personally meaningful projects" (p. 1). This is similar to the maker approach of passion and projects; however, PBL does not stress the community approach to learning found in educational making or the ability to tinker or alter the design. It may be present, but not a necessary component to PBL as it is in educational making. Still others view educational making as more open, with a less structured approach to project creation (Dougherty, 2013; Resnick, 2017; Stager & Martinez, 2013).

When students engage in activities that are meaningful and relevant, classrooms can create a setting that allows students to explore their passions and voice a sense of agency. In a recent study, Barton and Tan (2018) found making has the potential to foster student agency or the opportunity for students to explore personally meaningful topics or tasks when students engage in a community-based makerspace through meaningful creation. However, many times students are forced to surrender their agency to the rote procedures found in mathematics classrooms (Boaler & Greeno, 2000). Boaler (2002) argued there is a need for personal identity, or seeing oneself in the math, in mathematics as it heightens a student's ability to understand knowledge and practice in mathematics.

The National Council of Teacher of Mathematics or NCTM (2020) has also called for the broadening of school mathematics to cultivate student mathematical identity or agency. NCTM further details the importance of engaging middle school students in meaningful mathematics learning experiences as a foundational piece of school mathematics programs. By centering instruction on student passions, students can approach mathematics through personal connections or culture which increases the value of multiple ways of solving problems and the freedom for students to use home languages freely in the classroom (Barton et al., 2017; Civil, 2018). While passion has been found to be important in the mathematics classroom; like projects, it is only part of educational making.

When considering the idea of peers, the power of collaboration has been well researched in the classroom. Vygotsky's (1978) work on social developmental theory as part of the philosophy of constructivism defines the importance of socialization in the form of the zone of proximal development and reliance on the more knowledgeable other. Making creates opportunities in the form of collaboration in which students take part in a learning community (Kim et al., 2018). Fawcett and Garton (2011) researched the effects of collaboration on students' abilities to problem solve by applying the theories of both Piaget and Vygotsky and found students who collaborated collectively with other students scored significantly higher on problem-solving tasks versus those who were not allowed to speak with peers during the problem-solving process. Collaboration also engages student in the essential practices of mathematics of justifying and representing (Ball & Bass, 2000). Furthermore, when the classroom shifts from teacher-centered to student-centered, collaboration plays a key role in supporting the learning of all students

(Cicconi, 2014). There is also the belief that doing and thinking mathematically is best done as a social practice rather than an individual pursuit (Knapp et al., 2013).

In a study conducted by Moss and Beatty (2006), the researchers explored collaboration on pattern tasks with fourth grade students. The purpose of Moss and Beatty's study was to explore student-generated collaborative workspaces in relation to understanding patterns in mathematics. As educational making subscribes to the power of peers, collaboration has been shown to have benefits in the mathematics classroom. "Specifically, we have been investigating how Knowledge Forum can support students in working collaboratively to find algebraic rules for mathematics generalizing patterns" (Moss & Beatty, 2006, p. 442). Knowledge Forum is a type of software that allowed students to collaborate digitally when students were outside of class. The philosophies of the Maker Movement or maker ethos can flourish in this type of online environment. Resnick (2017) started the online community of Scratch which functions as a type of digital makerspace where students collaborate and share coding projects. The results of the study suggest this type of collaboration on patterns supports mathematics learning in that students presented justifications for their solutions when collaborating with their peers and students were able to engage in mathematical discourse on multiple approaches to solving problems (Moss & Beatty, 2006). There is power in collaboration as a means of improving learning in the mathematics classroom, and it will be a part of the exploration of the mathematics learning in an educational makerspace for this study.

In the last property of making—play, students have the freedom to learn from mistakes through the process of trial and error in educational making (Dougherty, 2013). This type of pedagogical approach is often referred to in the maker community as “tinkering” (Resnick, 2017). Tinkering (e.g., play) allows students to investigate ideas on their own terms. The ability to tinker or learn from mistakes has benefits in mathematics as research has shown that trying multiple approaches to problem solving improves understanding in mathematics. The work of Boaler (2016) and Dweck (2015) on growth mindsets in mathematics shows students learn more from mistakes and working through them than they do by simply finding the right answers. Research has also shown that when students address mistakes or try multiple strategies, they become more adept at developing problem solving skills and perseverance towards difficult mathematics problems (Rushton, 2018). “Tinkering and making have recently been taken up by educators as potentially rich intellectual activities, and as tools for broadening engagement in a variety of disciplines, including STEM (science, technology, engineering and math)” (Vossoughi et al., 2013, p. 1).

Mathematics benefits from tasks that are open to different types of thinking (Boaler, 2016). Not only does tinkering support students’ ability to learn from mistakes, it also allows them to discover multiple solutions to a problem. Part of the maker ethos is once a solution is found, how can that solution be made better, for example, improvement through iteration (Cohen et al., 2017). Play is also how mathematics concepts are often introduced to students at an early age. Trawick-Smith et al. (2017) studied the effect of playing with blocks in early childhood and suggested the complexity of the structures children are able to construct associated with growth in math learning. The freedom afforded to students through play or “tinkering” has shown promise to improve mathematics learning outcomes. It was in the totality of these four properties of projects, passion, peers, and play in relation to the development and implementation of educational makerspaces that this researcher explored.

When making is brought into the curriculum, there is a natural tension created between the philosophy of the Maker Movement and school-based curriculum. The goal of making is centered on the product students create rather than a prescribed set of learning outcomes (Halverson & Peppler, 2018). This is important because there is a "growing demand from educators and policymakers for definitions, measures, and guidelines for designs that capture the qualities of making as a learning process" (Brahms, 2014, p. iv). This tension brings about the need for the framework as constructed by Resnick (2017). Using this framework as a guide provided the needed direction in facilitating the educational makerspace experiences afforded students in this study and provided an exploration of mathematics learning.

Mathematical Proficiency

The goal of this study was to explore the mathematical learning of students as they engage in mathematics learning in an educational makerspace. To clarify the outcomes of the study, there was a need to define effective mathematics learning. In 1999, the NRC (2001) gathered a group of experts to examine research on mathematics instruction and define successful mathematics learning. The council settled on defining effective mathematics learning as mathematical proficiency. "Recognizing that no term captures completely all aspects of expertise, competence, knowledge, and facility in mathematics, we have chosen *mathematical proficiency* to capture what we think it means for anyone to learn mathematics successfully" (NRC, 2001, p. 5). Mathematical proficiency is further defined as the interweaving and interdependence of five strands of mathematics learning. The five strands as defined by the NRC (2001) are “conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition” (p. 5). The five strands being weaved throughout one another are of paramount importance (see Figure 1). Mathematical proficiency is not a singular idea but rather a combining of the five strands to create effective mathematics learning. “The most important observation we make here, one stressed throughout this report, is that the five strands are interwoven and interdependent in the development of proficiency in mathematics” (NRC, 2001, p. 106). The definitions of the five strands are explained in the NRC’s book, *Adding it Up: Helping Children Learn Mathematics.* This work has impacted mathematics researchers, curriculum developers, educators, and policy makers in how mathematics instruction should be implemented and measured (Graven, 2012). The five strands have allowed researchers to explore the effectiveness of teacher instruction and what types of mathematical learning have taken place in the study of mathematics lessons (Groth, 2017; Langa & Setati, 2007; Pothen & Murata, 2006; Samuelsson, 2010; Suh, 2007).

Exploring the five strands individually will provide a depth of understanding of the totality of mathematical proficiency. The first strand of conceptual understanding “refers to a functional grasp of mathematical ideas. Students with conceptual understanding know more than isolated facts or methods” (NRC, 2001, p. 118). It is gaining mathematical knowledge that is connected to the bigger picture or understanding of how mathematics works. Moser and Chen (2016) define conceptual understanding as “where children can grasp ideas in a transferable way” (p. 1). Conceptual understanding is more than a set of definitions, facts, or steps in solving a problem. It is the understanding of the principles and interrelations of the units of knowledge that consist within a domain of mathematics (Rittle-Johnson et al., 2001). Conceptual understanding is flexible and generalizable, not bound to a specific problem type and it enables students to construct meaning of mathematics in physical situations (Niemi, 1996). It is being able to understand mathematics concepts in a broader sense free from rote steps. Students who are taught for conceptual understanding are more likely to be engaged in what they are learning and will develop a sense of how interrelated concepts fit together.

Procedural fluency is the “knowledge of procedures, knowledge of when and how to use them appropriately, and skill in performing them flexibly, accurately, and efficiently” (NRC, 2001, p. 121). It is the skill of performing computations in mathematics efficiently and accurately to allow for the finding of a solution. NCTM (2014) defines procedural fluency as “the ability to apply procedures accurately, efficiently, and flexibly; to transfer procedures; and to recognize when one strategy or procedure is more appropriate to apply than another” (p. 1). Procedural fluency is the ability for students to apply the correct process efficiently and the actual action of completing the appropriate steps. It is often considered to be an understanding of a set of rote algorithms that are used to complete one type of problem (Rittle-Johnson et al., 2001). When a student has procedural fluency, they not only have the ability to perform calculations but analyze the calculations of others. Thus, procedural fluency is often associated with the assessment of basic facts and curriculum aligned measurements (Geary, 2006).

Strategic competence refers to “the ability to formulate mathematical problems, represent them, and solve them (NRC, 2001, p. 124). In other words, can students recognize a problem, interpret the problem into a mathematical situation, and then solve it correctly. It is about problem-solving and problem formulation. “Mathematical problem solving is central to mathematics learning. Genuine problem-solving involves people in accepting the challenge of tackling an unfamiliar task for which they know no obvious solution” (Groves, 2012, p. 123). When students engage in strategic competence, they discover the mathematical problem and are able to translate the problem into a solvable mathematical situation. Polya (1945) outlined a guide of problem-solving techniques in *How to Solve It* which details a process of understanding the problem, followed by discovering a connection between the given data and the unknown, executing a plan for finding the solution, and then examining the answer obtained. Strategic competence is the ability to recognize a problem, formulate an approach, and then arrive at the correct answer. Students who demonstrate strategic competence will have a basis of both conceptual understanding and procedural fluency (NRC, 2001).

Adaptive reasoning “refers to the capacity to think logically about the relationships among concepts and situation” (NRC, 2001, p. 129). It is the manifestation of being able to justify the outcome. To think mathematically is to not only be able to engage in problem-solving but to also be able to prove one’s work (Schoenfeld, 1992). Students need to be able to make sense of what they discover as they learn mathematics. Without adaptive reasoning, students will fall victim to answers that are mathematically correct but make little sense in the situation in which they are solved. For example, Seely (2015) posed a mathematics question in relation to the number of buses needed to transport students. Several students calculated the answer as a decimal, while the processes conducted to find their answer were mathematically correct it did not make sense in the situation that they were presented. When students have the ability to apply adaptive reasoning, they make sense of mathematical concepts as they construct problems, problem-solve, and justify answers to problems (Suh & Seshaiyer, 2017).

Productive disposition "refers to the tendency to see sense in mathematics, to perceive it as both useful and worthwhile, to believe that effort in learning mathematics pays off, and to see oneself as an effective learner" (NRC, 2001, p. 131). It is often challenging for students to develop productive disposition as it requires frequent opportunities to makes sense of mathematics. It has also been shown that teachers heavily influence productive disposition through their mathematical knowledge and in the way teachers present instruction (Jacobson & Kilpatrick, 2015). When students engage in mathematics in school they are not only learning about mathematics, but also what it means to be a learner and doer of mathematics (Boaler, 2002). Students who have a productive disposition towards mathematics are more likely to be motivated to attempt difficult mathematics which can lead to a more in-depth understanding of mathematics concepts or higher level of mathematical proficiency (Jansen, 2012). There is an important connection here between mathematical proficiency and educational makerspaces. Making is a way to present curriculum in a new and innovative way (Hatch, 2014), and productive disposition relies on the way mathematics is presented.

The five strands of mathematical proficiency provide a basis for understanding the mathematics learning of students when they engage in learning in an educational makerspace. Research has shown the five strands are an effective framework for understanding the learning of students in mathematics classrooms. In applying this framework, Samuelsson (2010) used the five strands to assess the impact of teaching approaches learners’ progress through in the first 5 years in school. His study gave an in-depth exploration of mathematic learning of students when implementing the mathematical proficiency framework based on the methods of instruction by teachers. In the current study, the researcher applied the framework as well to explore the mathematical learning of students in an educational makerspace.

In a study by Langa and Setati (2007), the researchers used the five strands to analyze data gathered from students on mathematical tasks for the purpose of exploring the impact of learners’ home language. The five strands allowed the researchers to understand the learning of students based on their home language in conjunction with classroom instruction. In another study conducted by Graven (2012), the researchers used the five strands framework to measure learning of mathematics students in third grade while exploring the role of teachers on student productive disposition. While Graven focused on the strand of productive disposition, the other four were measured as well because of the interwoven structure of the five strands. Groth (2017) used the five strands framework as means to help preservice teachers understand the learning of students in mathematics. Again, like the previous studies, the five strands of mathematical proficiency allowed the researchers to make sense of student learning. Through analyzing learning outcomes, the teachers were able to provide targeted instruction for students. Suh (2007) applied the framework to understand and improve the mathematical proficiency of students. Similar to Groth’s (2017) research, Suh (2007) used the framework as a means to create meaningful mathematics lessons for students.

While there are other ways to consider learning, the application of the five strands provides the necessary understanding of student mathematics learning or mathematical proficiency to explore the educational makerspace experience of students. In the methodology section, the researcher will go into further detail into the types of data to be collected and the process in which it will be analyzed using the fives strand of mathematical proficiency.

Research on Educational Makerspaces

Understanding the current state of research on educational makerspaces can help explain the potential educational makerspaces have on transforming the classroom and the need to explore learning in educational making. Halverson and Peppler (2018) summarized the current state of educational making and called for a need of further research in both how people learn to make and what they learn from making. They also detail why studying the Maker Movement is important as it adds to one's understanding on "how people learn," how to "design learning environments," and who gets to make as a means for "equity and diversity" (p. 285). While this call is important to understand the next progression in research on making, by examining other studies on educational making, this study can be better informed.

Kim et al. (2018) released a report titled: "Making Culture: A National Study of Education Makerspace." In this study, Kim et al. detailed the maker culture appearing in educational makerspaces across the country. Their report included a look at formal educational makerspaces found in kindergarten through high school and the researchers coded their data among three major themes: agency, community, and culture. The findings of the report contribute to the ongoing belief that there is potential in making in schools. For example, when discussing the impact of educational makerspaces, the researchers highlighted the experiences of English language learners and students who struggled with behavior. “Student interviewees suggested that working on creative problem-solving projects reduced the fear of making mistakes when speaking out loud, fostering greater fluency and retention” (Kim et al., 2018, p. 7). In discussing student behavior, the researchers noted how teachers believed there was improvement based on the levels of engagement in this new learning environment. “Teachers reported that makerspace involvement had a positive effect within the traditional classroom setting, revealing a marked improvement in behavior” (p. 7). While the article concludes with a statement regarding the potential of making, “we believe makerspaces offer tremendous potential to advance learning for today’s students” (p. 16), the report did not explore content specific learning of students.

In a study by Sheridan et al. (2014), the researchers conducted a multiple case study on makerspaces in which they sought to explore how makerspaces may function as learning environments. Their report, titled “Learning in the Making: A Comparative Case Study of Three Makerspaces,” gives an indication on the range of practices in makerspaces and how making may appear in educational settings (Sheridan et al., 2014). While this research focused on makerspaces outside of a school setting, it does indicate the promise in making as a vehicle for learning. In all three of the cases, two of which were in a community-based setting and one in a museum, the researchers found through creation, tinkering, and making of things, participants gained knowledge that spanned multiple disciplines. “Learning in each of these spaces is deeply embedded in the experience of making” (p. 528). This report contributes to the belief of the potential in making, but still leaves the question about what exactly is being learned when people engage in making unanswered.

To understand the learning potential of educational makerspaces, Hira and Hynes (2018) crafted a conceptual framework for best practices in educational makings as it pertains to learning. In their work titled, “People, Means, and Activities: A Conceptual Framework for Realizing the Educational Potential of Makerspaces,” they explored elements of educational making in the terms of people, means, and activities. While their framework is broad and less focused than the work of Resnick (2017) and Cohen et al. (2017), it does indicate when students engage in makerspaces with tools or means facilitated through activities designed to help students learn specific skills, there is a heightened opportunity for student learning. It does not go into the specifics of learning but calls for future research in the area of “capturing lessons to learn from different sites” (Hira & Hynes, 2018, p. 8). Through implementing lessons as a means to measure student mathematical proficiency, this study has the potential to explore this gap in current research.

In a national survey conducted by the research team of Peppler et al. (2017), the researchers examined the nature of assessment in makerspaces. Part of the report showed school subjects in relation to the use of educational makerspaces. The researchers found schools aligned makerspaces programming with mathematics 55% of the time. This gives an indication that mathematics content is currently being integrated into making. When it comes to assessment practices, 90% of schools conducted some type of assessment in relation to makerspace activities. However, the most common types were self-assessment (65%) in the form of an individual learning reflection or a defined rubric (60%) that promotes likely outcomes among makers in the form of creativity but not aligned with curriculum learning goals. The researchers also suggested most educational makerspaces stay away from traditional means of assessment such as multiple-choice questions due to a perceived disconnect between making and standardized testing. The report also details the need for high-quality assessment practices in school makerspaces. The implementation of the five strands of mathematical proficiency in this study may indicate a direction for further research in this area.

Finally, in a multiple case study of two schools conducted by Waldrip and Brahms (2016), the researchers explored taking making into schools and detailed the findings from the cases as a means to understand the process of making and the outcomes of making as it pertains to classroom integration. The two schools in the study, Stratford Elementary and Folk Elementary, had different approaches to classroom integration of making. Stratford implemented a moving cart and students engaged in makerspace activities outside of the structures of classroom curriculum. Folk, on the other hand, placed making as part of the curriculum and implemented lessons through a designated school makerspace similar to the aims of the current study. What the researchers found was making supported the learning in the literature classroom at Folk in which they observed. In fact, a teacher in the study reported to have concluded, “Making, for him, supported larger goals of creatively and collaboration, but at the same time could serve to further student understanding around concepts of literature” (p. 103). This gives some indication that content-aligned making has the potential to increase student learning outcomes. However, the researchers concluded more work is needed in this area, including grades other than elementary. It is this gap in the literature in relation to mathematics instruction and learning outcomes that the researcher aims to position the current study.

The field of making and education remains an emergent field with the need for more research in the development and implementation of educational making (Halverson & Peppler, 2018). The studies outlined in this section suggest there is potential in making when integrated into schools and curriculum (Barton et al., 2017; Dougherty et al., 2016; Hatch, 2014; Fleming, 2015). However, assessment measures are limited in the ways they have been applied to study student learning in educational making (Peppler et al., 2017). There is also a need for further research in the area of content specific learning outcomes in secondary education (Waldrip & Brahms, 2016). The goal of this study was to address these gaps in the literature in relation to educational making in the content specific area of mathematics curriculum.

Conclusion

The purpose of this study was to explore the mathematical proficiency of students when mathematics was taught in an educational makerspace through the implementation of design research. As the literature review demonstrated, educational making has the potential to heighten the learning outcomes of students, but few studies have addressed content specific learning outcomes when curriculum is introduced into a makerspace. If the Maker Movement has the potential to improve learning for students, further investigations are needed to explore what is being learned. Mathematics is a subject that has shown to benefit from components of making in the form of project-based learning, collaboration, agency, and tinkering, but not in the totality of these principles of educational making. Further research is needed to investigate if students are able to become mathematically proficient when educational making is introduced into mathematics curriculum. In the current study, the researcher sought to provide an in-depth understanding of learning outcomes of seventh grade mathematics students when engaged in education making. In Chapter Three, the researcher provides an overview of the methodology for this study.

CHAPTER THREE

Methodology

There is a need for more empirical research in the design and implementation of makerspaces in school-based settings. This researcher aimed to explore the mathematical proficiency of students when they participate in an educational makerspace experience as a way to provide insight into the issue of student learning in a school-based makerspace. Studies have demonstrated there is a need to explore the development and implementation of educational makerspace experiences (Halverson & Peppler, 2018; Kim et al., 2018). Other researchers have noted there is a need for understanding content specific making in a school-based setting (Waldrip & Brahms, 2016). The current study was designed to explore the complexity of this issue by conducting design-based research (DBR) through collaboration with two practitioners. All aspects of the research methodology used in the study are reported in this chapter. In the next sections, the researcher details the research design and rationale, the setting, participants, data collection, and analysis for this study.

Research Questions

This study was designed to explore the development and implementation of content specific (e.g., mathematics) makerspace experiences in a school-based setting. The research questions that provided the focus for the study were

1. What happens when an educational makerspace experience is developed to facilitate mathematical proficiency?

2. What strands of mathematical proficiency are evident when facilitating an educational makerspaces experience?

Research Design and Rationale

To answer the research questions, a DBR implementation was applied in collaboration with practitioners to explore the possibilities of a makerspace experience in improving teaching and learning (Penuel et al., 2011). The term design experiment was first coined by A. L. Brown (1992) and Collins (1992) as a way to study learning in context outside of a laboratory setting. This emerging research approach has evolved into DBR in which researchers study instructional strategies and learning through a systematic design (Anderson & Shattuck, 2012; Barab & Squire, 2004; "Design-based research," 2003). The underpinning or theory behind DBR is that it links research and practice as a means of improving teaching and learning (Anderson & Shattuck, 2012; C. Brown et al., 2016; McKenney & Reeves, 2012).

DBR is common in learning science as it not only provides solutions to significant education problems, but also produces knowledge that can be used by other researchers ("Design-based research," 2003; Wang & Hannafin, 2005). Another important aspect of DBR is it is iterative and adaptable to the results of implementation (Cobb et al., 2003). This occurs through altering aspects of the intervention or participant experience in the study after each implementation with the involvement of participants in the decision-making process (Collins et al., 2004). This allows the researcher to adjust various aspects of the makerspace experience design through the iterations to best address the research questions with input from collaborative partners (Barab & Squire, 2004; A. L. Brown, 1992; Collins, 1992).

Wang and Hannafin (2005) define DBR as “a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories” (p. 6). Wang and Hannafin’s framing of DBR includes the characteristics of “pragmatic, grounded, interactive, iterative and flexible, integrative, and contextual” (p. 7). This study was pragmatic, grounded, and interactive as it sought to address the issue of development and implementation of makerspace experiences in school-based settings. Thus, by exploring what happens when an educational makerspace is developed to facilitate mathematical proficiency, the study was situated in a real-world context with social interactions rather than laboratory settings (Collins, 1992).

As part of the study, three iterative data cycles occurred as the researcher and practitioners collaborated to develop and implement three different makerspace experiences. These three iterative cycles were divided into a pilot study followed by two makerspace experiences. The organization of the cycles in this manner was a result of the COVID-19 pandemic interrupting the initial planned study and some changes in the participants which is detailed later in this chapter. While the study was interrupted by COVID-19, the method of iterative design was followed as planned with a longer than intended break between the first and second data cycle. Furthermore, pilot studies or initial cycles of DBR are often used to inform future studies or iterations of implementation of DBR (McKenney & Reeves, 2012). The researcher used the pilot study or initial iteration as part of the overall research design to allow for three complete cycles to be finished to inform the study.

The purpose of having three unique experiences was that it promotes an iterative and flexible design which addresses how design choices in a school-based makerspace experience impact mathematical proficiency. Finally, methods in DBR are not unique as DBR is integrative in the use of other established methods of qualitative and quantitative research to fit the context of the study (McCandliss et al., 2003). Qualitative research allows for an exploration of an event and is flexible in that it can adjust to the setting (Creswell & Poth, 2018). Therefore, the current researcher employed qualitative methods of data collection and analysis, which are detailed later in Chapter Three, as a means to explore the complex issue of educational makerspaces in relation to the five strands of mathematical proficiency while allowing for the flexibility of the iterative process of DBR.

Also, a DBR method was chosen to increase the impact and translation of implementing makerspaces into educational practice and the need to develop a makerspace experience in the form of mathematics lessons that align with the classroom instruction in which this research took place (Anderson & Shattuck, 2012). According to McKenney and Reeves (2012), DBR uses existing theory to frame inquiry or research. As outlined in Chapter Two, this study builds on existing theories of educational making and mathematical proficiency. This partnership with teachers through a DBR tradition allow for a systematic engineering of the makerspace experiences through the implementation of Resnick's (2017) 4Ps of educational making to target the five strands of mathematical proficiency.

Iterative Design

As part of the DBR, the study was conceptualized within an iterative process. McKenney and Reeves (2012) provided a generic model for conducting design research in education as seen in Figure 2. Their design consists of three phases in the systematic application of DBR in which the arrows represent a flexible iterative design. The generic model as structured by McKenney and Reeves provided a guiding path for the iterative design: a) review of literature and analysis of the practical problem of educational makerspaces with cooperating practitioners and b) makerspace experience design and development applying Resnick's (2017) 4Ps of educational making to address the five strands of mathematical proficiency; c) implementation of three educational makerspace experiences with iterative redesign as needed to address the research questions, and d) reflection of the process toward the development of design principles to inform both theory and practice on educational makerspaces (Anderson & Shuttuck, 2012; McKenney & Reeves, 2012; Wang & Hannafin, 2005).

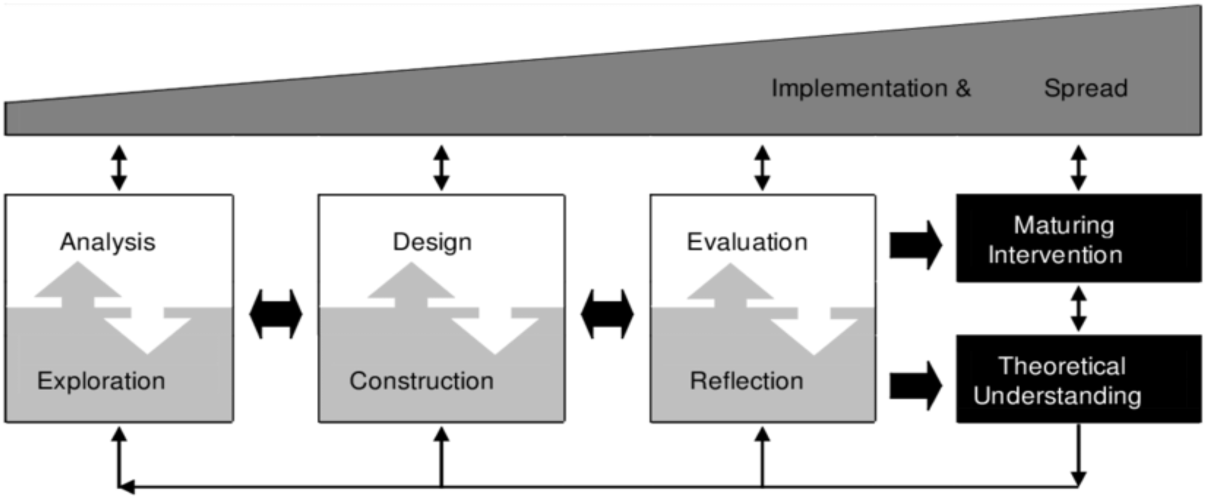


Figure 2. Generic model for design research (In *Conducting Educational Design Research* by S. McKenney and T. Reeves, 2012, p. 77. Copyright by Susan McKenney and Thomas C. Reeves.)

Phase 1

In the generic model, Phase 1 consists of analysis and exploration in which a literature review is conducted to gain theoretical understanding and identification of the problem. This also allows for the inclusion of other theoretical inputs that may shape the design (McKenney & Reeves, 2012). As detailed in Chapter Two, the literature review conducted for this study highlights the gap in research of the development and implementation of educational making (Halverson & Peppler, 2018). This researcher explored these issues by drawing on theory of educational making as a form of progressive education (Martinez & Stager, 2013) applied in a school-based setting. In particular, this researcher explored mathematics learning in the form of the five strands of mathematical proficiency through the design and implementation of an educational makerspace experience applying Resnick's (2017) 4Ps of educational making in keeping with the model for phase 1 of this study.

Also, during Phase 1, initial planning with practitioners began. This was a type of "informed exploration" (Bannon-Ritland & Baek, 2008) which allowed the researcher and practitioners to discuss the problem as characterized by the theory outlined in Chapter Two on educational makerspaces and mathematical proficiency and identify if there was a need for further review of the literature. It also allowed the formation of a plan in the form of a specific time frame for implementation inside the research window, identifying of the specific mathematics content to be taught, and the use of the frameworks of educational making and mathematical proficiency.

Phase 2

Phase 2 of the generic model consists of design and construction. This constituted a systematic process to arrive at a solution to the problem or in this study a makerspace experience to address the research questions (McKenney & Reeves, 2012). Designing solutions to educational problems involves some type of change through inquiry (Barab & Squire, 2004) and, in this study, it was regarding implementing educational makerspaces principles into classroom instruction. The properties of educational making in their relation to constructivism provided the educational theory that the basis of the makerspace experience or solution is formed (P. Bell, 2004; Cobb, 2000). This also acted as a type of skeleton framework or core features of the makerspace experience design in the form of the Resnick's (2017) 4Ps of educational making. As the process ensued, the researcher and the practitioners fleshed out details and iterated as needed based on theory and the educational problem (McKenney & Reeves, 2012).

In the case of this study, the researcher collaborated with teachers as a means to design and construct the makerspace experience in the form of makerspace lessons aligned to mathematical content goals by applying the properties of educational making from Resnick's (2017) 4Ps and Makification (Cohen et al., 2018). The mathematical content goals were the same as lessons currently implemented by the practitioners and as identified in Phase 1 of the DBR process. The differentiating factor or defining characteristic of the makerspace experience was the inclusion of all four of Resnick's (2017) 4Ps principles in the form of

- Projects–Students create a product that may be physical, digital, or a combination of both.

- Peers–Students work in collaboration with each other, and there are opportunities to share their products.
- Passions–Students can bring personal elements into their creations in the form of interests or relevant issues.
- Play–Students can “tinker” with the design to improve their product through peer suggestions or trial and error.

While there may be a need to modify the makerspace experience throughout the iterative process or in between macro cycles of implementation, theories on educational making acted as a framework for the systematic design of the research (Cobb et al., 2003).

Phase 3

During Phase 3, the implementation of the makerspace experience and the evaluation process take place (McKenney & Reeves, 2012). Three cycles of the design are conducted to compare data from a variety of mathematics makerspace experiences (e.g., three different units of mathematics instruction, with an iteration of the design following each implementation) and to gather sufficient evidence about the makerspace experience (Herrington et al., 2007). This also allows for alterations in the makerspace experience design, through the pilot study and following two iterations, to address the research questions better. Data was collected in the form of teacher interviews, student work, and classroom observations from each of the three educational makerspace experiences.

In the process of implementation, there were opportunities for reflection and evaluation as teachers completed each round in a micro cycle (e.g., after the teachers implemented the pilot study and following two iterations) and at the culmination of the study (e.g., after the third makerspace experience). This allowed systematic engineering of the makerspace experience to maximize the opportunity for translation from theory to practice and to address the research questions (P. Bell, 2004; “Design-based research,” 2003).

Participants and Site

An important aspect of DBR is the ability to conduct research in an already established school-based setting as a means to address a real problem (Barab & Squire, 2004; A. L. Brown, 1992; Collins, 1992). Building on current relationships with teachers as a school instructional specialist at a Central Texas school district, the researcher continued as a participant observer (Creswell & Poth, 2018) in two seventh grade math classrooms consisting of two sections of students each of approximately 20-25 students per course (87 total) during the second semester of the 2019-2020 school year for the pilot study. The researcher and the two practitioners were able to complete the first iterative cycle or pilot study prior to school closing due to the COVID-19 pandemic. Following the return to school in the fall semester of the 2020-2021 school year the participants were changed to one practitioner and two seventh grade classes (41 total students) to complete the final two cycles of the research design. The narrowing of the study to a small group was a result of COVID-19 restrictions as determined by the research site. While the students in the last two makerspace experience were different from the students in the pilot study, the practitioner took part in the pilot study and was able to use that experience to help with the design of the last two makerspace experiences and contribute to the iterative design of the study. These students in the pilot study and the following two makerspace experience were not randomly selected due to the already intact class structures of the school. These classes and instructors were chosen because each of the two practitioners (e.g., teachers) that the researcher partnered with as part of the DBR, teach identical course loads.

Data Collection and Analysis

In this section, an explanation of the type of data collected and the analysis procedures are described. As part of the DBR, the researcher collected qualitative data to inform the study. Qualitative research relies on multiple sources of evidence for data to provide a detailed description (Creswell, 2014; Merriam, 2009; Merriam & Tisdell, 2016). For the study, qualitative data were collected in the form of multiple interviews, observations, and student artifacts. Using multiple forms of evidence, researchers can triangulate data to help provide validity to the context of the study (Creswell, 2014).

Qualitative data to inform the study were collected from three sources: observations in the form of field notes, student work generated during the educational makerspace experience, and interviews with teachers. According to Creswell and Poth (2018), observations are a key tool for data collection in qualitative research. Observations and student work in the form of field notes were taken by the researcher from the three educational makerspaces developed and implemented as layers of qualitative data to integrate into the study for triangulation of results (Creswell & Plano Clark, 2011). The qualitative data in the form of observation notes and student work were coded using the five strands of mathematical proficiency. Applied together the five strands give a clear picture if a student is mathematically proficient in a given topic or learning objective (Groth, 2017; Pothen & Murata, 2006; Samuelsson, 2010; Suh, 2007).

The NRC (2001) described the five strands as follows and Table 1 represents a further description and example of each strand:

- Conceptual understanding–comprehension of mathematical concepts, operations, and relations (e.g., Are students able to understand the concept(s) being taught?)
- Procedural fluency–skill in carrying out procedures flexibly, accurately, efficiently, and appropriately (e.g., Are students able to apply the correct formula or procedure?)
- Strategic competence–ability to formulate, represent, and solve mathematical problems (e.g., Are students able to create or find the correct solution?)
- Adaptive reasoning–capacity for logical thought, reflection, explanation, and justification (e.g., Are students able to explain and justify their answers?)
- Productive disposition–habitual inclination to see mathematics as sensible, useful, and worthwhile, coupled with a belief in diligence and one's own efficacy (e.g., Are students able to understand how mathematics can be useful in their own life?)

Interview data from the two practitioners in the first iterative cycle and one practitioner in the final two cycles were also collected. In qualitative research, interviews are used to give an in-depth understanding of an experience (Creswell & Poth, 2018). In the context of this study, the interviews allowed the teachers to share their perspectives of student mathematics learning in the form of mathematical proficiency, development, and implementation of educational making during the three experiences.

Table 1

Strands of Mathematical Proficiency (NRC, 2001)

Strand	Description	Example
Conceptual Understanding	Students understand why a mathematical idea is used for a particular context. They see mathematics as more than isolated facts or methods and are able to view mathematics as a coherent whole.	Students may draw a picture or use concrete visuals to find the solution. They may also use multiple representations such as number lines, tables, and or graphs to make sense of the problem.
Procedural Fluency	Students are able to use knowledge of procedures appropriately and flexibly in the correct context. They are also able to perform procedures in a correct and efficient manner to solve problems.	Students apply algorithms and mental math as tools for computing and as methods to understand concepts. Students also understand procedures to solve entire classes of problems (e.g., properties of the mathematical operations of addition, subtraction, multiplication, and division.)
Strategic Competence	Students are able to deduce the type of problem and solve it. This strand is closely associated in literature with problem solving and problem formulation.	Students understand the situation or problem presented and then are able to generate a mathematics representation in various forms (e.g., numerically, symbolically, verbally, or graphically) that details the core mathematical elements needed in solving the problem.
Adaptive Reasoning	Students are able to navigate the many facts, procedures, concepts and methods to see that they fit together in a logical form. It is a type of deductive reasoning that allows students to determine the correct mathematical answer.	Students are able to describe how they arrived at their solutions to the problem. In other words, students are able to reflect on their process of solving in a logical order and describe the mathematical connections as a means of justifying their answer.
Productive Disposition	Students see sense in the mathematics as both useful and worthwhile. Students are also able to see oneself as an effective learner and doer of mathematics. Productive disposition comes from the development of the other four strands.	Students who have a productive disposition are confident in their knowledge and ability. They see themselves as an effective learner and doer of mathematics. Students are also willing to engage in the problem-solving process to find the solution.

Interviews also allowed the teachers to discuss the design choices they made in partnership with the researcher that impacted the mathematical proficiency of students when they engaged in educational making. In fitting with the flexibility of the DBR, the interviews were semi-structured. A semi-structured interview format allowed the research to respond to each of the makerspace experiences, explore new ideas that may emerge, and still seek data that addressed the research questions (Merriam & Tisdell, 2016).

Interviews were conducted at the conclusion of each iteration (e.g., after the pilot study and the following two makerspace experiences). This allowed for input from the practitioners to shape the next iteration with the purpose of better addressing the research questions through the DBR (Anderson & Shattuck, 2012). Also, collecting interview data from each makerspace experience allowed the researcher to triangulate the interview data with student work and classroom observations from that event. This provided data to aid the researcher in creating a narrative for each educational makerspace experience. Interviews were recorded in video format and then later transcribed. As part of the semi-structured interview, pre-determined questions were explored along with any other questions that may emerge through the study (Merriam & Tisdell, 2016). Table 2 provides an overview of the pre-determined questions.

Data from interviews, student work, and observations were initially coded using the theoretical framework on mathematical proficiency. However, to further explore the issue of development and implementation of makerspaces into school-based settings, the qualitative data in the study also went through generic inductive analysis.

A generic inductive approach to the data allowed for emerging themes to appear in relation to the educational makerspace experiences without being restricted to a particular qualitative approach (Thomas, 2006). As part of the inductive analysis data in the form of interviews, student work, and observations went through a process of open coding followed by axial coding as a means of data reduction to identify any emergent themes. Open coding is the process of creating labels from data that summarize what is happening as part of the research, while axial coding identifies relationships among the open codes (Creswell & Poth, 2018).

Table 2

Interview Protocol

Interview Questions	Theoretical Framework
Describe the development of this educational makerspace lesson. What mathematical content was the intent of the experience?	4Ps (Resnick, 2017)
What challenges emerged in the development and implementation of this educational makerspace experience?	4Ps (Resnick, 2017)
How was this educational makerspace experience structured to address mathematical proficiency?	Mathematical Proficiency (NRC, 2001)
What instructional design choices were made that impacted mathematical proficiency of the students?	Mathematical Proficiency (NRC., 2001)
What strands of mathematical proficiency emerged through the course of this educational makerspace experience?	Mathematical Proficiency (NRC, 2001)
What alterations could made to the development of educational makerspace experiences to address the 4Ps of educational making?	4Ps (Resnick, 2017)
What alterations could made to the development of educational makerspace experiences to address mathematical proficiency?	Mathematical Proficiency (NRC, 2001)

This creates the opportunity to further explore what is happening during the course study with the purpose of addressing the research questions and exploring the development and implementation of makerspace experiences in a school-based setting. Table 3 provides an overview of the data collection and analysis in relation to the research questions.

Table 3

Process of Data Collection and Analysis

Question	Data Collection	Data Analysis
What happens when an educational makerspace experience is developed to facilitate mathematical proficiency?	• Classroom field notes • Observations • Student work • Teacher interviews • Discussions with teachers during planning and iteration of design	• Coding of qualitative data based on the five strands of proficiency • Open and axial coding to address any emergent themes in development and implementation
What strands of mathematical proficiency are evident when facilitating an educational makerspaces experience?	• Classroom field notes • Observations • Student work • Teacher interviews	• Coding of qualitative data based on the five strands of proficiency

Conclusion

In this chapter, the research design, research questions, participants, methods of data collection, and analysis were described and explained for this DBR employing mixed methods study. A DBR study allowed the researcher to partner with practitioners to create an educational makerspace experience to explore mathematics learning outcomes when students participate in educational making.

CHAPTER FOUR

Results

With this study, the researcher explored the development and implementation of makerspaces situated in school-based settings through DBR in connection with specific educational content learning (Halverson & Peppler, 2018). A pilot study followed by two makerspace experiences was used as part of the research design. The pilot study was initially intended to be part of the research study, but due to school closures caused by the Covid-19 pandemic, the remainder of the study took place with different participants. Multiple interviews, classroom observations, and artifacts in the form of student work were collected to assist the researcher in answering the following questions:

1. What happens when an educational makerspace experience is developed to facilitate mathematical proficiency?
2. What strands of mathematical proficiency are evident when facilitating an educational makerspaces experience?

The theoretical framework used in the study, as described in Chapter Two, was based on the NRC's (2001) work on mathematical proficiency as found in *Adding it Up: Helping Children Learn Mathematics*. The five strands of mathematical proficiency as defined by the NRC are conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition. In conjunction with the five strands of mathematical proficiency, the study used Resnick's (2017) work on educational making in the form of the 4Ps—projects, peers, passions, and play—as guiding principles for implementing making in school-based settings as detailed in Chapter Two.

This chapter begins with an overview of the pilot study followed by the two makerspace experiences or lessons. Following the overview, a narrative of each of the lessons (pilot study and two makerspace experiences) details the experiences of the teachers and students who participated in the study. Data from each makerspace experience was coded in the five strands of mathematical proficiency detailed in Chapter Three and presented to support the findings. After each makerspace experience is presented, the research questions are addressed, and any additional themes are discussed.

Overview of the Makerspace Experiences

Pilot studies often inform DBR through systematic development and implementation of solutions to educational problems (McKenney & Reeves, 2012). As detailed in Chapter Three, the pilot study was conducted to refine the makerspace experience for future iterations of the DBR. The researcher identified two practitioners and 87 students in four seventh-grade mathematics classes in a suburban middle school located in Central Texas. The site and practitioners were chosen based on the availability of a school-based makerspace located in the school and the practitioners' familiarity with teaching in a makerspace. The pilot study took place in the spring of the 2019-2020 school year over a 3-week period prior to the Covid-19 pandemic that shut down schools worldwide. Pilot study participants included two seventh grade math teachers. Each teacher was given a pseudonym—Alice had 5 years of experience teaching and Rick had 10 years of experience. Between the two teachers, they had 87 students ranging in age from 12–14 in their seventh-grade mathematics classes. Student participants were also given pseudonyms when reporting data pertaining to them.

Informed by the pilot study, two makerspace experiences were implemented as detailed by the methods outlined in Chapter Three. The participants identified for the makerspace experiences were also seventh-grade students and one practitioner. The practitioner had also participated in the pilot study. The number of participants in the makerspace experience were reduced in keeping with Covid-19 protocols of limited visitors as set forth by the location site. The two makerspace experiences were conducted at the same Central Texas school as the pilot study during the fall of the 2020-2021 school year. The makerspace experience participants were Rick from the pilot study and his 41 seventh-grade mathematics students.

Pilot Study

Planning

In keeping with the DBR tradition of partnering with practitioners, the researcher partnered with Alice and Rick to develop the makerspace experiences as part of the study. Two planning meetings were held in which the researcher and the practitioners discussed the educational purpose of the makerspace lesson, the timeline for implementation, and how the makerspace experience fits with Renick's (2017) 4Ps of educational making, and the five strands of mathematical proficiency. Alice and Rick identified theoretical versus experimental probability as the target for student learning and mathematical focus of the pilot study. The selection of this mathematical goal was driven by the Texas Essential Knowledge and Skill (TEKS) seventh-grade math standard (7.6.1), "determine experimental and theoretical probabilities related to simple and compound events using data and sample spaces" (Learning Farm, 2020c, para. 7).

In the initial discussion, Alice stated “The carnival project we have done once in the past would fit well as a type of makerspace experience as students get to create their own carnival game.” Alice was referring to a project they had employed the previous school year in which students played carnival games to collect experimental probability. Rick agreed that the opportunity for student creation of games would fit with the proposed framework with a few modifications, such as providing more freedom in the choice of game they created, and the “tinkering” of design based on peers’ feedback. The researcher recommended they address the 4Ps framework while they designed the makerspace experience.

Addressing the 4Ps of Educational Making in Lesson Design

In designing the makerspace experience, the practitioners along with the researcher discussed each of Resnick’s (2017) 4Ps. They used the following four questions to guide their discussions and makerspace lesson design in addressing Resnick’s 4Ps:

Projects: What will students create as part of the learning experience?

Passions: How are students’ interests included in the learning experience?

Peers: How will students collaborate to support learning?

Play: How will students “tinker” with their designs or solutions?

First, Alice, Rick, and the researcher addressed projects. *Projects* are the maker’s product and can take various physical, digital, and performance-based forms (Resnick, 2017). In discussing projects concerning the makerspace experience. Alice recorded the following:

> Students will create a carnival game to explore probability. Students will determine the theoretical probability of winning their game and have other students play their game to collect experimental probability data for the basis of comparison. The carnival game can take various forms, such as a ring toss, prize wheel, or a duck pond type game.

In further discussion, Alice commented that they should talk about the types of games students want to create to limit repeats and as a result generate a wider variety of mathematical experiences. Rick added, "It might be a good idea for students to brainstorm the type of game they would like to create and share their ideas with the class before any creating." Both teachers wanted students to be thoughtful in their planning in order to create projects that addressed the 4Ps and mathematical content and also offer a variety to allow more opportunities for students to learn from one another.

Once Alice and Rick decided on the type of project, they addressed *peers* and *play*. Peers are the social learning component of the makerspace experience while play is the ability for students to tinker or alter the design as part of the learning experience. These two parts of the 4Ps were discussed together as the teachers believed feedback from peers would help guide students in making adjustments to their game. Rick stated, "We probably want them to tinker really before they write. Because what if they need to change every section of their game based on feedback." Alice added, "We probably want them to run a simulation for their peers or us, so if they get some good peer suggestions, they can go back to the drawing board to tweak their game." For peers and play Alice recorded the following:

> Students will work in three-person groups to build their projects addressing the requirements. The three-person groups will collaborate in game design and calculation of probability based on their game. Each group will partner with another group to simulate their games to get feedback before their final design. Students will tinker or alter design after receiving feedback from groups after testing their games. Groups will also explain the theoretical probability of winning their game and how they calculated the probability.

The last P, passions, was then discussed. According to Resnick (2017), passion should include agency or open-endedness as part of making. Resnick noted structure could help guide thinking, but a personal element must also exist when creating. Alice and Rick wanted students to have some autonomy in the type of game they created but also needed to guide students throughout the creation process to ensure the projects align with the mathematical goal of the makerspace experience. Rick stated, “It will be important to ensure that student games are not overly complicated or calculating the probability can be way beyond their mathematical ability.” In addressing passions, Alice recorded, “Students will have freedom in the type of game they create in design, materials, and theme.” However, they decided the students’ designs would need to be approved before construction or mathematics calculations began.

Addressing the Five Strands of Mathematical Proficiency

After designing the makerspace experience to target the 4Ps, Alice, Rick, and the researcher discussed how the makerspace experience would address the five strands of mathematical proficiency as part of the design. The five strands discussion was to target research questions one as listed at the start of this chapter. They used the following questions based on *Adding it Up: Helping Children Learn Mathematics’* (NRC, 2001) five strands of mathematical proficiency as detailed in Chapter Two to guide their discussions:

> Conceptual Understanding–What mathematical concept(s) will be included in the learning experience?
>
> Procedural Fluency–What properties and procedures will students need to use effectively?
>
> Strategic Competence–What mathematical situation will students need to understand and solve?

> Adaptive Reasoning–How will students explain the mathematical connections and apply them?
>
> Productive Disposition–Why will students view this mathematical experience as worthwhile?

Conceptual understanding is the comprehension of mathematical concepts, operations, and relations (NRC, 2001). For the makerspace experience, Alice and Rick set a mathematical goal for students to understand the concept of theoretical probability versus experimental probability as defined by the TEKS standard (Texas Education Agency, 2020). Specifically, as determined by Alice and Rick, students will explore the difference between theoretical and experimental probability. Through the context of a probability carnival, students will construct a conceptual understanding of the difference between theoretical probability or what students expect to happen mathematically compared to what happens through data collection.

Procedural fluency is the skill of carrying out procedures flexibly, accurately, efficiently, and appropriately (NRC, 2001). As part of the makerspace experience, students would apply the processes and procedures necessary to calculate the theoretical and experimental probability. For probability, students will determine the number of desired outcomes divided by the total number of outcomes. The probability will vary based on the type of carnival game students create and the amount of data they collect as part of the makerspace experience.

Strategic competence is the ability to formulate, represent, and solve mathematical problems (NRC, 2001). As part of the makerspace experience, students will encounter the mathematical situation of determining a given carnival game’s probability. Rick stated, “The context of the carnival game may stretch student thinking or problem solving as it will be a different situation than the types of problems they normally encounter related to probability." As part of carnival game creation, students had to represent the mathematical probability of their game and solve the experimental probability through data collection.

Adaptive reasoning is the capacity for logical thought, reflection, explanation, and justification (NRC, 2001). As part of the makerspace experience, students were required to complete a reflection on the makerspace experience. Alice and Rick wanted students to reflect on the experience and explain how they determined their theoretical and experimental probability, the connection between the two types of probability, and anything they would like to change about their games. Alice stated, "It will be important for students to explain how they determined their probabilities in accessing their mathematical thinking." As part of the final reflection, students were also required to apply their understanding to a similar mathematical situation created by Rick and Alice. They provided students with a new image of a prize wheel different from what the students had created with four equal sections and asked students to determine the probability of landing on one of the sections and to determine how many students would land on that section if 50 students spun the wheel as means to further explore student mathematical proficiency based on the makerspace lesson.

Productive disposition is the habitual inclination to see mathematics as sensible, valuable, and worthwhile coupled with a belief in diligence and one's efficacy (NRC, 2001). Rick commented, "Students don't always understand the purpose behind mathematics. The carnival setting will provide the opportunity to experience probability outside the classroom." Providing the freedom for students to create their own carnival game was part of the makerspace experience. As students create, they can see themselves as mathematicians and discover the purpose behind the math. The creation of carnival games was intended to target productive disposition.

Implementation

Implementation of the probability carnival makerspace pilot study took place over 6 days in the spring of the 2019-2020 school year. The timeline was,

- Day 1: Introduction of the probability carnival by the teachers and project requirements. Students also had time to begin planning.
    - Create a carnival game that other students in the class will play.
    - Determine the theoretical probability based on expected outcomes.
    - Determine the experimental probability based on data collected.
    - Provide feedback to other groups to support their project design.
    - Reflect on the learning experience.
- Day 2: Students planned their game and collaborated with other groups to discuss their ideas. Once students planned their game and received feedback in order to make adjustments, they began the initial project building.
- Day 3 and Day 4: Students built their games.
- Day 5: Carnival day where students played each other's games and collected data to determine the experimental probability.
- Day 6: Students analyzed their data and reflected on the experience.

Observations

The researcher acted as participant-observer during the creation and implementation of the makerspace game. *Participant observation* is a research method in which the researcher observes the group and participates in the activities or behavior of the group (Creswell & Poth, 2018). During the implementation, the researcher observed the classes and interacted with them as they created the carnival games. The students' interactions with the researcher were limited to questions the researcher asked for clarification of activities or as an employee of the site, interactions that would have been part of regular classroom behaviors.

For students on Day 1, they seemed excited to be out of the classroom setting and in the school-based makerspace. When asked if they liked going to the makerspace, many commented that they preferred the freedom of the makerspace, collaborating with peers, and the opportunity to create a project. The first day was spent with the teachers outlining the expectations and students discussing the types of games they wanted to create. Students reflected on personal experiences of playing carnival games and determined the game their group wanted to build. Teachers helped guide student thinking by reminding them to think about the associated theoretical probability when selecting a game to build. Some students chose a simple game of chance, such as a prize wheel that players would spin to win a prize. At the same time, other games involved a certain level of skill by players. For example, a bean bag or ring toss game, in which players toss an object at a target, has an element of skill not necessarily reflected in the theoretical probability. By the end of the first class, most groups had selected their game but had not yet determined their theoretical probability. The researcher did ask one group why they chose a prize wheel for their given game. One student responded, "I think it will be fun to give out prizes based on what other students spin, and it will be easy to find the probability." The researcher asked for further clarification on "easy" to find the probability, and the student stated, “It will be the number of winning spaces over the total number of spaces.” Day 1’s introduction set the stage for the rest of the makerspace experience.

Day 2 students determined the theoretical probability of the game they had chosen and shared their ideas with other groups. The two teachers guided students by having them take turns explaining their games. Students provided feedback, but it was primarily game-related and not math-related. Students offered each other suggestions such as, “Maybe you should have more winning spaces on your prize wheel” and “I think players should get five tosses at the target instead of three.”

However, some groups had difficulty determining their probability, and their discussions with the teachers provided some indication of the type of mathematical proficiency the students were experiencing. For example, one group created a bean bag game in which players attempted to toss bean bags into winning holes cut out of a rectangular board. The students asked Rick for help in determining their game. Rick said to the students, “Explain your probability to me.” One student replied, “We will find our probability by finding the area of the winning spots over the total area. However, we don’t know how to find the area of the area of the oval” (referring to their winning spots, which are circular on the ends and more rectangular in the middle). Rick directed the students to use a shape similar to an oval for which they knew how to find the area. The students decided to apply what they knew about composite shapes and used two half or semi-circles and a rectangle to determine the oval winning spaces’ area on their game board. The researcher asked the students to explain further their plan for finding their probability based on their discussion with Rick. The students said they would measure the oval diameter at the ends and use that measurement to find the area of the more circular ends and as the width for the rectangular portion of the shape. They would then add the area of the two circular ends with the rectangle to find the total. The makerspace experience of making a carnival game created a situation through which the students encountered an unintended mathematical situation—in this instance, determining the area of an oval-like shape.

A similar situation happened in Alice's class on Day 3 of the makerspace experience. A group of students had constructed a prize wheel in which players would spin the wheel to determine if they won or not. The wheel had 10 spaces with four spaces labeled as a "winner," five spaces labeled as a "loss," and one space labeled "spin again." Alice asked the group to explain their theoretical probability. One student responded with, "Our probability is four out of 10 because there are four winning spaces out of 10 total." Alice pressed further, "What about your spin again space? Is it a win or a loss?" The student responded with, "It is not a win or a loss; players get to go again." Students realized that they needed to consider this space differently because it is not a favorable outcome, but it also does not terminate the game for the player like the other non-winning spaces. After discussion, students determined the probability to be four out of nine. The spin again space causes the game to be played again with a probability of four out of nine chance to win the game versus a five out of nine chance to lose. Like the oval area situation in Rick's class, the makerspace experience leads to a level of problem-solving that might not have occurred otherwise.

Day 4 of the makerspace experience, the students completed their games, and most of class time was spent coloring and decorating their games. Some students tested their games as they finished, and a few of them commented that they were worried that their theoretical probability might not be close to the experimental probability. The researcher asked one group to explain why they were worried that their theoretical probability would not matching their experimental. One student stated, “Because it is a bean-bag toss game, it depends on how good they are at throwing the bag.” They were referring to the skill of the player of the game. A group discussion followed in which they spent time trying to determine where players should stand concerning their game board. As one student stated, “If they stand too close, they will make almost every toss.” The real-world aspect of players tossing an object versus a simple game of chance presented a type of problem-solving that may not be present without this making experience.

On Day 5, students played each other’s games and collected data. One group member would facilitate the playing of their carnival game while another collected data. The third member went to the other groups and played the games. The teachers did not limit the number of plays that the students needed to collect but encouraged them to try to have as many play-throughs as possible to generate a better data set. The teachers told students that the more data they had, the more likely that they will be able to determine if their theoretical data matches their experimental data. Most groups had about 30 to 50 play-throughs, depending on how long it took for players to complete the game. Some skill-based games took longer to play, while the more straightforward games like the prize wheel were completed faster. Students enjoyed playing the games and recorded the data to use for the following day in their analysis and reflections.

On Day 6, students were asked to answer the following questions as part of reflection the makerspace experience.

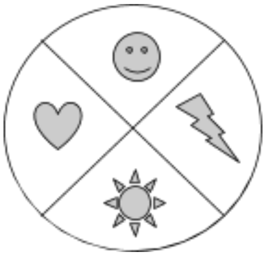
Student Reflections on Pilot Study

Part 1

1. What was the theoretical probability for your game? How do you know?
2. What was your experimental probability for your game? How do you know?
3. How do theoretical and experimental probability compare to each other? Why do you think this is?
4. Are there any additional variables/factors that you did not consider when calculating the theoretical probability of your game?
5. Looking back, what would you change about your game? What impact would the change have on your theoretical or experimental probability?

Part 2

1. Mr. V made the Prize Wheel shown below for the carnival. Players will get to spin the wheel two times. If they land on a lightning bolt on both spins, they win no homework for a month. What is the theoretical probability of winning Mr. V's game? Explain.



Prize Wheel

2. If 40 students played Mr. V's game, how many would you expect to win? Why?

Part 3

1. How would you describe your experience with the probability carnival?
2. Do you prefer to learn math in a makerspace project or in a regular classroom setting? Why?

Which setting (makerspace vs. regular classroom) do you find to be more beneficial to your mathematical understanding? Why?

Post-Interviews

After the makerspace experience, both Alice and Rick participated in an interview separately to discuss the lesson and inform future iterations of the makerspace experience as part of the DBR. The interviews conducted were semi-structured. Semi-structured interviews allowed the researcher to collect open-ended data with each participant while still following a flexible interview protocol (Creswell, 2018). Also, semi-structured interviews provided the researcher opportunities for follow-up questions or comments to seek further clarity on participant answers. The interview protocol is further detailed in Chapter Three. The interview questions asked to both Alice and Rick are in Table 2.

Alice. Alice had some experience before the study in the school-based makerspace and project-based learning. She is an accomplished teacher and a previous winner of teacher of the year for the campus. During the experience, she indicated she enjoyed the makerspace experience but had some suggestions for improving future iterations of the makerspace experience.

Alice indicated all 4Ps of educational making were present throughout the experience. The project piece was evident in the student creations. According to Alice, students had the opportunity to play throughout the makerspace experience to alter the design, play each other's games with the intent of collecting data, and explore other groups' probability. Passion was included through student choice in game type and design. Finally, students worked in groups to collaborate which Alice also mentioned this as well in the interview. When asked about the 4Ps (Interview Question 7), in particular, what alterations could be made to the experience design as part of the DBR, she responded:

> I don't know that there's changes that I would make to the lesson, but I don't know that they are necessarily targeted at those. Like, I think that we pretty well hit them all. They definitely got to play, and they got to, you know, play around in the design of their game. Um, they got to play as they collected data about their games literally. The whole thing was very reliant on peers and discussed how we, how are we going to make this work? I let my students choose from the list of games, which one they wanted best. They got to incorporate their passion in that it was just kind of a vague framework of a type of game, but how you make that happen is up to you.

Alice's response details the makerspace experience's connection with the framework and how the 4Ps were leveraged into the lesson. Her belief about the makerspace experience also mirrors the makerspace experience's intent as it was created in the planning of the lesson.

In discussing the mathematical content in particular, Alice detailed the makerspace experience's mathematical goal in exploring theoretical versus experimental probability. In response to the question, "Describe the development of this educational makerspace lesson. What mathematical content was the intent of the experience?" Alice responded,

> We were hoping that students would have a real-world, hands-on experience with probability, um, most specifically theoretical versus experimental seeing the difference between, um, kind of the expected outcomes of a probability experiment versus what happens. And then we were able to get students to kind of dig deeper into some of the more advanced math in seeing how the experimental probability is not always going to match up because there are so many different variables that seventh graders weren't able to calculate into their theoretical probability, just because it's a little bit too advanced.

She also indicates how students further develop their understanding through a "dig deeper" into the concept through various experiences as part of the makerspace experience. However, as mentioned previously, depending on the game students chose, the mathematics was more or less challenging. Alice states,

> And so I think it was challenging trying to figure out, how do we push the kids who had like a duck pond or shell game into some of the more advanced math

> that, like ring toss and bean bag toss people stumbled into, and like, trying to keep it to where the timeframe given was appropriate for all of the different games.

In further addressing mathematical proficiency as part of the lesson, the researcher asked Alice what strands were evident as part of the makerspace experience. She responded,

> The lesson itself led into productive disposition and conceptual understanding. I would say there was definitely a lot of the disposition. I think that we pretty well met all of them either in the creation of the games or the reflection piece.

Alice further explained that because they were targeted during the makerspace experience's creation, she believed that they were all evident.

Finally, Alice and the researcher discussed what could be done differently to improve the design of an educational makerspace experience applying Resnick's 4Ps and the five strands of mathematical proficiency. She believed that time was an important consideration in how long to create and the opportunity for students to dig into their math. Alice stated, "I don't know if we quite figured that out because I know there were quite a few groups that were basically done halfway through Day 2, and they weren't challenged to think quite as much as others." Her statement further indicates the lesson's mathematical goal and difficulty are essential things to consider when developing an educational makerspace experience. As future iterations of the makerspace lessons were developed, the researcher discussed the importance of the mathematical goal and rigor of mathematics with the participants in the study.

Rick

Like Alice, Rick had some prior experience with the makerspace and project-based learning. He is also a former teacher of the year winner and well respected by his peers. Unlike Alice, Rick has teaching experience in multiple school districts in two different states. Rick enjoyed the implementation of the makerspace experience and getting the opportunity to teach in the school makerspace.

In describing the makerspace experience, Rick noted how it fits well with the curriculum and the current understanding students had with probability. He stated,

> Whenever we started this, we had dealt with simple probability in class, and we were moving into compound probability, making predictions, and experimental probability which lent itself toward the project we put together and the mathematical understanding of the students.

The design of the makerspace experience is to target the classroom curriculum as opposed to an open makerspace experience. Rick's response indicates the makerspace experience did align with the curricular goals of the mathematics class or learning standard.

Rick also indicated the makerspace experience targeted Resnick's 4Ps of educational making. When asked to go into more detail about the 4Ps, Rick stated,

> There were projects as part of the process in the creation of the carnival games. Students had the opportunity for passion through the selection of games, theme, and decorating their games. The play came through in the students' changes in their games from their initial plans. I would like to have seen more of peers in the form of groups offering each other suggestions and explaining the math behind their games.

The researcher followed his response up by asking Rick the clarifying question, "So, more time for groups to explain how they found their probability and offer ways to improve their designs to guide their tinkering?" Rick stated, "Yes, I felt that part was kind of rushed, and students weren't sure how to offer good feedback, maybe a little bit more time to dig into that part of the collaboration." His response details the 4Ps inclusion yet offers an area of improvement or iteration in the design. Dedicating more time for peer interaction in other makerspace experiences could provide more beneficial feedback for students and learning opportunities as part of the creation process. In the future lessons included in the study, peer interaction was discussed based on Rick's reflection on the pilot study.

In discussing mathematical proficiency as part of the design and implementation of the makerspace experience, Rick stated,

> One of the most interesting things that happened was, even with the rubric we had designed to target the mathematics, students were going outside of the scale that we had initially planned on doing. Students were stepping into an experimental probability that had to do with the area of shapes and different things that we would typically not address.

The theme of students encountering mathematics that is more complex than intended in the makerspace experience has been evident in student work, observations, and now in Rick's response here as well. He further expanded on this when Rick stated, "The makerspace opened it up where they could play and tinker with things was making it where they were going beyond the math we were trying to teach them." The educational makerspace experience could benefit from allowing students to extend their learning beyond what would have commonly occurred as part of routine classroom teaching and learning.

In further discussing mathematical proficiency and in response to the question, "What strands of mathematical proficiency emerged through the course of this educational makerspace experience?" Rick stated,

> I expected the conceptual to come out, and I expected there to be some procedural proficiency coming in, but the adaptive piece, um, was interesting to me just because kind of how they would take it. And they would take something that might have seemed very procedural to work through and then say, like on the spinner; they would add an extra spot that said spin again. So, I had to think about how they would adapt that to, um, just like their procedural understanding of probability. It just kind of opened up some interesting questioning we had not intended in relation to adaptive reasoning and strategic competence of determining probability in a different context. Students also had a productive disposition through the enjoyment of the carnival.

According to his response, Rick believed all five strands were evident. Conceptual understanding and procedural fluency, as he indicates, were expected to have taught the mathematical concept of theoretical versus experimental probability. Productive disposition was also logically going to occur as students got to create and play games. However, Rick's response to strategic competence and adaptive reasoning indicates potential benefits of educational makerspace experiences toward mathematical proficiency. As students create, they may encounter unexpected situations that require them to apply mathematics in a different context and determine a strategy for problem-solving.

Lastly, Rick was asked what needed to be altered for future iterations of the makerspace experience. He alluded to dedicating more time for peer interaction, as found in his response when asked about the 4Ps. He also stated, "Students could have benefited from more time to play with design and that some students could have been pushed more mathematically." The researcher asked Rick to expand on what he meant by *pushed mathematically*. Rick responded,

> For some students that had a simple game, the mathematics was pretty easy, while others had games with a more complex probability that took a higher level of mathematics to solve. I wished we would have pushed all the students to do more complex probabilities and then only scale it back for the ones that needed it.

The mathematical goal is an integral part of the makerspace experience and having a more precise goal for all students could benefit future iterations to ensure students are challenged mathematically and was addressed in future lessons as part of the DBR.

Coding Data into the Five Strands

The student responses, interviews, and observations were coded using a priori framework of the five strands of mathematical proficiency to address the research questions detailed in Chapter Three. Applied together, the five strands give a clear picture if a student is mathematically proficient in a given topic or learning objective (Groth, 2017; Pothen & Murata, 2006; Samuelsson, 2010; Suh, 2007). It is important to note that the five strands of mathematical proficiency are intertwined, indicating the qualitative data collected in the study could be coded into more than one strand.

Conceptual understanding. As defined by the NRC (2001) and listed previously, conceptual understanding is the comprehension of mathematical concepts, operations, and relations. There were indications of conceptual understanding in student responses, particularly in the answers from the first three questions. Students had to determine their theoretical probability, experiment probability, and discuss how the two compared. For example, in responding to a question, one student wrote that their theoretical probability was 3/10 and that, "There were 10 ducks, and three of them had stars on the bottom." The student was referring to their game where players would pick up a rubber duck out of a pond and based on what was on the bottom of the duck; a player would win or lose.

The same student stated their experimental probability was 10/38 or 5/19. The student's reasoning for the experimental probability was, "We added our total number of attempts and found the total number of wins." The student indicated conceptual understanding in relation to theoretical and experimental probability in that they found their theoretical probability by creating a ratio between the number of winning ducks and the total number of ducks. The student also detailed experimental probability through creating a ratio of wins to total number of trials based on the data they collected. This fits with the coding framework for mathematical proficiency found in Chapter 3, as the student is able to view the mathematics in the form of experiment and theoretical probability as a coherent whole in determining the values from the makerspace lesson. The probabilities are close as 3/10 is 0.3, and 5/19 is 0.26, yet different because of the students' real-world data. There was similar evidence in all the students' work. Students showed a distinct difference between theoretical and experimental probability in their methods of calculation and explaining how they used the data set they collected to calculate their experimental probability.

Procedural fluency. Procedural fluency is the ability to carry out procedures in mathematics. In this school-based makerspace experience, teachers evaluated student procedural fluency through the accuracy of the probability calculations. The formula or method for calculating probability is to determine the number of favorable outcomes over the total number of outcomes. For example, one student group had a game where students tried to select one cup with a winning prize out of four total cups. Students running the game would place the prize under the cup and then shuffle them for a player to attempt to find the winning prize.

One of the student participants in the group, George, wrote, "The theoretical probability for our game was one-fourth. I know this because there were four cups and one prize underneath one of the cups." George demonstrated the process his group used in determining the probability, in other words, the number of winning conditions over the total. Like George's reasoning on theoretical probability, his group found the experimental probability by dividing the favorable outcomes or wins over the total amount of games played. George wrote, "The experimental probability is eight out of 21. I know this because 21 people played our game, and only eight people won." The statement here by George also illustrates the student's understanding of how to find experimental probability procedurally. Every group of students had answers similar to those of George. They exhibited procedural fluency by applying their knowledge of probability in favorable outcomes over total outcomes in both theoretical and experimental types of probability. This flexibility with procedures is why George's responses were coded as evidence of procedural fluency according to the framework on mathematical proficiency.

Strategic competence. In viewing strategic competence, the researcher viewed students' ability to formulate a strategy in determining the theoretical and experimental probability. This approach to analyzing student responses fits with the NRC's definition of strategic competence or student ability to represent and solve mathematical problems. The type of game students chose influenced strategic competence in the complexity of representing and determining theoretical probability. Students who chose simple games of chance, such as a spinning wheel of chance or a duck pond type game in which students selected something to reveal if it was a winning or losing item provided little challenge for the students. In this case, students found it simple to represent the problem using mathematics to determine both the theoretical and experimental probability by counting the winners and the total number of outcomes to compute their probability.

However, when students chose a more complicated game, students demonstrated some difficulty representing the mathematics and formulating a strategy to calculate theoretical probability. For example, one group created a game in which players tossed rings onto 10 bottles placed on a board. Students in the group asked Alice for help in determining the probability. Alice asked students first, "What would be a favorable outcome or how would someone win your game?" One student responded with, "Landing a ring on a bottle." Alice followed this response with, "How does someone lose the game?" Another stated, "Landing the ring on the board." After a little more discussion, the students in the group decided to find the board's area using the formula for a rectangle area as their total outcomes as a ring tossed can land anywhere on the board to count as an attempt. The group determined that landing on a bottle was a favorable outcome, so they found the area of the top of the bottles using the formula for the area of a circle. As one student in the group, Aaron, wrote, "The theoretical probability for our game was 4.85 divided by 198. The area of the box was 198 (inches squared), and the area of the (top) bottle was 0.485 (inches squared), then multiplied it (4.85) by 10 to get 4.85." While students could dispute their theoretical probability as far as its accuracy, the makerspace experience created a situation through which students had to develop a strategy to finding theoretical probability in a new context. This example of a ring toss game required more exploration of mathematical representations than a standard probability problem.

Adaptive reasoning. Adaptive reasoning is logical thought, reflection, and justification as defined by the NRC (2001). To further explore adaptive reasoning in this makerspace experience, Alice and Rick crafted a question described above. Students had to apply what they learned to a different game with a prize wheel that was provided by the teachers to all the students. However, they added a little variation to the problem. Students had to find the compound theoretical probability, in other words, the probability of two consecutive events to create the desired outcome. Every student was able to determine the probability of one spin or one winning condition out of four totals. Yet, 51 of the 87 total students correctly calculated the compound probability. Those that did get it correctly employed one of two strategies, either multiplying one-fourth times one-fourth to get a probability of one out of 16 or counting out each of the 16 possible outcomes using a diagram or tally marks. Students who incorrectly found the probability accurately found the simple probability of each spin but were unsure how to compute the total. Some students added the two events and got an answer of two-fourths or added incorrectly and got two-eights. Other students believed the probability did not change because of the additional event and wrote one-fourth as their final answer.

Students were also asked to make a prediction based on the probability they found for two spins. Alice and Rick believed making a prediction would provide more insight into a student's logical thought and reflection on mathematical proficiency from the makerspace experience. Of the 51 students who correctly found the probability from two spins, 43 of the students were able to make an accurate, as in mathematically correct, prediction to the question, "If 40 students played Mr. V's game, how many would you expect to win? Why?" It is important to note that if students applied the probability of 1/16 to 40 players, they would get two and a half. However, 24 of the students adjusted their answer from two and a half. Six of them wrote their response as three; one student stated, "I rounded up to three since you can't have two and a half people." Eight of them wrote both two and three; one student wrote, "I would expect 2-3 people since you get 2.5." The remaining student gave an answer of two. One student that had two as their answer wrote, "You can't have two and ½ people." The reflection of the learning as part of the makerspace experience provided students the opportunity for logical thought, reflection, and justification in the follow-up questions asked by Alice and Rick which fit with the coding of adaptive reasoning strand of mathematical proficiency.

Productive disposition. Productive disposition is seeing mathematics as valuable and worthwhile (NRC, 2001). Several students referenced how probability is a useful mathematical concept when asked to describe their experience with the makerspace lesson. One student wrote,

> I found it very fun and creative! It certainly helped me learn this material better visually. I think it was a good way to learn how probability is in many everyday activities and how we can use it to improve games.

This student response references how the makerspace experience allowed them to discover the purpose of probability which is why the response was coded as productive disposition. Similarly, another student wrote, “It (referencing the makerspace) helped me learn about probability.” And a third student responded with, “Makerspace, I feel like I learned more while having fun.” Indicating how the makerspace experience supported their learning. While most students did not specifically mention seeing probability as being worthwhile, almost every student used “fun,” “creative,” “hands-on,” or similar words while describing their experience as part in the makerspace lesson as positive.

Yet a few students indicated that while they enjoyed the makerspace, they prefer learning in the classroom. In considering the productive disposition, their efficacy or self-belief in understanding mathematics plays a role. One student wrote about where they prefer to learn, “Regular classroom because I feel like I stay more focused in a regular classroom.” Another student responded, “Regular class setting because I like doing notes and everything we normally do.” A third student answered, “In the classroom, because we are used to it and it has examples around the room, but I like the makerspace better.” These responses indicate that students value the predictability and structured procedures found in the typical classroom setting. The makerspace experience did allow for the possibility of students to explore the usefulness of probability, but some still preferred the standard classroom.

Summary of Pilot Study

In partnering with the two practitioners, Alice and Rick, the researcher helped develop a makerspace experience specifically designed to address Resnick's (2017) 4Ps of educational making and the five strands of mathematical proficiency (NRC, 2001) to target the first research question. Specifically, for the pilot study, the researcher and the teachers developed a makerspace experience, the probability carnival, that allowed students to create a project targeting the mathematical content of basic probability. The intentional development of the makerspace lesson was to target the first research question related to what happens when an educational makerspace experience is developed to facilitate mathematical proficiency. Through observation, student work, and interviews, there was evidence to suggest all five strands of mathematical proficiency were evident in the makerspace experience in addressing Question 2 as detailed previously.

The data collected demonstrated the potential impact of a makerspace experience on student understanding of mathematical content as a means of addressing the second research question on what strands of mathematical proficiency are evident when facilitating an educational makerspace experience. There is evidence of the five strands of mathematical proficiency. One particular emergent theme surfaced as part of the inductive coding of the data in exploring the makerspace experience's impact. Due to the freedoms afforded students in creating their projects, there were multiple instances where students studied mathematical content to a more profound complexity than intended as part of the mathematical goal of the makerspace experience as detailed in the previous section. Future iterations of the makerspace experience will aid in determining if this theme will be a reoccurring product of mathematical concepts explored through makerspace driven lessons.

Makerspace Experience 1

Planning

Similar to the pilot study, the researcher partnered with Rick to develop the makerspace experience used in the educational makerspace experience. Two meetings were held again to discuss the design and implementation of the makerspace experience and address Resnick's (2017) 4Ps and the five strands of mathematical proficiency. For this makerspace experience, Rick wanted to target the mathematical concepts of scale, proportional relationships, and measurement. In particular, he wanted to focus on the TEKS standards of "solve mathematical and real-world problems involving similar shape and scale drawings" (Learning Farm, 2020a, para. 1) and "convert between measurement systems, including the use of proportions and the use of unit rates" (Learning Farm, 2020a, para. 2).

After determining the makerspace experience's mathematical goal, Rick and the researcher discussed what type of project students would make and how that would address the 4Ps. Rick stated, "Having students design a blueprint and then create something from it would be a real-world use for scale and proportion." After further discussion, Rick and the researcher determined students would design a city block or street. As part of the project, students would first develop a blueprint and scale from the blueprint. Students will then use their scale and apply proportional relationships to create their city blocks. With the challenges of Covid-19 and using technology as a tool to help students with their creations, Rick and the researcher determined that the educational suite from Minecraft, a computer educational game where students can build objects using cube shaped blocks, would allow students to build digital versions of their city. The school district had already purchased the Minecraft education suite for students to use on their school-issued iPads. In Minecraft, each group would have a digital sandbox where students could build whatever they want. Minecraft would also allow students to collaborate and develop together in a digital forum.

Addressing the 4Ps of Educational Making in Lesson Design

In addressing Resnick's (2017) 4Ps of educational making, Rick and the researcher determined the digital Minecraft creation would address projects as each group would create a city block. Second, students would again work in groups to develop their cities together for the peers' principle. Also, Minecraft could allow other students to visit the digital worlds where creations were being made. Rick stated,

> I think Minecraft will present the opportunity for groups to visit each other's worlds and allow for more collaboration than the previous makerspace lesson from last spring. I will make sure students have the opportunity to do this during class time.

Students would be given the freedom to determine the theme of their project to implement the passion principle of the 4Ps. Rick also mentioned, "Maybe we allow students to build a city to address a problem, such as pollution or something else they are passionate about?" After further discussion, Rick and the researcher decided to let the students choose to address a problem with their city design or create one with a theme related to their interests. Rick stated, "I think freedom of choice is when we will see student passion come out as part of their project."

Finally, the play would again take the form of tinkering with design in both the blueprints and the final digital creation in Minecraft. However, Rick stated, “I think letting students play with Minecraft first to determine what they can build may help their planning. It will give students a better idea of what they can create and allow them to alter their blueprints by testing designs.” Students would once again receive feedback from peers and Rick to help alter their designs. The freedom to build and plan simultaneously could provide more opportunities to tinker with the design.

Addressing the Five Strands of Mathematical Proficiency

Rick and the researcher then discussed the five strands of mathematical proficiency and how the makerspace experience would be designed to target conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition. Students would develop a conceptual understanding or grasp of mathematical ideas through connecting the blueprint to the creation in Minecraft. In particular, Rick stated, “Students will experience how scale and proportion are used through designing a blueprint and then carrying out the action of creating that blueprint in Minecraft. The math needed to connect the two will draw out the concepts of scale, proportion, and measurement as determined in our mathematical goal.” The visual presentation of scale and scale through student creation would help students explore the intended mathematical content.

Procedural fluency or the processes needed to use proportion and scale were apparent when students determined the size of their city block on the blueprint and then created proportional measurements in Minecraft. This process included creating a scale and using proportions to determine how large the city structures should be in Minecraft.

Students needed to apply the ratios flexibly, as structures in their projects varied in size depending on what they wanted to create. The students' ability to apply the procedures to create proportional buildings demonstrated strategic competence as part of the makerspace experience. There was also an opportunity for strategic competence to be shown in this context if students developed structures that were not rectangular prisms or were other shapes students have not yet encountered. For example, students could create a composite of multiple rectangular prisms or have a non-rectangular base.

As part of the makerspace experience, students would have to take the concept of scale in two dimensions and apply it to a three-dimensional Minecraft figure. As Rick stated, "It will be interesting to see how students use a scale with their buildings. We have never taught scale converting from 2D to 3D before, usually with just maps and like real-world distances of cities." Rick's comment indicates how creating in Minecraft would provide the opportunity to apply scale and proportion in a different way than students may have experienced before. This type of experience aligns well with the definition of adaptive reasoning. Finally, drawing on the real-world application of blueprints to construction may allow students to determine the purpose of scale, proportions, and measurement. Students would experience some of a city planner or architect's work and how mathematics plays a role in these professions.

Implementation

The city planning makerspace experience implementation took place over 7 days in the fall of the 2020-2021 school year. The timeline was as following:

- Day 1: Rick explained the introduction of the makerspace experience and the purpose of planning a city block for students. Rick provided the following requirements:
    - Create a city street or block in Minecraft with at least five buildings and a type of transportation system.
    - Determine a scale and proportional relationship between blueprint plans and Minecraft creation.
    - Create an overview video and images that demonstrate the scale used and the proportion of the buildings.
    - Provide feedback to other groups to support their project design.
    - Reflect on the learning experience.
- Day 2: Students created a rough draft of their city block and determined their project themes.
- Day 3: Students finalized their blueprints and found the scale they would use to build their structures in Minecraft. They also began making their structures.
- Day 4: Students built their structures.
- Day 5: Students visited each other’s Minecraft worlds and offered suggestions for project improvement.
- Day 6: Students made final adjustments and created videos and images to demonstrate their understanding of scale, proportions, and measurement.
- Day 7: Students completed the final reflection.

Observations

As in the pilot study, the researcher acted as a participant-observer to develop and implement the makerspace experience. During the implementation, the researcher observed the classes and interacted with them as they built their cities. Using Minecraft as part of the makerspace experience allowed the researcher to visit student worlds digitally for observation during class time.

Rick began the makerspace experience by showing students a video clip about the World's Smallest Skyscraper in Wichita Falls, Texas. The video narrator explains how inaccurate blueprints lead to the skyscraper being 400 inches tall instead of 400 feet and investors being swindled out of money. The video potentially provided students some understanding of the purpose of creating accurate blueprints before building in Minecraft. Students were also introduced to the mathematical concepts of scale, proportion, and measurement through the video. Rick also explained how students would create blueprints for their city streets, select a theme, and build their Minecraft city. One student asked the following, "I know in Minecraft that one Minecraft voxel (block) is 1 meter cubed; can I use that as part of my scale?" Rick responded, "Yes, but you are not limited to that, you are free to create whatever scale you want, but the proportional relationship between your blueprint and Minecraft buildings needs to be mathematically correct."

Students appeared excited about the prospect of using Minecraft in class and began playing with the technology and discussing ideas for the themes. One student stated, "If we have waterways for our streets, we can reduce pollution as citizens can get around in rowboats." Another group liked the idea of creating a Harry Potter themed world, one student in the group stated, "We can use the books to help us determine how big to make the buildings." A third group began discussing the idea of creating an amusement park instead of a city block. They asked Rick if this would be ok. Rick responded, "I am ok with it, but you need to make sure you have the required number of structures and create a scale that is accurate to your park." As in the pilot study, the student chosen theme or purpose invited student passion to the makerspace experience.

On Day 2 students created drafts and began the process of determining scale for their blueprints. Rick had provided the students with grid paper that had ¼ inch squares to help students create measurements for the project. Students began to ask questions concerning the two-dimensional grid paper and planning three-dimensional shapes. Rick showed students an example of an overhead view of a city block and guided students to focus on the length and width first and then move to height after creating their project's overhead view. Most groups were able to determine their project scale with no assistance and did some initial building of their structures bases to check their scale and make modifications as needed. One student did ask Rick the question, "Is it ok to have our blueprints in inches and our Minecraft blocks in meters?" Rick responded, "Yes, converting measurements is a useful application of scale and proportion." By creating blueprints for structures to be built in Minecraft, students could see a purpose for scale and proportions.

Students finalized their designs and began the construction process on Day 3. Rick engaged in multiple conversations with students about their creations during this phase of the makerspace experience. One group in particular wanted to create a circular building as one of their structures. One student from their group asked Rick, "How do we determine the dimensions of our circle?" Rick responded, "How would you find the dimensions of a rectangle?" Another student in the group responded, "We can count diameter in each direction to use for length and width for our bank (circular building)." Students in Rick's class had not yet learned about finding area and circumference or other properties of circles. However, the makerspace experience provided the opportunity for students to explore a variety of shapes.

As students built their Minecraft structures over Day 3 and Day 4, student discussions were centered around ensuring their blueprint plans matched their buildings in Minecraft and vice versa. Students ventured into their Minecraft-generated world on their iPads and went through the labor of stacking Minecraft blocks and items to create their projects. The researcher observed students counting and referring to their blueprints to ensure their measurements matched. Rick and the researcher used their school-issued iPads to visit Minecraft worlds for each group and observe the process of building. The researcher noted that students collaborated in a variety of forms. Some groups had each student take a different building and build separately and then check each other's structures. In contrast, other groups built each building one at a time together as their preferred collaboration method. There were also a couple of groups in which one student took on more of a leadership role and directed the other students to build while referring to the plans.

While visiting various student Minecraft worlds, Rick would also ask students to explain their scale and how they created it. Some students used measurements such as inches and meters, while others created a scale in terms of a number of Minecraft blocks. For example, Rick asked one group to explain their scale, and a student from the group responded, "1/4 of an inch on the grid will be worth 5 Minecraft blocks." Rick asked the student to go into further detail about how their group determined the scale, and the student responded, “We went into Minecraft and laid out some blocks to plan for our city and then drew our blueprint sketch. We used ¼ of an inch to 5 blocks so our sketch would fit on the page.” Rick asked the same question to another group, and a student from this group responded, “We knew that each grid was ¼ of an inch and each block was 1 meter, so we used ¼ of an inch to 1 meter.” Every group responded to Rick’s questions similarly. They were comparing ¼ inch to 1 meter or a number of blocks in their Minecraft world. While every group used the ¼ inch grid paper as a starting point for creating scale, the varying size of Minecraft projects influenced the scale students used.

On Day 5, students took turns visiting the Minecraft worlds created by other groups to offer suggestions. Students showed the other groups what they were building and discussed the themes of their cities. The suggestions offered were primarily cosmetic. One group had suggested adding a tank structure to a group that had made a military base. Another group suggested increasing the width of a water transportation pathway so that boats could move in both directions. One group of students had constructed a haunted city block, and students visiting that world suggested adding spiderwebs to the buildings’ roofs. Finally, one group had built a roller coaster track but wanted a minecart to move on the path. Students from another group assisted them and showed them how to make the cart move to simulate a roller coaster. While the student feedback was not mathematics based, allowing the groups to collaborate on design, enabled them to learn from each other and make more complex projects.

The day following the student collaboration visits and the last day of project construction, groups finalized their projects and collected videos and images to submit. The video clips were 30 seconds to 1-minute flyovers of their city block, and students labeled images to compare their blueprint measurements with the final structures. All student groups were able to match up the measurements accurately from their blueprints to the images of Minecraft's structures as part of their final project, which is detailed in the following section. The project required students to construct five buildings, a transportation method, and a theme; however, every group created something extra as part of the project.

Some groups added inside features to their building, such as furniture, rooms, and one group added an elevator. While other groups added extra features such as a cattle pen with cows, a tank, and a working roller coaster, the makerspace experience provided opportunities for students to create outside of what would have traditionally done with this lesson of study.

On Day seven, students were asked to answer the following questions as part of reflecting on the makerspace experience:

Student Reflection on Makerspace Experience 1

Part 1

1. What was the scale for your blueprint? How did you determine the scale?
2. What would the dimensions of a building that is 480 by 50 by 80 feet be on your blueprint or city map? How did you determine these values?
3. What purpose does scale and proportion have in creating your blueprint or city map?

Do you think scale and proportion are important mathematical ideas to understand? Why or why not?

Part 2

1. The Tower of Americas in San Antonio, Texas, stands at 750 feet. On a map, the tower is 37.5 mm tall. Can you determine a scale between the map and the actual Tower of Americas?

The Alamo has a height of 1.5 mm on the same map. How tall is the Alamo?

Part 3

1. How would you describe your experience with the city building project?
2. Do you prefer to learn math in a makerspace project or in a regular classroom setting? Why?

Which setting (makerspace vs. regular classroom) do you find to be more beneficial to your mathematical understanding? Why?

Post-Interview

As in the pilot study, at the conclusion of the makerspace experience, Rick was interviewed to discuss the makerspace experience as another source of data and inform future iterations of the makerspace experience as part of the DBR. The interview conducted was semi-structured and followed the same format as detailed in Chapter Three.

Rick was first asked to describe the makerspace experience and the mathematical learning goal (IQ1). He responded,

> Students understood proportion based on what was previously taught in class but had yet to do anything with scale or scale factor. We thought that we could have students explore these mathematical relationships through this project by building things in, um, Minecraft. We used the tiny skyscraper's hook and then let students get creative to explore these math concepts. I thought students might get into volume-based creating buildings, but I had many conversations about converting

> different widths and lengths that hit the math target of scale. We did trip into some mathematical ideas of comparing 2D on the grid to 3D in Minecraft.

Rick's response outlines the intent of the mathematical concepts of proportion and scale. He was also anticipating students might get caught up in other mathematical ideas such as volume. Still, as he mentioned, and which was observed, most conversations did connect to the mathematical goal of proportion and scale.

I asked Rick to say a little bit more about the 2D vs. 3D he stated in his response. He responded,

> Just like students understanding that you will not see height on the grid and that the corner pieces of buildings will count three ways toward your measurement in the length, width, and height. Almost like counting in 2D, you only count two ways, but in 3D, you have that third dimension that has to be thought about.

Rick's response to this follow-up question provides a potential benefit to the makerspace experience. Students got to experience how scale may be realized a little differently in the real-world through experiencing 3D scale and proportion, which was not part of the originally intended mathematical goal or curricular content of Rick's math class.

Rick was then asked about the 4Ps (projects, passion, peers, and play) and how the educational makerspace experience was structured to include all 4 of Resnick's principles (Interview Question 6). Rick responded:

> We did projects, which to me, they created some high-level stuff. I think that was, that was through the roof. I felt the passion piece was strong in the variety of creations students made. There was some potential for some cool peer stuff in the digital world and opportunities to collaborate in new ways in Minecraft. Looking back, though, I would have assigned roles because I did notice even on the planning document and the final plans, it seemed like one person just took control of that while others were building in Minecraft world, which was good. Still, some students might've missed some of the mathematics on it. However, I think we should potentially let students play even more before introducing the mathematics. Maybe even spark an idea and let them play and tinker to figure out what the technology can do or can create and then present the mathematics as a turning point to guide final project design. This restructuring may open up more

> opportunities for passion, learning through play, and peers if the project is even more broad to start.

Rick's response to the implementation of the 4Ps as part of the makerspace experience details how the lesson included all four principles. Unlike the pilot study, the project in this makerspace experience was a digital product in the form of the Minecraft creations. Students once again had the opportunity to bring in passion in the themes and purposes of their city blocks as part of the makerspace experience. Rick's response to passion and the variety of student creations refer to how some students chose to address pollution through a water transportation system. At the same time, some built a project related to books that interest them while other students built familiar structures such as a local grocery store. The students' ability to digitally collaborate was new in this makerspace experience. Still, it did allow students to build their structures simultaneously as alluded to by Rick and for students to visit each other's worlds.

The issue of play once again is brought out in the responses by Rick. There appears to be a conflict between students' level of freedom to play or tinker with design and when to attach the mathematical learning goal. Rick was asked to further explain this as part of what can be improved with the subsequent iteration makerspace experience. He responded,

> I worry we're almost limiting students by putting too much mathematics first. We almost had the Minecraft piece as a reward for doing some of the math. I think if we push even more of the play piece on the front in and then unfold the mathematics along the way and students can make adjustments to the design based on that.

The researcher and Rick made note to consider when to release the mathematical goal as part of the makerspace experience design for the next iteration or makerspace experience.

Rick and the researcher then discussed the five strands of mathematical proficiency (Interview Question 5). Rick was asked what strands of mathematical proficiency appeared as part of the makerspace experience. Rick stated:

> I think students having to create a scale and then apply it along with proportional reasoning brought out most of the strands. There was a lot of conceptual understanding in the beginning when students created their scale; they had to think about what this looks like whenever I transfer it over to the Minecraft world, even before we let them go into Minecraft. They were also forced to develop a strategy to solve the problem of scale because it wasn't given to them, and if they did not use proportional reasoning and the proper procedures, their Minecraft structures would not have looked right.

Rick's initial response indicated conceptual understanding in students creating their scale as well as adaptive reasoning and strategic competence in using logical thought in developing a strategy to apply their scale to Minecraft. Rick also mentioned students using procedures, in other words, procedural fluency, as part of finding the measurements of their Minecraft structures based on the scale students created.

The researcher noticed Rick did not mention productive disposition, so the researcher followed up this response by asking, "What about productive disposition? Did students see a purpose or usefulness in the mathematics?" Rick responded, "Absolutely, students understood that scale is important in everyday life. I had several students ask me if this is what an architect does. They saw developing a map or blueprint and then building as a real-world skill." Rick's response indicates students made connections with mathematics to useful applications in real-world settings.

Finally, Rick was asked if alterations should be made to the makerspace experience to address the 4Ps of educational making or the five strands of mathematical proficiency. He responded:

> I feel like we have done an excellent job of bringing in both the 4Ps and the five strands and that this makerspace experience was better than the project carnival

> last spring. I still think the most significant change is when we release the mathematical information to students. I would like to see them, um, play more first. Let them tinker and figure out what the technology or materials can do and then slowly release mathematical ideas throughout the experience. We may have put too much information about scale initially, and the mathematics was a little disjointed from Minecraft. Most of the students did the math and then built, maybe having those things happen more simultaneously. Overall, I thought it was an excellent experience for students. They discovered the importance of scale; we want to guide students to the mathematical goal by creating instead of reaching the goal and then doing the project.

The alteration Rick described is similar to the alteration from the first iteration. There appears to be a tension between the freedom of creation students get as part of the makerspace experience while still targeting a learning objective. Rick's proposed idea of allowing more play at the beginning might allow for more passion and creativity to be brought into the makerspace experience and weaving the mathematical goal throughout the experience could strengthen the attachment to the five strands of mathematical proficiency.

Coding of the Data

As in the pilot study, student responses, interviews, and observations were coded using a priori framework of the five strands of mathematical proficiency to address the research questions as detailed in Chapter Three.

Conceptual understanding. In developing a conceptual understanding of scale and proportion, students need to develop that scale is the ratio of a drawing or model to the actual object and that proportion is the comparison of two given ratios. In the makerspace experience or makerspace project, students were to develop a scale between their blueprint or sketch and the sizes of the buildings created in Minecraft. Students also used proportional reasoning to find missing measurements once they had developed scale as a relationship between their blueprints and Minecraft creations. The first two questions in the written reflection and students' final projects demonstrated their conceptual understanding of scale. For example, Chelsea (all participants were given pseudonyms) wrote:

> The scale or key for our map was $2m^2$ = ¼ inch. I determined the scale by comparing the Minecraft blocks to the ¼ inch cubes on the map. Two blocks fit across the top and the side so that the dimensions were $2m^2$ for each square on the map.

Chelsea also used the scale that she created to answer the second question accurately, "What would the dimensions of a building that is 480 by 50 by 80 feet be on your blueprint or city map? How did you determine these values?" Chelsea responded:

> My scale was $2m^2$ = ¼ inch, and you get from 2 to ¼ by dividing by 8, so I did the same thing to these numbers. But after I divided by eight, it was just showing me the (number of) ¼ inches, so I divided by four again to give me the total inches.

The two responses by Chelsea indicate her understanding of scale and proportion as part of the makerspace experience. Chelsea drew a comparison between the blueprint plans on the grid to the size of the Minecraft blocks to develop a ratio between the two measurements. She was also able to take this ratio and apply it to a given building. Her demonstration of creating a scale and then using it in a new situation potentially provides insight to her conceptual understanding of scale and proportion and led this artifact to be coded as conceptual understanding as part of the mathematical proficiency framework.

Similarly, a student from a different group, Patrick developed a scale for his blueprint and Minecraft project, yet approached the problem a little differently. Patrick responded,

> The scale or key for our map is ¼ inch = 5 Minecraft blocks. We determined the scale because we believed that if we thought in increments of five, it would be easier to determine how many inches for every five blocks.

Patrick also addressed the second question and applied his scale to the new situation. He wrote, “I determined these values by using the scale that we used for the project. ¼ inch: 5 blocks or 1 inch: 20 blocks.” Like Chelsea, Patrick took his ¼ inch scale and created a new one for 1 inch. He was also able to find measurements for the new shape using proportional reasoning to find the new building’s missing values. The two different approaches to solving the problem of scale and proportion, one involving measurement in meters while the other counting blocks potentially demonstrate that student thinking about scale, was not bound by a particular measurement but rather by comparing the blueprint plans to the structures in Minecraft. Not being bound by facts or procedures is why the two responses were coded as conceptual understanding.

Procedural fluency. Procedural fluency is the ability for students to carry out mathematical procedures as part of the problem-solving process. The two examples above potentially show procedural fluency. Both students created a proportional relationship between their scale and the new building and then used either multiplication or division to find the missing value. Like Patrick and Chelsea, other students provided examples of mathematical procedures related to scale and proportion to find missing values.

Jason, like the other two students, took his scale and determined how to find the missing values. He wrote, “I used my scale (1 block = 5 feet) to figure out that I can just divide the numbers by five and get the amount of blocks for each dimension.” Unlike the previous two examples, Jason left his answers in terms of blocks instead of inches. Nevertheless, like the previous two, Jason’s procedural understanding let him determine an answer that worked for his blueprint or map size. Another student, Casey described her process for solving as follows, “We determined our scale by lining up the photos with the grid to determine a scale of 1 Minecraft block is ¼ of an inch. To find the missing sides, I used my scale and divided by 4.” In all four of the examples, students referenced using their comparison or scale to set a proportion and then divided to find the missing value. This approach was the typical way in which students described their procedural use of scale and proportion. The process of dividing by 4 to find the missing sides displayed Casey’s ability to flexibly using procedures in the correct context to solve the problem of finding the missing side and is why Casey’s response was coded as procedural fluency as part of the study.

Strategic competence. The researcher viewed strategic competence in this makerspace experience as a student’s ability to determine a strategy for creating scale and finding missing measurements. While most students took a similar approach to applying their scale to find missing measurements as detailed in the procedural fluency section above, many student groups took different approaches to find the scale between their blueprint and Minecraft project. This may have been attributed to the freedom students had as part of the makerspace experience in the size of their Minecraft structures. In coding responses as strategic competence the researcher looked for student written responses that demonstrated various approaches to solving the mathematical problems associated with the makerspace experience.

As listed in the previous section, Casey’s description discusses using Minecraft images to compare to the ¼ inch grid paper. In observing this group’s process for finding scale, students created their first building, took a picture, and then sized up on their grid to create their scale. This approach was different from most of the other groups. Other students referenced what they knew about building size and the size of characters in Minecraft. Scott wrote, “The average size of a story is 10 feet, and a Minecraft character is two blocks tall, so each block is five feet tall. So, we made our scale ¼ inch = 5 feet.” Similarly, Eli stated, “The average size of a story is 10-15 feet, so we used three blocks is 15 feet to find our scale.” Other students were concerned about making sure their blueprint included all their buildings. Ashley stated, “If we were to have a smaller difference in scale, our city would not fit on the grid, so we used ¼ inch = 5 ft.” Finally, some students were concerned about their measurements being realistic; Heather wrote, “I thought that ¼ of an inch to 4 blocks was proportional to real life so that it looked realistic.”

The variety of strategies by student participants indicate two aspects related to the makerspace experience and strategic competence. First, students did not have any strict guidelines as part of the makerspace experience on the scale needed for various strategies to be used by students. Second, students’ variety of strategies is potential evidence that students gained strategic competence concerning scale.

Adaptive reasoning. Adaptive reasoning is the capacity for logical thought, reflection, explanation, and justification. The student work related to this makerspace experience detailed previously indicates some adaptive reasoning in justification, explanation, and justification of finding scale and missing measurement. Students also had to apply logical thought in developing a strategy for determining the scale as described in the strategic competence section. However, similar to the pilot study, students were asked to apply what they had learned to a different situation to explore student adaptive reasoning. As part of this makerspace experience, students were asked to find a scale between the Tower of Americas, located in San Antonio, Tx, 750 feet tall, and a given map measurement of 37.5 mm and describe how they found the scale.

The San Antonio problem is the type of problem students would typically encounter when practicing how to find scale. However, the students had not been exposed to a scale problem of this type in Rick's classes. Every student in both of Rick's classes could determine the scale to be 1 mm is equal to 20 feet. All the students also discussed dividing 750 by 37.5 to determine the scale of 1 mm to 20 feet. Students being able to apply the facts of the building in San Antonio to determine the mathematical value of scale is this context led to the student responses on this problem to be coded as adaptive reasoning. There is value in students being able to find an answer to a given problem accurately as a form of assessment and measuring student learning. However, a potential benefit to the makerspace experience was students' freedom to solve problems in various ways, as described in the strategic competence section.

Productive disposition. Productive disposition is related to a student being able to see mathematical content as valuable and worthwhile. As part of the makerspace experience, students were asked if they believed scale and proportion were valuable and important mathematical ideas to understand as part of Questions 3 and 4 in the student reflection. Every student responded positively about scale and proportion as meaningful mathematical concepts.

For example, Chelsea, whose work was referenced previously, wrote the following when asked about the purpose of scale and proportion, "While creating the city map, scale and proportion helps me know how to show the correct dimension when I was building. I had to stick to the plan and not just build something random." Her response indicates her understanding of scale and proportion to create a building that matched the plans she created. When asked about scale and proportion being important mathematical ideas, Chelsea wrote,

> Scale and proportion are important mathematical ideas to learn because when graphing and using any sort of fractions, you need to know how to make equivalent and proportional numbers, and to do that you need to use a certain scale. Scale and proportion are used in a majority of math classes or units, in order to be successful, you need to thoroughly understand these things. This was a great project to help us understand them!

Chelsea's response potentially demonstrates her viewing these concepts as useful in many aspects of mathematics. She details their value not only in this project, but in exploring other number relationships.

Other student participants explained how scale and proportion are helpful in real life. Michael wrote, "Scale helps so that you won't have a 30-foot-tall doghouse and so that all things you built looks realistic to real life." He further detailed scale and proportion as important when he stated, "I think they are because if you are an architect, you can tell that in the blueprints a foot may actually be 100 feet in real life." Like Michael, Scott wrote, "Scale allows us to upscale accurately using the same dimensions." He also addressed the real-world usefulness of scale and proportion when he wrote, "It is required in everyday tasks such as making multiple batches of food, but also other tasks like building a bridge." In seeing mathematics as applicable, students should understand where mathematics potentially fits in everyday life. Like Michael and Scott, most students referenced where scale and proportion are evident outside of the mathematics classroom. Similarly, every student described scale and proportion as an essential part of creating a project that matched their blueprint plans.

Students also referenced the makerspace experience of the educational makerspace as impacting their learning experience. One student stated, “I prefer the makerspace projects because I get to be more creative while I feel more restrained in regular classroom projects.” Another student referenced the experience by stating, “I enjoyed the makerspace because it’s more hands on and easier to retain information because of the experience.” Other students referenced the visual element and collaboration aspect of the makerspace experience in supporting their learning. “I liked the makerspace because I think I learn better if there’s a visual example and getting to work with other students helped me understand the math.” While not all students mentioned the makerspace experience in supporting their learning, it was a common theme in most participants’ reflections.

Summary of Makerspace Experience 1

Following what was learned from the pilot study, Rick and the researcher planned an educational makerspace experience to target the mathematical concepts of scale, proportion, and measurement. Students were tasked to create a scale from a blueprint they created and then built the structures from the blueprint and used proportional reasoning to determine the sizes of the structures in Minecraft. The makerspace experience was designed to address Resnick’s (2017) 4Ps of educational making. For this makerspace experience students created a city block as their project, worked with peers as part of the creation process, developed a theme or purpose for their city block to address passions, and students were allowed to play with design based on feedback from their peers by making adjustments to ensure their buildings matched their scale. Students were able to create a variety of projects in Minecraft that demonstrated all aspects of the 4Ps.

The makerspace experience was also intended to address the five strands of mathematical proficiency in addressing both Research Questions 1 and 2. Students explored the concept of scale through creating their own, used adaptive reasoning and strategic competence to apply their scale to their Minecraft structures, applied procedural fluency to calculate measurements, and developed an understanding of how scale and proportion can be useful mathematical ideas. The reflections and observations of students as they worked provided evidence that all five strands were potentially evident.

Like the pilot study, several themes emerged. Students once again explored mathematical concepts in unintended ways and created things that were not required as part of the makerspace experience. Some students built structures in shapes that they had yet to explore mathematically such as circular objects. Others created complicated scales that required the application of multiple steps to build their structures with a variety of factional elements, and other students built structures that were not required, like furniture inside buildings, because of the desire to create a meaningful project.

After this makerspace experience, Rick and the researcher discussed ways to improve the next iteration of the makerspace experience as part of the DBR. The tension between educational making and mathematical learning goals appears to remain as an area of improvement. Rick and the researcher agreed it was important to consider when to release mathematical information to students to support them in the learning goal of the next iteration and ensure students have more opportunities to play or tinker with design from the outset of the makerspace experience.

Makerspace Experience 2

The researcher and Rick met to plan the final implementation for the educational makerspace experience utilizing the alterations informed from the pilot study and the first lesson implementation. They discussed how to include the 4Ps and the five strands of mathematical proficiency as part of the makerspace experience and what mathematical concept to target. Rick wanted to target the concept of operations with rational numbers, notably addition and subtraction of rational numbers, to address the TEKS standard of "add, subtract, multiply, and divide rational numbers fluently" (Learning Farm, 2020b, para. 1). *Rational numbers* are defined as "a number that can be made by dividing two integers (an integer is a number with no fractional part)" (Math is Fun, 2018, para. 1). In other words, the makerspace experience was intended for students to add or subtract both negative and positive numbers, including fractions, decimals, and be able to represent the value on a number line. Given the freedom to choose their own values, most students did not use fractions or decimals. However, Rick was more concerned with students understanding the operations of adding and subtracting both positive and negative numbers.

Planning

Rick and the researcher discussed how to include Resnick's (2017) educational making principles (4Ps) and the five strands of mathematical proficiency. In addressing projects, students would create a movement path for an Ozobot. Ozobots are small toy robots designed to blend physical and digital worlds to teach kids programming skills (Ozobot & Evollve, 2020). The programming is simple in that you train the robots to follow patterns on the surfaces they rollover. Students for this makerspace experience will create a movement path attached to a number line that will demonstrate rational number addition and subtraction based on the distance the Ozobot travels. As part of the project, students will select a theme for their Ozobot and tell the story of the Ozobot's travels to address passion. Passion would be address through student selection of them and creation of a meaningful story line. Students would once again have the opportunity to work with a peer; for this makerspace experience, students were placed in pairs. Finally, as students matched their Ozobots' movements with their stories, they had the opportunity to tinker with design to make the two match. Students were also given a chance to provide each other feedback to guide some of the tinkering with the design. Rick stated, "I want students to have time to tinker with the robots before addressing the mathematics. I want them to know what their Ozobot can do and then fold the math into their project." His comments match his modification recommendation of allowing additional time for students to tinker with the materials before addressing the math related concepts.

The makerspace experience was once again structured to address the five strands of mathematical proficiency to address the research questions. According to Rick, "Students will develop conceptual understanding through the movement of the Ozobot on the number line. Moving to the right will show addition or subtracting a negative and moving to the left will show subtraction or adding a negative." The researcher asked Rick what subtracting a negative would look like with an Ozobot. Rick responded,

> If facing right is positive and facing left for the robot is negative and moving forward is addition and moving backward is subtraction. So, if a student subtracts a negative, the robot would face left and move backward the same as a positive movement.

Rick later added, “The conceptual understanding will be shown with the Ozobot moving in the correct direction.” Rick’s response indicates that student understanding of the concept of rational number operation is not necessarily dependent on students calculating the operations correctly but rather which direction on a number line the Ozobot would travel based on the operation preformed.

In discussing strategic competence and procedural fluency, Rick and the researcher discussed student approaches to determining their Ozobot movement. Rick stated,

> I think we will see some strategic competence in the approach students use in calculating the distance the Ozobot traveled and their final location. They will also have to use the operations correctly and flexibly to mirror their stories as a type of procedural fluency.

Rick’s response indicates how the mathematical operations completed by the students as part of the makerspace experience provide evidence of strategic competence and procedural fluency. Next, Rick and the researcher discussed adaptive reasoning. The researcher asked Rick where he sees the potential for adaptive reasoning; Rick responded,

> We should see adaptive reasoning in the stories they, um, created to match their Ozobot movement. It should be a fitting reflection of the math involved and some logical thought in matching the two. They are not just doing operations. They are telling the story of the operations.
>
> Finally, Rick and the researcher discussed productive disposition. Rick stated,
>
> I think students will see the purpose of the mathematics when it is attached to the movement of the Ozobot (referencing movement on a number line) and when they create a story. I imagine some students will apply it to movement on a football field or a car going up and down a road.

Rick’s response indicates there is a natural connection between movement and rational numbers. The makerspace experience will potentially draw out this connection through the intentional coordination of the math with the Ozobot movement's story. Students would have the opportunity to experience the math in context to exploring the real-world purpose of the content.

Implementation

The Ozobot makerspace experience implementation took place over 6 school days in the fall of the 2020-2021 school year. The timeline was as following:

- Day 1: The makerspace experience was introduced, and students had the opportunity to tinker with the Ozobots.
- Day 2: The requirements of the makerspace experience were given to students and an example was shown to guide student thinking. The requirements were as follows:
    - Create at least eight Ozobot movements; Ozobots must move in two directions.
    - Determine a number line to show the operations; addition and subtraction must both be used.
    - Create a story that details the movement of your Ozobot.
    - Calculate the value of the final location of your Ozobot and the total distance traveled.
    - Create a video that shows the movement of your Ozobot and tell the story of the movement.
    - Complete a reflection on the learning experience.
- Day 3: Students began drafting their stories and determining their operations.

- Day 4: Student groups offered each other feedback, finalized their stories, and programmed the movement of their Ozobots.
- Day 5: Students completed their Ozobot projects and finished their calculations.
- Day 6: Students filmed their final project and completed the reflection.

Observations

On Day 1 Rick began the project by showing students a clip from the Alabama-Auburn football game from 2013. He explained to students how a football's movement up and down the field demonstrated rational number operation. Rick also gave football-specific examples, such as a run of 11 yards would be similar to adding 11 while a sack of 7 yards would be akin to subtracting 7 or adding a loss of 7 yards to the football movement. After the introduction, student pairs were given an Ozobot, some colored markers that were used to program the movements, and scratch paper. Rick showed students how the Ozobot will follow the lines drawn on a paper and how the different color makers are used to program the movements. Rick encouraged students to try different things with their Ozobots. He told students, "Try having your Ozobot turn, move forward and backward, and speed up or slow down. You can also make it do extra movements such as spin or shake." Students appeared to enjoy the introduction and experimented with the Ozobots. Most appeared to be successful in making their Ozobot complete a variety of movements.

Day 2 students were given the requirements as listed above for the project. Rick showed students an example of a path for an Ozobot with a labeled number line. He also gave examples of how each movement could match rational number operations and a sample story of someone walking back and forth on a path. Students were then free to plan and work on their Ozobot project. As students began to work, they started asking Rick questions related to the project. One pair of students asked Rick if they could make a vertical number line and have their Ozobot move primarily up and down to represent number operations. Rick responded, “Yes, you are welcome to have a vertical number line, but why did you choose vertical over horizontal?”

One of the students replied, “My dad was a diver in the marines, and I want our Ozobot to move up and down like a diver.” The student’s choice of a vertical number line to match their dad’s connection indicates the passion principle as part of the makerspace experience.

Similarly, other group projects displayed passion elements due to the themes and stories students choose to connect to their Ozobot’s movement. Another group also choose a vertical number line to represent their Ozobot going up and down a mountain. Other students selected a soccer field for their Ozobot to move on as both students played on the school soccer team. The makerspace experience allowed students to attach personal meaning to the mathematical content.

By Day 3 all student pairs had selected a theme, were attaching mathematical representations to their Ozobots, and were programming the movements by drawing different colors on their Ozobot paths. As students connected the real-world elements of their stories to mathematics, questions began to arise. One pair of students asked Rick the following question, “Our Ozobot is a gymnast doing a floor routine; how do we find the distance if our Ozobot moves diagonally?” To calculate the diagonal distance of straight-line motion, students would need to use the Pythagorean Theorem. However, the

Pythagorean Theorem is traditionally not taught until the eighth grade, so the students had not yet encountered this mathematical concept in the classroom. They developed a need for Pythagorean Theorem because of the makerspace experience. Rick discussed the Pythagorean Theorem concept with the students and had them only find the horizontal movement of their Ozobot to match their number line. The opportunity to dive deeper in the mathematics presented itself as part of the makerspace lesson, but Rick chose to stick with movement in only two directions when discussing the mathematics with students.

Students also had questions related to the operations themselves. One pair of students asked Rick, "We want our Ozobot to move forward, pause, and then move forward again. Is it ok to have multiple operations in the same direction?" Rick responded, "Absolutely, you have the freedom to make multiple operations in one direction but be sure your Ozobot heads in both directions." Multiple students also asked how to represent subtraction with a negative number. After fielding the question a couple of times, Rick paused the class and addressed all the students. He posed this question to the class, "If facing left and moving backward are both negative, what would it mean for your Ozobot to face left and travel backward?" One student responded, "It would be the same as subtracting a negative, which would be like the Ozobot moving right." Rick followed up, "Give me a little more detail; what do you mean moving right, isn't that addition?" The student stated, "The robot will move right, but backward." Rick responded, "Did you hear what (student) said? The Ozobot will move right but backward, which would demonstrate subtracting a negative is also a positive movement." Rick's conversation potentially demonstrated how the makerspace experience brought out the visualization of mathematical concepts, which might impact student mathematical proficiency.

Day 4 students finalized their stories, met with other groups to discuss their projects, and began programming their Ozobots. The collaborative conversations among groups primarily began with the stories students had crafted for their Ozobots. However, as students offered suggestions or groups made alterations based on peer feedback, the conversation often switched to mathematics. For example, one group created an Ozobot story about a trip to the grocery store. In the story, the Ozobot went up and down the aisle to collect items for purchase. A student from a different group offered the suggestion, "Maybe your Ozobot could back the shopping cart up to return an item?" A student responded, "I like that idea, but how do we write that with the math if the Ozobot is already traveling to the left?" After some debate, the students decided the Ozobot would stay facing left but move to the right, subtracting a negative value.

Similarly, another group offered suggestions for an Ozobot that was going up and down a mountain. One student offering feedback asked the students with the mountain climbing Ozobot, "What happens when your Ozobot is going up the mountain? Does it slow down?" The student responded, "Yes, it slows down as it goes up, but it doesn't change our math, it just takes the Ozobot longer to go up the mountain than it does to go down the mountain." Without realizing it, the students were beginning to enter into a conversation about how the mathematical idea of how rate, time, and distance are related. As in the other two makerspace experiences, the nature of creating a project presents opportunities for students to extend their mathematical discussion beyond the intended learning goal.

Day 5 students finished programming the path of their Ozobots by drawing lines with colored patterns, decorated their number lines, and recorded themselves reading their stories. At the same time, the Ozobots moved along the programmed path. It was also an opportunity for students to see the final projects of other groups. While there was little student interaction related to mathematical proficiency or the makerspace experience's mathematical learning goal, students appeared to have a sense of accomplishment as they had the opportunity to display their projects and create videos of their final project.

On Day 6 students were asked to answer the following questions as part of reflecting on the makerspace experience.

Student Reflection on Makerspace Experience 2

Part 1

1. Describe the movement of your Ozobot in terms of mathematical operations.
    - When would the Ozobot traveling to the right?
    - When would the Ozobot travel to the left?
2. What was the final location of your Ozobot?
3. Did the movement of the Ozobot help you in determining the operations? Why or why not?
4. Do you think rational number operations are an important mathematical idea to understand? Why or why not?

Part 2

1. The following is a play summary from a drive in a football game between Baylor and Texas. Can you write it as a series of operations?

    - Baylor started at the 20-yard line and completed a pass to move forward 13 yards.
    - Texas sacked Baylor's quarterback and Baylor was moved backwards 5 yards.
    - Baylor broke a long run to move 37 yards forward.
    - Texas was penalized a negative 15 yards to move Baylor forward.
    - Baylor fumbled the ball but picked it up 10 yards behind their current location.
    - Baylor completed a pass for 29 yards.
2. If it takes 80 yards to score a touchdown when Baylor starts at the 20-yard line. Did Baylor score a touchdown? Why or why not?

Part 3

1. How would you describe your experience with Ozobot Operations?
2. Do you prefer to learn math in a makerspace project or in a regular classroom setting? Why?
3. Which setting (makerspace vs. regular classroom) do you find to be more beneficial to your mathematical understanding? Why?

Post-Interview

After the makerspace experience, Rick was once again interviewed to discuss the makerspace experience. The interview conducted was semi-structured and followed the same format as in both the pilot study and makerspace experience. Rick was first asked to describe the makerspace experience and the mathematical learning goal as detailed in the first question. He responded,

> So, we were thinking about a way that we could do a real-world scenario with rational numbers, specifically operations, because we had introduced them. However, students were still struggling with some of the negative values. So, we kind of started from there. We noticed we had, uh, a resource through technology with Ozobots. So, we wanted to let students be creative and use the Ozobots to mimic rational number operations to help with their understanding. The story's element attached to the Ozobot movement was to hopefully get the students to think a little bit more about the operations themselves.

Rick's response details the mathematical goal of the makerspace experience to target rational number operations for students, which he stated students were having a little difficulty in understanding. The makerspace experience was also created based on a technology the school already owned. The creation of the story as part of the project was to give students a voice to the mathematics being done; this element of adding student voice to the mathematics was due to how the makerspace experience was implemented.

Rick was then asked about the challenges that emerged as part of the development and implementation of the makerspace experience. He stated,

> Yeah, so I think we thought the parameters were a little bit too tight early after the last one. So, we wanted to open up with an opportunity for them to play in the beginning. We introduced the project and then we let the kids have some time to play. So, it kind of opened up where they'd get an understanding of—what can the Ozobots do. Which I think helped spark some ideas. And then we put the boundaries in place for the actual project. Um, but the challenges we recognized early were we wanted to deal with rational number operations, which would either move horizontally or vertically. And the kids naturally wanted to get into more challenging things where they would be moving in multiple directions, horizontally, vertically, and diagonally. I don't know if it is a challenge, but every time we let students create things, they try to push the mathematics to a high level depending on what they want to make. The challenge is often bringing them back to the mathematical goal of the lesson.

His response indicates a couple of unintended common themes that have emerged as part of the makerspace experience's refinement. First, the timing of the introduction of the mathematical information within the makerspace experience is introduced could potentially have some importance. Rick believed that introducing too much of the mathematics too early could hinder creativity on the students' part. As part of the iterative process of the DBR, Rick and the researcher decided to move to more student play in terms of experimenting with the tools and technology before constraining the students with the mathematical goal. As Rick mentioned, getting to play without project stipulations may open up some student thinking and creativity.

Second, Rick alludes to the disconnect between educational making and addressing learning standards. The researcher intended to explore what happens when an educational makerspace experience is created to address mathematical proficiency, as stated in Research Question 1. There is potential conflict when students are free to create as part of the makerspace experience versus reaching the targeted learning goal. Rick's response indicates this tension when he mentions allowing students to play versus when to introduce mathematical or project requirements too early juxtaposed with students pushing mathematics beyond the intended learning goal. This appears to be one of the biggest challenges when an educational makerspace experience is created to target mathematical proficiency, as it seemed to be a common theme across the pilot study and the two iterations of the DBR.

The researcher then asked Rick about how the design choices that were made impacted mathematical proficiency. Rick stated,

> Students first created their path, and then along with their path, they had to have operations to match the path, but what I thought was interesting was the student-created stories. At first, they would talk about the movements going from one point to another point. I got to address a lot of questions about this because they would look at making a positive movement and then a negative movement and would have to talk through what that means in terms of mathematics, the Ozobot movement, and their stories. Designing a project where students connected the math to a visual of the Ozobot and a story or reflection brought out a deeper understanding of the mathematics and kind of addressed all the strands. Students understood the purpose of the math because of what they created.

The makerspace experience design choices had multiple ways that students explored the mathematics in the form of mathematical operations, Ozobot movement, and student-created stories. Rick's response indicates how the various representations helped bring out the different strands, and the design choice of having students create stories was a contributor to student mathematical proficiency. When students created their stories, they had to develop a strategy for connecting the mathematics to the visual movement and what they wrote. As Rick stated, it was a reflection on the mathematics that helped with mathematical proficiency. The instructional design choices made by Rick and the researcher—in particular, the multiple ways students explored mathematics—helped bring out the mathematical proficiency, which is part of Research Question 3 in how these choices impact mathematical proficiency. The instructional design choices of having students craft stories and tie it to visual movement and mathematics played a role in student mathematical proficiency.

The researcher then asked Rick to go into a little more detail about the strands that emerged due to the makerspace experience. Rick responded,

> Students developed the conceptual understanding from the connection of the math with the movement of the Ozobot, and through the actual process of the math. They did some procedural fluency, particularly with adding a negative being the same as subtracting a positive. Um, they had to develop strategies in crafting the story, particularly as some wanted their Ozobot to move horizontally while others went vertical and how to kind of navigate the two-directional movement with the story and the math. The total distance was not something I was expecting much from as far as challenge, but it was interesting how students determined that value. It kind of forced the students to think about rational numbers differently and apply them or come up with a strategy to find that distance. Of course, they saw some purpose in the math with the visual of the Ozobot. I think once again, they did all emerge, but we kind of intended that to happen when we developed the lesson.

Rick believed all the strands were evident as part of the makerspace experience. He also alludes to Research Questions 1 and 2, in that the makerspace experience was developed to facilitate mathematical proficiency and the strands appeared as part of the makerspace experience. There was intentionality for students to develop mathematical proficiency concerning rational number operations as the experience was developed to facilitate the mathematical learning; however, it is essential to note that Rick believed the strands did appear because of the way the makerspace experience was crafted. In particular, crafting the makerspace experience with the intention of the mathematical strands along with Resnick's (2017) 4Ps created the conditions for all strands to be present.

Following the strands discussion, the researcher came back to the 4Ps of educational making and asked Rick to go into more detail about the presence of these principles in the makerspace experience and if any alterations could be made to address them better in future makerspace experiences. Rick responded,

> So obviously, we have the project in the creation of the Ozobot path and the stories. I felt the stories are where the passion came through. It was personal for the students, and they got to kind of express how rational number operations could be part of something they were interested in. We also did it in smaller groups which helped with the passion part as well. I also thought having them play first before the math was key, it was like when they got to the part when they had to tinker with design to fit the math, they already had a good sense of what the technology could do, so it was alterations for math reasons if that makes sense. I also thought the peer sharing was better this time as well; again, it may be because the project had more passion or personal attachment. I think this was the best one we did as far as the 4Ps.

His response potentially indicates the importance of passion. While we had passion in the pilot study and the first makerspace experience, the passion piece here required more reflection and justification on the students' part. The students in the first two projects had the opportunity to select a theme or something important to them, but in this final makerspace experience, students also had to write about what they had selected for the personal element as part of the storytelling. In this storytelling element, students were able to bring out a stronger connection to math in their personal view.

Finally, Rick was asked about mathematical proficiency and what alterations could be made to the development of educational makerspace experiences to address mathematical proficiency. Rick answered,

> Again, I thought this was probably the best of the three we had done because we took time to reflect after each one and make a few changes. The structure and pacing of the experience were the best because I think putting some of the play up front with the technology kind of got that out of the way to focus on the mathematical goal later on. As I said earlier, the multiple ways the math was presented with the visual of the Ozobot and the mathematics being used as part of the storytelling helped students justify their understanding and apply the mathematics in a new way by creating the project. I think all those things kind of contributed to their mathematical proficiency. The first two were good, but this one I think, really kind of hit what we were after in developing a lesson to target mathematical proficiency while using the 4Ps.

The iterative aspect of the DBR allowed Rick and the researcher to modify the structure and implementation of the educational makerspace experience. Rick's response targets two of the primary changes that were made through the iterative process. The first of which was allowing students to become familiar with the tools and technology before any learning goals were introduced. Students were free to discover what they could create without any constraints, which may have helped spark some creativity before funneling student thought to the learning goal. Second was the importance of student passion and justification. In the first two makerspace experiences, students choose a theme that may have been personal but did not necessarily have to justify the mathematical connections to their passion. In the final makerspace experience, the narrative students created told the story of the mathematics, which may have improved the 4Ps' inclusion and impacted student mathematical proficiency. In summary, Rick's responses did indicate that the makerspace experience addressed the intended learning goal along with the 4Ps and five strands of mathematical proficiency.

Coding of the Data

As in the pilot study and first lesson makerspace experience, student responses and observations were coded using a priori framework of the five strands of mathematical proficiency to address the research questions as detailed in Chapter Three.

Conceptual understanding. The makerspace experience's mathematical goal was for students to develop mathematical proficiency with rational number operations, notably addition and subtraction, as detailed previously. As part of conceptual understanding, students were to discover the relationship between increasing or decreasing values on a number line concerning the operations of addition and subtraction with rational numbers. As a strategy to develop conceptual understanding, the makerspace experience had students connect the mathematical operations to the movement of an Ozobot on a number line.

In the observations, students made connections between the direction their Ozobot moved, the way the Ozobot faced, and the rational number operations. When asked, "When would the Ozobot travel to the right?" almost all students responded with "adding a positive number" or a similarly worded variation. Most students also included "subtracting a negative number" as well as part of their answers. However, some students described a positive movement for the Ozobot in different ways. Isaac, one student who matched his story to a diver, detailed a positive movement as "my Ozobot moved up when adding a positive number or subtracting a negative number." The use of the word up in his response is a potential indication of how the makerspace experience of creating a story helps shape conceptual understanding of the mathematical concept of rational number operations. Likewise, other students referenced their project or story when detailing the Ozobot movement. Madison described the movement as "traveling east when adding a positive" and Stan stated, "when Derrick Henry (football player) rushes for a 16-yard touchdown, the movement is to the right or positive." The variety of ways students discussed the rational number operations is evidence of students' conceptual understanding in relation to rational number operations.

Responses to the question, "When would the Ozobot travel to the left?" mirrored the response to the other Ozobot movement question in that almost all students responded with "subtracting a positive number" or a similar worded variation. Many also included the context of "adding a negative number," and some students drew from the stories they created once again. Isaac detailed the negative movement as "moving down when subtracting a positive," Madison described the negative movement as "traveling west," and Stan stated, "when Ryan Tannehill (football player) gets sacked for -12 yards." The connections between student generated stories and mathematical ideas indicate how the makerspace experience helped shape conceptual understanding. Student misconceptions about movement on the number line—discussed in the observations—seemed to be resolved by the time students completed their final reflections.

Procedural fluency. For students to have procedural fluency concerning rational number operations requires students to add and subtract positive and negative numbers within a given context; in other words, use the procedures of addition and subtraction with rational numbers. As part of the project, students had to describe the movements in the stories they crafted. They also had to write out the rational number operations used to calculate the total distance their Ozobots traveled and the final locations. The students' ability to use the procedures of rational operations fluently to craft their Ozobot stories is a potential indication of procedural fluency as part of the makerspace experience.

For example, here is part of a story from one student, Max, about an Ozobot traveling. "Ozzy needs to find Ozo in the store and started at -20. Ozzy moves 35 down the aisle to positive 15. Ozzy sees that the aisle is blocked, so Ozzy went back 25 paces back to negative 10." Max partnered this part of his story with these rational number operations:

$$-20 + 35 = 15$$
$$15 - 35 = -10$$

Max used the procedure of adding rational numbers, in this case, a negative value with a positive movement for his Ozobot followed by subtracting a positive value to accurately indicate how his Ozobot traveled. Similarly, another student, Ani, detailed a story about her Ozobot:

> Oswald is playing in a playground. He walks into the entrance of the playground (0 altitude). He climbs to the top of the playground and declares that he is the king of the castle (5). His evil sister, Rachel Woods, pushes him down the slide (slant down). The slide leads to a ball pit (-3). After he manages to climb out of the ball pit, he runs to try to find Rachel. After climbing to the top (5) and sliding back to the ball pit (-3) and diving down in the ball pit (-4), he finds her swinging on a swing under a playground (-1).

Ani again paired her story with mathematical procedures to potentially illustrate her procedural fluency with rational number operations.

$$0 + 5 = 5$$
$$5 + (-8) = -3$$
$$-3 + 8 = 5$$
$$5 + (-8) = -3$$
$$-3 - 1 = -4$$
$$-4 - (-3) = -1$$

Ani potentially illustrated her procedural fluency in a variety of ways. While Max used horizontal movements with his Ozobot, Ani used vertical movements in the form of altitude. She also used rational number operations and subtraction with both positive and negative values. Students can use the procedures of rational number operations with positive, negative numbers both horizontally and vertically to detail students' potential procedural fluency. The flexibility shown in artifacts by Ani and Max led to the coding of the student work as procedural fluency.

Strategic competence. The researcher viewed strategic competence in this makerspace experience as the student's ability to determine a method for finding both the location of the Ozobot and the total distance traveled based on the defining characteristics of strategic competency as found in the framework. While students may have had some familiarity with rational numbers before, connecting rational number operations to movement on a number line and calculating total distance may have been new for most students. In particular, finding total distance may have been a completely new concepts as it often involves higher level mathematics such as absolute value. Developing a strategy for solving a problem by applying a mathematics concept is an indication of strategic competence.

Students, as part of the makerspace experience, applied several different strategies in connecting mathematics to their stories. Some students used a horizontal number line, while others chose vertical lines depending on which made more sense in their stories. Also, based on the movement of their Ozobot, they chose to add or subtract and use a positive or negative rational number. In particular, adding a negative rational number is the same as subtracting a positive rational number, but depending on their story, one operation and number combination could have potentially fit the narrative better. For example, Jason, as part of his story, wrote, “They turn around and go 40 miles back to the house as fast as they could.” He accompanied the statement with the operation “40 - 40 = 0” because the Ozobot turned around; he chose to use subtraction instead of adding a negative value to signify the Ozobot is moving backward. While either operation, subtracting 40 or adding a negative 40 would have the Ozobot end at the same location. Jason determined a strategy for his rational operation to match the movement of his Ozobot.

As part of the makerspace experience, students also had to determine the total distance traveled. Students understood that a negative rational number and a positive rational number would result in movement in both directions on a number line when their values when added or subtracting numbers with the same sign would result in a smaller value. Yet, the distance still had to be considered. In the example from Jason, he had the operation “40 - 40 = 0,” this indicated the Ozobot traveled a total of 80 units, but was at the location of 0 on the number line. In Jason’s final document, his Ozobot finished the story at 50 units from zero, yet his total distance traveled was 490. To calculate the total students used several strategies, Jason in his report totaled all the number and disregarded their sign, in other words, made all the movements positive. Other students counted each movement individually and kept a running total. Finding total distance was not part of the makerspace experience's mathematical goal; it was included to view student strategies when working with rational numbers. In particular, how well students understood the relationship between positive and negative rational numbers and the distance traveled on the number line.

Adaptive reasoning. Adaptive reasoning as a strand of mathematic proficiency is the capacity for logical thought, reflection, explanation, and justification. As part of the makerspace experience, students were tasked to connect the story of their Ozobot with their rational number operations and reflect on the connections they made. Having the students draw connections with their operations and stories they crafted is potential evidence of student explanation and logical thought related to rational number operations.

In this story, a student participant, James, details the movement of an Ozobot on a trip to California.

> Little Bob, left for his road trip to California. He started at his house and went east 20 miles. He is happy he's 20 miles in, so he does a dance. Now that he's 20 miles east, he decides to go 50 miles west at a very fast speed. He goes a little bit south and pauses for a lunch break. Then goes back east 30 miles. Then back west 20 miles. After that, he goes east 50 miles on the fastest speed because he is tired.

James reflected on the Ozobot movement and connected the left and right horizontal change to the east and west movement on the map. Reflecting on the mathematical operations in directional change is a logical way for a student to consider the movement associated with the operations. Moreover, the potential justification of the mathematics in story form was a direct result of the makerspace experience in allowing the student-created narrative.

Another student participant, Lisa, gave a similar reflection of Ozobot movement aligned with her rational number operations. In her story she wrote:

> A little birdie named Ozo was flying to find the perfect tree. He started at a tree and flew 10 feet to the next tree. Then he flew 12 feet backward to another tree. He did not like that tree, so he flew about 2 feet forwards and paused to examine the tree for 3 seconds. Then he flew 25 feet backward to a tree with very tall branches and once again paused for 3 seconds.

Lisa's story detailing the journey of Ozo, again attaches movement to the mathematics of rational number operations. As Lisa reflects on the mathematics attached to the story, she wrote out the matching operations:

$$\begin{gathered} 0 + 10 = 10 \\ 10 - 12 = -2 \\ -2 + 2 = 0 \\ 0 + (-25) = -25 \end{gathered}$$

Due to the nature of creating the story part of the project, the makerspace experience potentially sets up the opportunity to reflect on the connections of mathematics to Ozobot movement. Each student was required to turn in their story of the mathematics as part of the makerspace experience, which allowed all students to reflect and justify their understanding of rational number operations.

Productive disposition. Students were asked about the makerspace experience as helping them understand the rational number operations and if they believed that rational number operations were an important mathematical idea to understand. The purpose of these two questions was to explore student productive disposition, seeing the mathematics as meaningful due to the makerspace experience's implementation.

The first question, "Did the movement of the Ozobot help you in figuring out the operations?," targeted the makerspace experience as helping students make the real-world connection between movement and rational number operations. Most students (35 of 41 answered yes) referenced the movement of the Ozobots as providing a level of clarity when it came to the different rational number operations. One student participant, Jamie, wrote, “It did because once we mapped out the movement, it was easier to figure out the operations.” Another student participant, Mitchell, recorded, “Yes, because it helped me decide if it would be negative or a positive.” Jason answered the question with, “Yes, we could see where he [Ozobot] changes directions, so that helped with the operations.” In all three of these responses, the visual element of the Ozobot movement indicates the connected purpose of movement with mathematical operations and how the makerspace experience provided the opportunity for students to explore the connection.

The second question, “Do you think rational number operations are an important mathematical idea to understand?,” was intended to address student disposition toward the mathematics itself, in this case, rational number operations. In addressing this question, all 41 students answered yes, however, the responses were less related to each other than the previous question. Jamie responded with, “Yes, because we might need to know how to solve equations that include different operations.” Jamie’s response indicates that he sees utility with rational number operations as a tool for doing math. Mitchell wrote, “Yes, because it can help in traveling knowing if you are going a positive or negative number.” Mitchell was probably alluding to positive, and negative being attached to the east and west movement, similar to what he had in his story. His disposition was more about the connection he had made with his story and less about the mathematics itself. Yet, he still found purpose in rational number operations as part of the makerspace experience.

Finally, Jamie responded, “Yes, because if you are the owner of a store and you get a shipment and then sell product, you need to know how many things you have.” Jamie’s response alludes to seeing rational number operations as a meaningful mathematical idea in a completely different context. Yet, his understanding is similar to that of the makerspace experience. It is related to a quantity changing due to rational number operations. In his response, it was adding and subtracting product from inventory. The student responses to this question fell in one of these three categories: seeing rational number operations as useful as a mathematical tool, connected to the story the student-created in the makerspace experience, or applied to a new context. However, in all three cases, students indicated a productive disposition to the intended target of rational number operations as far as seeing the mathematics as purposeful which led to their responses being coded as productive disposition.

Summary of Makerspace Experience 2

The researcher and Rick developed a third iteration of the makerspace experience in an educational makerspace experience intended to explore mathematical proficiency. They implemented alterations to the design based on the pilot study and first makerspace experience. In particular, they targeted allowing students to play with the technology and tools before introducing the learning goals. They found that when the mathematical information was released and learning goals were discussed too early, student thinking may be hindered.

The makerspace experience was designed to address Resnick's (2017) 4Ps of educational making. Students created a project that entailed programming an Ozobot and creating a story to match a series of student-created rational number operations. They were allowed to play or tinker with design to get the three parts of the project, Ozobot movement, rational number operations, and narrative, to connect. Students worked in pairs and offered each other feedback. The makerspace experience's narrative piece invited student passion in the form of a story they could create based on interest. Students experienced freedom with their story creation, which invited a personal connection to the project.

The makerspace experience was also intended to address the five strands of mathematical proficiency. Students explored rational number operations through the previously described project. As part of the mathematics learning, students had the opportunity to visualize the concept of rational number operations to target the conceptual understanding strand. Students also exhibited procedural fluency and strategic competence in the strategies they used to determine how rational number operations matched the Ozobot movement and the computation of the values. Students applied a level of adaptive reasoning in connecting what they knew or learned about rational number operations to make the movements and directions of the Ozobots fit their operations and find the total distance the Ozobot traveled. Finally, the stories students crafted provided a sense of productive reasoning toward the rational number operations.

Similar to the pilot study and first iteration, several other themes emerged. Again, students explored mathematical concepts beyond what was intended as part of the makerspace experience's mathematical goal. Students encountered mathematical concepts such as the Pythagorean Theorem as their Ozobot traveled diagonally or absolute value when calculating total distance. Students also explored rational number operations beyond addition or subtraction procedures in determining what mathematical ideas such as subtracting a negative value would mean in terms of direction and movement of an Ozobot.

After this makerspace experience, Rick and the researcher discussed the implementation and future changes to the makerspace experience. The disconnect between educational making and math learning goals seemed less prevalent due to some structural changes in the makerspace experience. Rick believed having students explore the technology first and then introducing the mathematics improved the implementation. Rick also thought that the inclusion of the student-created narrative helped with the passion principle of educational making and invited students to justify the makerspace experience's mathematics. Finally, Rick believed this was the most successful implementation of the makerspace experience due to the design-based alterations.

Summary of Results

In this chapter, the data analysis and results were presented. Through a DBR approach, the researcher sought to explore students' mathematical proficiency as part of an educational makerspace experience implementing Resnick's (2017) principles of educational making. The data in the form of observations, student work, and practitioner interviews were collected and coded using the five strands of mathematical proficiency to address the research questions:

1. What happens when an educational makerspace experience is developed to facilitate mathematical proficiency?
2. What strands of mathematical proficiency are evident when facilitating an educational makerspaces experience?

Research Question 1

The makerspace experiences were designed to address mathematical proficiency. The researcher and the practitioner(s) met and discussed how to craft learning experiences in the school makerspace that would facilitate the five strands of mathematical proficiency while using Resnick's principles of educational making. The five strands of mathematical proficiency, as previously detailed, outline if a student is proficient with mathematics or a mathematical concept. In the pilot study and the two lesson makerspace experiences, the researcher and the practitioner(s) identified how the lessons would be facilitated to address each strand and how they emerged in each makerspace experience.

Conceptual understanding.

- Pilot Study: Students explored the concept of experimental versus theoretical probability through the creation of carnival games.
- Makerspace Experience 1: Students explored the concept of scale drawings and proportional relationships by creating blueprints or scale drawings that they later built in Minecraft.
- Makerspace Experience 2: Students developed the concept of rational number operations through the visual of Ozobot movement on a number line.

Procedural fluency.

- Pilot Study: Students demonstrated procedural fluency through the computation of experimental probability and theoretical probability.
- Makerspace Experience 1: Students used the process and procedures of scale to find the dimensions of shapes in Minecraft based on the plans they created.
- Makerspace Experience 2: Students used the procedures of addition and subtraction with rational numbers to model the movement of Ozobots.

Strategic competence.

- Pilot Study: Evidence of strategic competence will potentially be in the variety of approaches students use in determining theoretical probability.
- Makerspace Experience 1: Students developed a strategy in creating a scale used to determine values in their Minecraft world based on their plans.
- Makerspace Experience 2: Students developed strategies to model the Ozobot movement that involved more complicated operations such as subtracting a negative.

Adaptative reasoning.

- Pilot Study: Students applied their understanding of theoretical and experimental probability to another scenario and justified their reasoning.
- Makerspace Experience 1: Students justified the connections between their plans, developed scale, and final creations.
- Makerspace Experience 2: Students justified their mathematical operations by crafting a story and applying rational number operations procedures to another scenario.

Productive disposition.

- Pilot Study: Students discussed experimental and theoretical probability as practical mathematical skill in designing carnival games.
- Makerspace Experience 1: Students explored how scale and proportional relationships are useful mathematical skills in creating real-world structures.

- Makerspace Experience 2: Students explored the utility of rational number operations to determine movement values in a real-world scenario they crafted.

The intentional planning of makerspace experiences that targeted the five strands of mathematical proficiency contributed to their inclusion in the makerspace experiences. Since the five strands are woven together and do not exist singularly, when facilitating a makerspace experience intended to support student learning of mathematics content, all five will likely be included. However, it is important to note when addressing this research question that the makerspace experiences appeared to support all five strands as part of the student learning experience and were not an extra part that was added outside of the designed makerspace lesson or student reflection on the lesson. Students seemed to experience the five strands as part of the structure of Resnick's (2017) principles when applied to the learning of mathematics content.

Research Question 2

The research artifacts in the form of observations, student work, and interviews with the practitioner(s) provided evidence of all five strands as being present as part of the makerspace experiences. Similar to previous research, the makerspace experiences were intended to address all five strands, however, the makerspace experiences and their structure from Resnick's (2017) 4Ps provided the opportunity for the strands to be included. Projects created students' conditions to have hands-on experiences with mathematics content that often lead to conceptual understanding. The project and play principles provided the opportunity for students to engage in strategic competence and procedural fluency. Through play, students would develop strategies for completing their projects, leading to the need for students for procedural fluency as designs would often be modified. Students would often justify or apply their reasoning in the makerspace experiences when working in collaboration with their peers. Finally, students would develop a productive disposition often related to either the passion they brought into the project or the project's completion as it was apparent how the makerspace experience had real-world connections.

When creating the makerspace experiences, the practitioner(s) instruction design choices in structuring the experiences using Resnick's (2017) principles supported the inclusion of the five strands. As detailed in the previous research question, there is a potential connection between the 4Ps and the five strands of mathematical proficiency when crafting a makerspace experience. Real-world mathematics applications often create the best learning experiences for students and using the 4Ps to target the fives strands as a learning makerspace experience is rich in possibilities for student learning of mathematics. Rick's and Alice's primary design choices were what mathematical content to target and what real-world challenge or project students would complete. Rick's primary alteration in instruction design as part of the DBR was to decide when to release the mathematical information and ensure the mathematics was appropriately challenging. As detailed in the interview responses, allowing students to explore the included technology or resources of the makerspace first appeared to spark more ideas than when the mathematics was front-loaded in the makerspace experience.

Emergent Themes

The data were coded using the five strands of mathematical proficiency. The data went through open coding to determine if any emergent themes beyond the five strands of mathematical proficiency appeared. In this study, two themes outside of the framework appeared consistently. As detailed in the pilot study and in the two makerspace experiences, students frequently explored mathematics beyond the intended learning goal. The exploration of more advanced mathematical content resulted from students being in control of the lesson in the form of project creation or educational making. This is consistent with Hira and Hynes' (2018) notion that there is a heightened opportunity for student learning when engaging in educational making and Boaler's (2016) idea that student understanding of mathematics benefits from the opportunity for students to explore mathematical concepts.

In the pilot study case, students sought to find the area of irregular shapes as a strategy to determine their theoretical probability. Students usually do not learn about finding the area of irregular shapes until higher level mathematics in high school. They also attempted to find the probability of complex games such as those with a spin again space. Similarly, in the first makerspace experience, students sought to create structures outside of the intended makerspace experience depending on their choice. This led to students trying to determine dimensions of shapes like circles or composite three-dimensional objects that they were first encountering. Finally, in the second makerspace experience, students attempted to calculate diagonal distance and apply the mathematical concept of absolute value to determine the travel of their Ozobot. For most students, calculating diagonal distance is first experienced in the grade level above the participants, and absolute value is not explored until high school. One of the potential benefits of educational making is giving students the freedom to create. The creation process in the study provided a reason for students to seek unintended mathematical concepts that were often more challenging than the intended learning target.

Another theme related to the implementation of the makerspace experiences also emerged. Rick and Alice both referred to a balancing act between the freedom of educational making and the mathematics learning goal of each makerspace experience. Alice discussed that not all students were mathematically challenged to an appropriate level in the pilot study. Some students' carnival games lacked mathematical complexity due to some of the freedoms afforded to students as part of the educational makerspace experience. Furthermore, Rick discussed the fear of front loading too much mathematics in limiting student creativity and play. Halverson & Peppler (2018) indicated a potential tension between the freedom of educational making and the structures of learning standards in schools. Resnick (2017) also discussed how student creativity could be limited when too much importance is placed on mathematics and literacy. The observation data collected along with the interview data from Rick and Alice brought to light some of the challenges in implementing an educational makerspace experience.

In Chapter Five, a thorough discussion of the findings is presented, along with a discussion of the findings' implications and resulting recommendations for teachers implementing makerspace experiences. The researcher also provides implications for future research to identify opportunities to contribute to the body of knowledge related to educational making and mathematical proficiency. Finally, Chapter Five ends with concluding remarks for the study and analysis.

CHAPTER FIVE

Discussion and Implications

Educational making allows students to engage in hands-on, real-world applications that promote critical thinking and problem-solving skills (Martinez & Stager, 2013). However, little is known about the development and implementation of makerspaces situated in school-based settings in connection with specific educational content (Halverson & Peppler, 2018). As school-based makerspaces continue to grow in popularity there is a need to research the content specific learning of educational making or makerspaces. In this study, the researcher sought to explore the mathematics learning or mathematical proficiency of students as mathematics content was taught in a school-based makerspace.

The participants in this study included two practitioners and their seventh-grade mathematics students. A pilot study was conducted which informed two iterations of makerspace experiences as part of the DBR. The researcher partnered with the practitioners to develop three makerspace experiences that were designed to facilitate mathematical proficiency. Data that informed the study included observations, semi-structured interviews, and artifacts in the form of student work. The different forms of data were coded using the five strands of mathematical proficiency (NRC, 2001) to explore the mathematical proficiency or student understanding of mathematics as part of the makerspace experience. The data also went through a process of open coding and data reduction to determine if any emergent themes outside of the five strands of mathematical proficiency were evident. Results from the makerspace experiences and their analysis are presented in Chapter Four of this study. Chapter Five includes a discussion of significant findings from the study juxtaposed with the established framework presented in the first three chapters. Chapter Five also offers implications and recommendations for educators and recommendations for future research.

Discussion of the Findings

Through a DBR approach, this researcher sought to explore the mathematical proficiency of students when they engaged in a school-based makerspace learning experience. In particular, when applying Resnick's (2017) 4Ps of educational making in the form of projects, peers, passions, and play to the learning of mathematics content, the researcher sought to explore what strands of mathematical proficiency are evident in a school-based makerspace. The researcher collected observation data from the makerspace experiences, semi-structured interviews with the practitioners, and student artifacts in the form of student work to answer the research questions:

1. What happens when an educational makerspace experience is developed to facilitate mathematical proficiency?
2. What strands of mathematical proficiency are evident when facilitating an educational makerspaces experience?

The coding analysis of the data resulted in several significant findings pertaining to the five strands of mathematical proficiency and the learning experience for students when mathematics is taught in a school-based makerspace.

- Finding 1: Presence of All Five Strands of Mathematical Proficiency–As part of the makerspace experiences, there was significant evidence of all five strands—conceptual understanding, procedural fluency, adaptive reasoning, strategic competence, and productive disposition—in the pilot study and the subsequent makerspace experiences in the form of student work, observations, and as detailed by the practitioner in the post lesson interviews.

- Finding 2: Educational making does live up to the potential promises of supporting student learning of mathematics through hands-on experiences, fostering constructivism, and allowing students to direct aspects of their education.
- Emergent Theme 1: Learning Beyond the Intended Mathematical Goal–Student participants in all three makerspace experiences in the study explored mathematical content in increased difficulty or complexity than the intended learning goal due to the freedom given when implementing the 4Ps of educational making.
- Emergent Theme 2: Navigating the Tension Between Educational Making and Content Specific Learning–As part of the DBR, the practitioners and the researcher navigated the inherent disconnect between the freedom of educational making and mathematics learning goals and developed an approach to teaching mathematics in a school-based makerspace connecting Resnick's (2017) 4Ps and mathematical proficiency.

Finding 1: Five Strands of Mathematical Proficiency

Mathematical proficiency is the label given to the successful learning of mathematics (NRC, 2001). Furthermore, Schoenfeld (2007) describes mathematical proficiency as the framework to understand what students learn and what they can do with that knowledge. In this research, a pilot study and two makerspace experiences were developed to teach the mathematical concepts of probability, scale, and rational number operations. The data were coded into the five strands of mathematical proficiency—conceptual understanding, strategic competence, procedural fluency, adaptive reasoning, and productive disposition—to explore the learning of students as they engaged in the school-based makerspace lessons. It was apparent in the pilot study and the two makerspace experiences that all five strands were present as significant data in the form of student work, observations, and were collected and coded into each of the five strands. However, it is also important to note that the variability or depth of the findings for each strand was not quantified as part of this study. In addressing the second research question, the research sought to explore the presence of each strand in the data as an indication of mathematical proficiency.

Conceptual understanding. This strand is the grasp of the mathematical idea which is not limited to a set of facts or definitions (NRC, 2001). When students understand something conceptually, they have a grasp of the interrelations of the pieces of knowledge that exist in mathematics (Rittle-Johnson et al., 2001). In the instance of the pilot study, students developed an understanding of the relationship between theoretical and experimental probability through the makerspace experiences. Students created games and determined what they believed the outcome would be when other students played their game (i.e., theoretical probability) and were able to compare that to what actually happened (i.e., experimental probability). Their understanding was transferred to the carnival games that they constructed as part of the makerspace experience. Students were able to explain the difference between these two mathematical ideas in detail without using any formal definitions or numerical computation and transfer that understanding to their carnival games.

The same was true in the two following makerspace experiences. Student developed a distinct understanding of scale when they applied their blueprint plans to the construction of their cities in Minecraft. Through the creation of the Minecraft buildings, it was necessary for scale to be applied to create something that mirrored the student drawn plans. The mathematical concept of scale was the driving force in connecting the blueprint representation and the Minecraft representation of their creations. For the final makerspace experience, students developed the concept of rational number operations. The movement of the Ozobots provided a visual exploration free from numeric computation. Students were able to describe operations without the use of numbers. For example, students would describe moving to the right facing forward as the addition of a positive rational number. They could detail the relationship of the movement on the number line without having to use numerical computation to justify their understanding. In all three, the pilot study and both makerspace experiences, the creation of projects supported students in developing conceptual understanding of the mathematics intended for the makerspace experience. The transfer of mathematical understanding in a non-computation manner as demonstrated in the pilot study and the two following makerspace experiences is a strong indication of conceptual understanding (Moser & Chen, 2016).

Procedural fluency. For classroom teachers, this strand is often overemphasized as teachers will place value on students using a set of procedures or formulas to generate an answer that is easy to assess (Geary, 2006). Furthermore, NCTM (2014) describes procedural fluency as the ability to apply procedures in an accurate and efficient manner.

In the case of this study, procedural fluency was viewed as students’ ability to use the appropriate procedures in solving mathematical problems related to their project. For the pilot study, students were able to determine both the theoretical and experimental probability appropriately in the form of the mathematical procedure of creating a ratio to compare variable outcomes over the total number of outcomes. However, as mentioned in Chapter Four and later in this chapter, some probabilities were more challenging to determine based on the complexity of the game students created. Yet students were still able to calculate probability by applying the appropriate procedures.

In both of the makerspace experiences that followed the pilot study, students also applied procedures efficiently to determine either scale or rational number operations. For the Minecraft project related to scale the connection of the 2D plans with the 3D objects appeared to support student application of scale. In particular, students had a general understanding that in the Minecraft program, one block represented one cubic meter. This prior knowledge and the visual of the blocks in Minecraft supported students in the procedures of creating a scale, which for this makerspace experience was the ability for students to create a measurement comparison between the 2D blueprints and their 3D buildings. Likewise for the second makerspace experience related to the Ozobots, students used the procedures of addition and subtraction with rational numbers to determine the location of their Ozobot as it traveled along a number line. Similar to the pilot study, some challenges to the procedures arose when students wanted to create more complicated movements such as moving backwards in a positive direction or moving diagonally. While students did not end up calculating the diagonal movement, they did understand that the rational number operations in the form of the mathematical processes of addition and subtraction represented movement along the number line. The students' abilities to use procedures flexibly to calculate mathematical values as demonstrated (NRC, 2001) in the research artifacts indicates procedural fluency as being present in the study.

Strategic competence. This strand is the ability for students to formulate mathematical problems and then solve them (NRC, 2001). Problem-solving is also viewed as a key aspect of mathematics learning (Groves, 2012). As students engage in problem-solving, they have to determine an approach for determining the solution which is often referred to as strategic competence. When students built their carnival games in the pilot study, they had to determine a method for finding their theoretical probability. For some students it was the counting of winning spaces on a prize wheel as compared to total spaces in the carnival game. However, some students encountered more complex situations which required different strategies that demonstrated some unintended strategic competence. For example, those students who had spin again spaces on their prize wheels or those who used geometric applications to find the area of the winning conditions over the total area. The variety of strategies employed by students to engage in the problem solving of finding probability and the way students justified their process of problem solving is indicative of strategic competence (Schoenfeld, 1992).

The two makerspace experiences following the pilot study also included evidence of strategic competence. When developing scale in the first makerspace experience, students decided how they wanted to compare the 3D blocks in Minecraft to the 2D blueprints they created. Some students used the fact that Minecraft blocks were intended to be one cubic meter and created a ratio or comparison to the size of the shapes on their plans. Other students created a scale based on the number of blocks, by stating one block would be equal to a set length on their plans. Determining a strategy for how to establish scale provided evidence of strategic competence in the first makerspace experience. For the second makerspace experience students connected Ozobot movement along a number line to rational number operations and their constructed narrative. Again, there were a variety of strategies employed to connect the mathematics. Some students used a vertical number line, while others employed a horizontal number line in the initial set up to solving the problem. For some students counting the movement of the Ozobot along the number line and then translating that into a mathematical expression and written scenario was the strategy they adopted. Yet other students took the opposite approach. Beginning with the narrative, then translating their words into a mathematical operation, and then finally coding their Ozobot movements to match. One of the benefits of educational making is the freedom students have in creation, and this freedom produced a variety of strategies in problem solving.

Adaptive reasoning. This strand is the justification of one's thinking about concepts and relationships in mathematics (NRC, 2001). Thinking mathematically is also the ability to prove one's work and apply it in a different context (Schoenfeld, 1992). For the pilot study students were asked to explain how they found their probabilities and then apply their understanding of probability to a new problem as part of their reflection on the makerspace experience. Students justified their answers by explaining how they determined the number of winning or favorable outcomes as part of their carnival game compared to the total number of spaces. They also collected data to determine experimental probability and justified the difference between the two through explaining the difference. Similar to conceptual understanding, all students were able to justify the difference between the two, stating the theoretical probability is what students thought the probability would be prior to collecting data versus the experimental probability in what actually happened as part of playing the carnival games. As part of the reflection students also applied the two probabilities to a new problem that none of the students had seen prior to the reflection involving a spinner, as detailed in the previous chapter, where students determined the theoretical probability and then drew conclusions based on some experimental data.

As part of the two makerspace experiences following the pilot study, students also demonstrated *adaptive reasoning*. In the first makerspace experience students justified their scale through detailing how they determined the relationship between the blueprint plans and their Minecraft construction. As mentioned previously, students explained what they knew about Minecraft blocks, such as the size and how they applied that knowledge into crafting their scale. They also had to develop a scale based on a real-world building. The application of scale in another context, in this case the Tower of Americas, provided some insight into the students' abilities to adapt their understanding of scale outside of the project or Minecraft World. Students making sense of the mathematics in the makerspace lessons and being able to justify their answers indicates *adaptive reasoning* (Suh & Seshaiyer, 2017). Educational making has the potential benefit of students seeing mathematics as a useful tool in the creation of their projects.

Productive disposition. The fifth strand is the student's tendency for seeing mathematics as both a useful and worthwhile endeavor (NRC, 2001). Students engaging in mathematics they view as worthwhile also allows student to see themselves as both learners and doers of mathematics (Boaler, 2002; Lee, 2018). In the pilot study, students were able to see probability as useful in predicting the outcome of their carnival games. After collecting the experimental data, students were able to draw comparisons between the two types of probability. The theoretical probability of a game provided students with an understanding of how difficult a carnival game may or may not be to win. Students were able to adjust their games to alter the outcomes or even determine which games would result in a higher likelihood of winning based on their theoretical probability. It is important to note the adjusting of games to alter the outcomes could also be considered *adaptive reasoning* as the five strands of mathematical proficiency are interwoven (NRC, 2001). In this case, the *adaptive reasoning* students used in making changes to their carnival games created the opportunity for students to discover the usefulness of the concept of probability in relation to the carnival games created by students. The utility of mathematics as part of the makerspace experience served a purpose in helping them create the type of carnival game they wanted. Students also got to act as mathematicians as they collected experimental probability data to help them further explore the concept of probability.

The two following makerspace experiences also supported students discovering purpose behind the mathematics or productive disposition. For example, during the Minecraft makerspace experience, students developed a purpose for scale. Scale allowed students to create a 3D representation out of their 2D blueprint plans. The freedom of the makerspace experience also supported student choice in the type of scale they wanted to use either in terms of measurements such as inches or centimeters or in less formal terms like number of Minecraft blocks as compared to grid spaces on their plans. It created conditions in which they chose how to approach the mathematical problem of creating scale and how to use scale to create what they envisioned. In the last makerspace experience, students attached movements of their Ozobots to values on a number line and crafted a narrative to match the mathematics. The context of creating a story generated a purpose that reflected a productive disposition for rational number operations. Students that used a vertical number line were able to connect changes in elevation to the mathematics that created a utility for rational number operations. Similarly, horizontal distances and movement manufactured purpose for rational number operations that students were able to experience visually. While students applying rational number operations to determine movement in the context of elevation change could be seen as *adaptive reasoning*, the visual movement provided connections to the mathematics of rational number operations. These visual connections gave purpose to the mathematics which is an indication of *productive disposition* (Graven, 2012).

Mathematical proficiency is the defining of mathematical understanding and the five strands provide the framework for identifying the learning of mathematics for students. Students that participated in the pilot study and the following two makerspace experiences consistently demonstrated all five strands as detailed previously. The makerspace principles or 4Ps outlined by Renick (2017) provided the structure for the lessons and allowed for the exploration of student artifacts that indicated all five strands appear when teaching mathematical content in a school-based makerspace. Also, no one strand appeared substantially more than the others due to the structure of the makerspace lessons and the fact the five strands are woven together (NRC, 2001) and most student artifacts could have been coded as multiple strands similar to the altering of the carnival games as mentioned previously. In determining coding, some student artifacts were placed in more than one category based on the data with fits with the framework of interwoven strands of mathematical proficiency. In reporting the data, the researcher drew from a variety of student artifacts to prove a more robust explanation of the study.

Finding 2: Delivering on the Promises of Educational Making

While educational making appears to be promising for student learning, the gaps in the research indicates that it is uncertain what people learn through making (Halverson & Peppler, 2018). However, the makerspace experiences in this study through the implementation of Resnick's (2017) 4P's fostered the student learning of mathematics or mathematical proficiency for the student participants. Furthermore, this study supported the belief that educational making can deliver on the promises of constructivism through the educational making's hands-on, collaborative, and student-centered nature (Stanger & Martinez, 2013) and is worth educational researchers conducting further studies.

In the pilot study and the subsequent makerspace experiences, students created projects as part of the implementation of Resnick's (2017) 4Ps. Students took control of the learning at times as they made decisions on what their final product would become. For example, in the pilot study all students explored theoretical and experimental probability, depending on the choices they made in project design, students had the opportunity to explore a variety of mathematics. Some students chose to build ring toss or bean bag toss carnival games in which they calculated area to determine the theoretical probability. Similarly in the first makerspace experience or city planning project, students created their scale and the types of buildings they wanted to create. Depending on the choices students made they had the opportunity to create scale based on customary measurements or in terms on the number of Minecraft blocks as well as the opportunity to determine the shape of their buildings. Student choice and engagement with mathematical ideas helps contribute to student’s positive mathematical identity (NCTM, 2020) which the student-center learning of the makerspace experiences supported.

The makerspace experiences as part of this study also delivered on the promise of hands-on learning. In the pilot study students created carnival games and through the physical playing of the games were able to collect data that supported their understanding of experimental probability. Likewise in the following two makerspace experiences hands-on manipulation in the form of the movement of digital blocks in Minecraft or the programming of the Ozobots contributed to the student mathematical proficiency. Students even mentioned the impact of the hands-on learning in their responses. As detailed in Chapter Four one student wrote, “I enjoyed the makerspace because it’s more hands on and easier to retain information because of the experience.”

Students also collaborated in the process of design, construction, and exploration of the mathematical content in all three of the makerspace lessons. In the pilot study, students worked together to develop their game, took turns playing it and determined the theoretical and experimental probability based on data they collected. In the first makerspace experience students collaborated in a variety of ways to develop their Minecraft cities. Some groups had students work together to build each structure in Minecraft, while others divided up the responsibilities and built different structures that all fit the group determined scale. In the last experience, students worked together to connect all the different pieces - operations, coding of the Ozobot, number line, student created story - of the Ozobot project to support their mathematical proficiency in relation to rational number operations. The collaborative nature of the peers element of Resnick's (2017) 4Ps supports the belief that the learning of mathematics is best done as a social endeavor (Knapp et al., 2013).

Educational leaders have been pointing to the promise of educational making in supporting constructivist learning through hands-on learning, collaboration, and student agency (Halverson & Peppler, 2018; Martinez & Stager, 2013). The data collected as part of this study indicated that educational making does live up to this promise as student mathematical proficiency was supported by the makerspace experiences. Further studies on educational making could help advance this belief and unpack critical aspects of educational making and learning.

Emergent theme 1: Learning beyond the mathematical goal. In addition to all five strands of mathematical proficiency being present in the data, evidence existed that students engaged in learning beyond the intended mathematical goal of the pilot study and the two makerspace experiences. As part of educational making, students took control of elements of the learning experience through the projects they created. Many students wanted to create carnival games, buildings in Minecraft, or Ozobot movements that were more complex than initially intended from the planning phase of the project. The desire for complexity in creations by students lead to exploring mathematical concepts other than those intended by the teachers. Making is a way to present curriculum in a new and innovative way (Hatch, 2014) which allowed for some of the mathematical discoveries made by students. This study through the use of Minecraft, Ozobots, and carnival games sought to present mathematical concepts in innovative ways to address mathematical proficiency. The creation of carnival games, the construction of buildings in Minecraft, and the programming of the Ozobots created opportunities for student to potentially explore learning beyond the intended mathematical goal of the makerspace experience.

In the pilot study, students were free to choose the type of carnival game they wanted to create. The practitioners, Alice and Rick, had discussed as part of the planning that students might create games where students would spin a wheel or draw an object to determine if they won or not. They had also mentioned that students might want to create a ring toss or bean bag toss game where the board would be divided into spaces for winning or non-winning conditions based on where the object was tossed. However, they did not anticipate that students might want to create games that were more complex mathematically. Because the students were motivated by the creative element of the makerspace lessons, students desired to attempt difficult mathematics to see their creation realized which can lead to a more in-depth understanding of mathematics concepts (Jansen, 2012).

The mathematics learning goal was for students to discover simple and compound probability which would involve students creating a ratio of winning possibilities compared to total possibilities in one attempt for simple probability or multiple attempts for compound probability. Students added elements such as spin again or draw again which altered the mathematics to a level that Rick and Alice had to pause and spend time working through with the students. A spin again space is not a winning possibility, nor is it a losing possibility, which made it difficult for students in determining the ratio of favorable outcomes to the total number of outcomes. The student’s creation sparked a level of mathematical discussion which would not have happened without the element of project creation. There were other examples in the pilot study which were mentioned in Chapter Four such as students trying to find the area of unfamiliar shapes on their game board in order to create a comparison of the area of winning spaces to the total area of the game board.

The Minecraft or city planning makerspace experience also had some unintended mathematical discoveries and discussions. Similar to the pilot study, students created buildings that had geometric shapes for which the students were not familiar with finding measurements as these were more advanced mathematical concepts. One group of students wanted to have a circular type building, yet students had not been taught properties of circles such as how to find the circumference of a circle or the relationship of the diameter to the perimeter of a circle. Several groups created buildings that were made of composite shapes or a combination of shapes that they also had yet to experience. Some students wanted to create triangular roofs with overhangs or buildings that progressively got smaller as the building increased in height. While the students were able to work through the necessary mathematics to apply the scale they had created, it was another instance where the creation element of the makerspace experience coupled with the freedom for student input as part of the makerspace experience design led to mathematics beyond what Rick had intended as part of the learning goal for the makerspace experience.

Like the pilot study and the first makerspace experience, with the Ozobot makerspace experience, students encountered mathematical content more complex than the intended learning. The mathematical learning goal was for students to explore these movements using rational number operations in the form of addition and subtraction of positive and negative numbers. Students first approached the project by discussing either vertical or horizontal movements of the Ozobots. However, students soon began discussing other movements based on the narratives they created to describe the Ozobot movement. One group wanted their Ozobot to travel in a diagonal direction, to calculate diagonal distances accurately students would have to use the Pythagorean Theorem. Pythagorean Theorem is not traditionally taught until eighth grade or high school mathematics. The desire for the diagonal movement as part of the makerspace experience not only created a need to explore the more advanced mathematics, but it also provided students with the context of why the Pythagorean Theorem is worth exploring. While Rick and the students did not go into an exploration of the Pythagorean Theorem—other than Rick telling the students that they would discuss Pythagorean Theorem in eighth grade—to accurately find diagonal distance, the makerspace experience did set the stage for future study. A similar occurrence happened for most groups when finding the total distance traveled. Rick had planned the question of total distance as a way for students to further explore the difference between a rational number that is negative and one that is positive. He anticipated students would just count the number of spaces moved on the number line to find the total. However, students took the idea a step further and began asking questions about absolute value, which once again is a higher-level mathematical idea often taught in high school.

In all three makerspace experiences the majority of students engaged in mathematics more complex than the intended learning outcome. The catalyst for the change was the opportunity for student input or passion and student project creation as part of the educational making principles. Students who have a purpose or utility for exploring mathematics are more likely to be motivated to attempt difficult mathematics (Jansen, 2012).

Emergent theme 2: Navigating the tension between educational making and content learning. Educational making in a school-based setting remains an emergent field and there is the need for more research in development and implementation in particular with curricular content such as the learning of mathematics (Halverson & Peppler, 2018). Studies suggest there is potential for educational making in supporting student learning when integrated into schools and school curriculum (Barton et al., 2017; Dougherty et al., 2016; Fleming, 2015; Hatch, 2014). Resnick's (2017) principles or 4Ps of educational making offer a guide for teachers in implementation yet there is a tension that exists between the freedom of educational making and the structures of learning standards in schools because making is focused on student products rather than content specific outcomes (Halverson & Peppler, 2018). As part of the DBR, educational makerspace experiences were developed with the intent of navigating the disconnect between the freedom of students to be makers or creators of projects and content learning in mathematics or mathematical proficiency. While there were instances where the two did clash, the iterative process of the DBR led to findings based on the makerspace experience implementation.

In the pilot study and the two makerspace experiences that followed, there were mathematical learning goals for the students that Rick and Alice had hoped the students would achieve. In the pilot study, Alice noted some students' projects were less complex or that she wanted students to delve more into the mathematics. She stated, "Some groups were finished halfway through Day 2." There was a notable difference in the level of mathematics some students explored as part of the pilot study. A few groups had very simple games where players of the game would pick one out of three options to determine if they won. Yet other students had complicated game boards with winning targets of various shapes and sizes that involved a much more complex level of problem-solving to determine the probability. The opportunity for more complex levels of mathematical problem solving speaks to the potential of educational making in advancing student learning (Kim et al., 2018).

As Rick and the researcher developed the following two makerspace experiences, they were more intentional in establishing requirements for students to meet the mathematical learning goal of the project. In the Minecraft or city building makerspace experience, they provided students with a baseline number of structures that students had to apply their scale as part of the mathematics learning. Likewise, in the Ozobot or rational number operations makerspace experience, students had a minimum set of operations and had to detail both addition and subtraction of positive and negative numbers that were explained through the narrative they created. However, it is important to note these requirements were intended to act as floors to the student learning and in no way constrict any learning that could be beyond the intended learning goal. In fact, students were encouraged to think beyond the requirements to support the creation of a project that included their passions. For teachers engaging in educational making with students, setting non-limiting learning targets for students is a potential strategy to ensure learning standards are included in educational making. The strategy of including non-limiting learning targets supports the findings of Waldrip and Brahms (2016) in that educational making can support larger learning goals when students' understanding is centered on content learning goals.

Another recurring theme involving the blending of educational making with content learning standards is the question of when to discuss the content standard, or in other words, when to release the mathematical content. Rick, in reference to the pilot study and the first makerspace experience mentioned the aspect of when to discuss the mathematics with students. He stated after the first makerspace experience, "I think the most significant change is when we release the mathematical information." In both the pilot study and the first makerspace experience, the mathematics was frontloaded. Rick and Alice presented theoretical and experimental probability to the students during initial days of the pilot study probability carnival experience, and for some students, there was little further discussion of mathematics that took place until the reflection at the end experience. The Minecraft makerspace experience was similar in that Rick discussed scale during the first day, and students spent most of the initial makerspace experience calculating scale and determining measurements.

However, in the final makerspace experience, Rick intentionally held on to some information about rational number operations. He let students play with the Ozobots first and let them craft their stories prior to digging into some of the mathematics. Students were more familiar with what the tools could do as they began contemplating the mathematics and student thinking about the mathematics was not limited. In the Minecraft makerspace experience, many students used a similar scale in relation to the Minecraft blocks as it was discussed prior to the students building anything. In contrast, students had number lines that were vertical and horizontal. Some students used single digit rational number operations while other used three- and four-digit numbers. When students struggled halfway through the Ozobot project with subtracting negative values, Rick was able to spend some time discussing the mathematics and students were far enough along in the making process they could connect it to the project they were working on. There appears to be value in folding content learning standards or releasing them after students have had an opportunity to explore the tools available to them as part of the making. Front loading the content could potentially limit student creativity or devalue the learning of mathematics as it is placed aside when students complete the mathematics requirements early in the makerspace experience. Resnick (2017) detailed how too much focus on mathematics and literacy can potentially shut down some students' creativity, it is important for teachers to find an appropriate balance between content learning and student freedom as indicated by this study and Resnick's work.

Summary of the Findings

The study's finding articulated the potential for educational making in supporting the learning of mathematics content. In particular, the student artifacts, observations, and interviews provided ample evidence of the five strands of mathematical proficiency as being evident across the pilot study and the following two makerspace experiences in addressing the learning of the content standards in a school-based makerspace. The evidence of mathematical proficiency along with the collaborative, hands-on nature of educational making supported the belief that educational making can deliver on the promise of supporting student learning of content. Furthermore, because of student passion and the making or creating of projects, often student learning of mathematics was more complex than the intended learning goals. However, as detailed in the last finding, there needs to be intentionality in how the mathematics learning standards are blended with educational making. Students should explore the mathematics as part of the creative process and not as a separate lesson that is loosely connected to the projects students create. During design and implementation, teachers should be intentional in how they structure the lesson to include principles of educational making, in this study Resnick's (2017) 4Ps along with the content learning or in the case of mathematics, mathematical proficiency.

Implications and Recommendations for Practice

The findings from the study resulted in several important implications for educators. These implications are worth noting as there is considerable momentum for incorporating educational making into schools by educators and policymakers if educational making is shown to support the learning process (Brahms, 2014). The exploration of mathematical proficiency in the study implicated how educational making as a makerspace experience can support the learning of mathematical content while inviting additional benefits beyond the more conventional mathematics lesson structures in the form of project creation, student passion, and collaboration. However, for teaching and learning to benefit from what educational making in a school-based makerspace can offer, there must be a deliberate implementation of the makerspace experience blended with curricular or content learning goals.

In this study, the researcher implemented Resnick's (2017) 4Ps—projects, passion, peers, and play—as a guiding framework in designing the makerspace experiences. The framework worked well in including elements of educational making that benefited students. Project creation is at the center of making as the goal of educational making is for students to create a product. Including student passion as part of the experience provided students a purpose or the opportunity to take control of part of the learning. Peers invited the benefits of student collaboration into the learning experience as students were able to work together and provide meaningful feedback. The last principle of play supported student learning through exploration. There is an inherent benefit to trial and error as students learn through making adjustments to or tinkering with their products. As educators seek ways to merge the traditions of classroom learning with educational making, Renick's work functions as a starting place when developing school-based makerspace experiences.

Along with employing Resnick's (2017) principles, educators should be intentional about when and how they introduce content specific learning goals. Educational making has the potential to benefit classroom learning (Waldrip & Brahms, 2016), yet educators must determine how to incorporate the content learning into the experience. If introduced too early, content learning can limit student's creativity and passion. As part of the school-based makerspace experience students need to bring in elements that are personal and determine an approach to creating a product. Frontloading the learning goals and numerous project restrictions can have a negative impact on student input to making. In the study, Rick was intentional in the last makerspace experience to release the mathematical information slowly and as a result, student products had a wider variation, there appeared to be more discovery learning on the part of the students, and there seemed to be a stronger connection between the mathematics and the student products as the content learning was unfolding as students created. Content learning should not be frontloaded information or only addressed after students create projects, rather content learning should unfold as part of the making process. Learning should be synchronous with the progression of creating.

There is the potential fear of the unknown in educational making for some educators. While the makerspace experiences in this study were crafted to foster learning of specific mathematical content, students encountered a variety of other mathematical ideas based on what they wanted to create. In the pilot study, students began asking questions about more complex probabilities. In the first makerspace experience, students wanted to build shapes that were not part of the curricular goals for their grade level. In the final makerspace experience students encountered advanced mathematical ideas such as Pythagorean Theorem and absolute value. Teachers must be prepared to handle these unplanned learning moments; in particular, if students begin asking about content the teacher has never taught before. Rick had the opportunity to expand these mathematics ideas with his students and while the discussion was brief, the opportunities to explore these mathematical ideas were there. While it is impossible to predict every type of mathematical question students may ask when they have control of some aspects of the learning, teachers can anticipate concepts that may naturally connect to the curricular goals of the lesson. Furthermore, if a mathematical question arises that a teacher may not know how to answer, this creates an opportunity for the teacher to partner with their students in the learning process. The freedom embedded in educational making presents the potential for numerous learning opportunities not all of which may be anticipated. Teachers should be prepared to support students even when unintended learning occurs.

Finally, there is value in educational making in school-based settings. In Kim et al.'s (2018) report titled "Making Culture: A National Study of Education Makerspace," the authors concluded their nationwide study with the statement that “we believe makerspaces offer tremendous potential to advance learning for today’s students” (p. 16). While this study was exploratory in structure, the outcome supported their statement. Not only did students engage in mathematics learning both in terms of specific mathematics content and unintended mathematics, but there was also a variety of learning and education that took place as part of the experience. Educational making presents an opportunity to learn outside of content standards, particularly with technology. As part of the makerspace experiences, students used technology to construct buildings in Minecraft, collaborate in a digital space, and code Ozobots. Furthermore, students also practiced collaborating with peers, providing feedback, and developing strategies to create a project that met the goal of each makerspace experience. Educators should seek ways to capitalize on the potential of educational making through developing makerspace learning experiences for students.

Implications for Future Research

While this study provided significant data and implications for the field, it also brought about opportunities for further research in the field of educational making. The DBR used in this study was primarily exploratory in nature, collected only qualitative data, and was limited to only the discipline of mathematics. It was also small in scope, in that only three learning standards in one grade level were targeted. There are opportunities for future research on school-based makerspaces in other disciplines outside of mathematics, exploring quantitative data collected on student learning, and developing research studies that go beyond exploration. These recommendations fit with the current state of educational making as an emergent field in need of more research in the areas of development and implementation, in particular with content specific learning outcomes (Halverson & Peppler, 2018; Waldrip & Brahms, 2016).

This study was exploratory in nature as the researcher sought to explore the presence of the five strands of mathematical proficiency to address (RQ2). While the five strands are interconnected or woven together (NRC, 2001), there is the potential to further explore the strands and the variability among them. For example, does strategic competence have more variability because of the freedom of educational making than another strand like procedural fluency which may be less reliant on student choice. Productive disposition may also have more variability as the creation of projects support students seeing mathematics as purposeful. This depth and variability bears further study.

The five strands of mathematical proficiency acted as the framework for data exploration in this study. However, the five strands are intended for use with mathematics. Students in disciplines outside of mathematics would require a different framework but would add to the body of knowledge on educational making as a means for teaching subject specific content. Exploring student learning in another subject areas such as science or language arts could not only shed further light on the potential for educational make to advance student learning it would also address the recommendation of content specific learning outcomes learning outcomes by Waldrip and Brahms (2016). Furthermore, educational making is often associated with science, technology, engineering, and mathematics (Martin & Dixon, 2016). There is the potential to explore the impact on student learning on multiple subjects with interdisciplinary learning goals. Rick and Alice also made a choice in teaching the mathematical content goals of probability, scale, and rational number operations as part of the study. Not all mathematical content or student mathematical practices may fit well with educational making. A study of exploring different subjects other than mathematics or different types of mathematics, would also potentially further validate Resnick's (2017) 4Ps as principles for educational making in school-based makerspaces.

As part of the DBR in the study, qualitative research was collected in the form of student work, observations, and interviews. The aim of the study was to explore student learning in the form of the five strands of mathematical proficiency and the qualitative data told the narrative of the student learning and allowed the data to be coded into the five strands. However, student learning was not measured by any quantitative means. School districts often use quantitative data in the form of standardized tests to measure student learning of content standards. This researcher chose not to use quantitative means as qualitative data allowed for the categorization of student work into the five strands of mathematical proficiency. However, quantitative data could benefit a study as it allows for larger sample sizes that could include a variety of student grade-levels, multiple research sites, and a set of measurable data that could be used for comparison to student learning that does not take place in a makerspace. A quantitative data study could also support the research done by Peppler et al. (2017) where the researchers examined the nature of assessment in makerspaces. Schools can also use the quantitative data to help inform decisions on implementing makerspaces as part of the school's curriculum.

This study's focus was narrowed to a pilot study and two makerspace experiences that followed exploring the students' learning of mathematics or mathematical proficiency limited to three learning goals in one grade level. Creating a longitudinal study over more learning targets in multiple grades could provide further insight into how educational making can impact mathematical proficiency. A longitudinal study would help address the issue of what students learn through educational making (Halverson & Peppler, 2018). The study could be positioned over multiple years or a variety of mathematical courses.

Increasing the scope of the study could also create the opportunity to research the impact of teaching through educational making on the teachers themselves. This study was structured to explore the mathematical proficiency of the students and through the process, Rick, in his interview and planning discussed some changes in his approach to teaching in an educational makerspace. As discussed earlier, when to release the mathematical information as not to hinder student creativity. An exploration of the mathematical teaching practices as defined by the NCTM (2014) when teachers lead instruction in a school-based makerspace could benefit the knowledge on how educational making can benefit teaching and learning.

Similar to the exploration of teacher mathematical teaching practices NCTM (2014) in an educational makerspace, the professional development and preservice teacher preparation needed to teach effectively in a school-based makerspace is worth further exploration. As part of the DBR, the researcher did meet with Rick and Alice to discuss the development and implementation of the makerspace experiences. The discussions were primarily related to Resnick's (2017) 4Ps and the fives strands of mathematical proficiency, and there were a few discussions on pedagogy. In particular, ensuring that students had the freedom to create projects while still learning mathematics. If Rick and Alice had not had previous experience in teaching in a makerspace, there may have been a need for more training or professional development for teachers to be able to facilitate the lessons. Potentially, the study could have had different findings if the teachers were not prepared to teach in a school-based makerspace.

A final proposal for study would be to develop an experimental design in which student learning in a school-based makerspace is compared to learning that takes place in a traditional classroom setting. While this study indicated that student learning of mathematics content took place when students engaged in educational making, there is a lack of clarity if the student learning was any different from what might have taken place in lessons not in a school-based makerspace. Through developing a study that would compare student learning in a school-based makerspace versus that of a non-school-based makerspace or control setting, researchers could add to the understanding of the potential of educational making as a makerspace experience to support learning. This study's results did reveal there may be potential for educational making in advancing student learning in the emergent theme of student learning beyond the intended mathematical learning goal, but there is more research needed to further understand the theme that was uncovered.

Conclusion

In Chapter One, this researcher illustrated the need for further research on school-based makerspaces and what students learn through making. Many studies point to the potential for educational making for the advancement of learning, few, if any studies known to the researcher detail the learning of mathematics by students when engaged in a school-based makerspace experience. With this study, the researcher sought to explore the mathematics learning of students or mathematical proficiency of students when learning takes place in a school-based makerspace.

Mathematics learning in the form of mathematical proficiency along with principles of educational making were defined in Chapter Two of this study. The literature review emphasized that while it is difficult to capture what it means for one to have knowledge and expertise in mathematics, according to the NRC (2001) the five strands of mathematical proficiency detail what it means for someone to learn mathematics successfully. Chapter Two also detailed the historical lineage of educational making and defined the principles of educational making used in the study in the form of Resnick's (2017) 4Ps. The review ends with an examination of studies that used the five strands of mathematical proficiency to measure student learning and current research on educational making.

In the third chapter, the researcher presented the design and rationale of this study and the need to explore mathematical proficiency through student artifacts, observations, and interviews. Through partnering with practitioners and employing DBR methods, the researcher was able to implement a series of makerspace experiences to explore the mathematical proficiency of students on several mathematical concepts and make alterations to the makerspace experience to target the research questions. The participants in the study were seventh-grade mathematics students and the practitioners were two seventh-grade mathematics teachers. The site was selected based on access to a school-based makerspace. Modifications in the number of participants and practitioners were made to the initial study design based on response to the Covid-19 global pandemic; however, the data collection methods remained unaltered. The study results provided a rich description of the mathematical proficiency of students when an educational makerspace experience is implemented to foster mathematics learning.

In Chapter Four, the data were organized and presented based on a priori decision of coding using the five strands of mathematical proficiency. The data collected detailed the strands of mathematical proficiency experienced by the students and the practitioners in the study. In the pilot study and the two makerspace experiences, there was ample evidence to suggest all five strands—conceptual understanding, procedural fluency, adaptive reasoning, strategic competence, and productive disposition—were present in student work, observations, and teacher interviews. The data connecting to all five strands in the makerspace experience supported student learning of mathematics. Additionally, two other themes emerged, most notability that students experienced mathematics in increased complexity due to the opportunity to create projects and incorporate student passion as part of the makerspace experiences.

Finally, the last chapter of the study was the significant findings from the data analysis and the implications for educators. The researcher found educational making in a school-based makerspace supports the learning of mathematics. Furthermore, educational making supports student learning through its collaborative, hands-on, and student-centered nature. Students also experienced mathematics beyond the intended learning goals due to the freedom of educational making. As part of the DBR, the researcher and the practitioners navigated the tension between content specific learning and the freedom of educational making. The researcher also included recommendations for educators based on the study's finding and suggestions for future research. Based on this study, educational making has the potential to advance student learning in mathematics and educators should seek ways to incorporate making into school curriculum.

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