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The Effect of an Afterschool Makerspace Program on Academic Achievement of Sixth-Eighth Grade Students

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THE EFFECT OF AN AFTERSCHOOL MAKERSPACE PROGRAM ON ACADEMIC ACHIEVEMENT OF SIXTH-EIGHTH GRADE STUDENTS

by

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Abstract

This quasi-experimental study investigated the effect of participation in an afterschool makerspace program on middle school students' academic achievement, grades, and school attendance. An experimental group of 237 sixth-eighth grade students participated in an afterschool makerspace program during the 2019-2020, 2020-2021, and 2021-2022 school years. A control group was selected using stratified random sampling of students from the same schools, grades, and special education designation who did not participate. The data included science and math NWEA scores, science and math grades, program attendance, school attendance, and gender. The data were analyzed using an independent *t* test with a 95% confidence level. A two-way ANOVA and Scheffé post hoc test were used to analyze the effect of gender and makerspace participation on academic achievement. Participation in the afterschool makerspace had no statistically significant effect on math and science achievement test scores or math and science grades. For 2021-2022, students participating in the afterschool makerspace program had significantly fewer school absences than nonparticipants. For the 2020-2021 school year, the interaction between gender and makerspace attendance had a statistically significant effect on NWEA math and science scores. However, further analysis showed that the effect was for nonparticipants. This study did show promising results for afterschool makerspace participation improving school attendance which could be important because school attendance has been shown to have a positive effect on grades and academic achievement.

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Chapter I: Introduction

To improve the nation's educational system, Congress reauthorized the Elementary and Secondary Education Act as the No Child Left Behind Act of 2001. The new law provided sweeping reforms to ensure schools were held accountable for student instruction and achievement. An unintended consequence of the law was a high-stakes testing environment in schools. Teachers often resorted to rote memorization and basic knowledge to help students pass the test without providing long-lasting learning (Ladd, 2017). More recently, the implementation of Common Core and Next Generation Science Standards have ushered in a move to inquiry-based, personalized, experiential, and hands-on teaching and learning (Allensworth et al., 2022).

Paralleling these educational changes was the development of the Maker Movement, a grassroots effort centered on the creative production of digital and physical artifacts, commonly called making. Making can be no-tech, low-tech, or high-tech; however, it often involves creating a physical object from a digital design. Making is “a class of activities focused on designing, building, modifying, and/or repurposing material objects, for playful or useful ends, oriented toward making a ‘product’ of some sort that can be used, interacted with, or demonstrated” (Martin, 2015, p. 2). Although making is a new term in education, early 20th Century educators John Dewey and Maria Montessori were proponents of children building and making as a part of their learning process (Nielsen, 2001).

The place where people gather to make is called a makerspace. According to the Maker Ed organization, “Makerspaces come in all shapes and sizes, but they all serve as a gathering point for tools, projects, mentors, and expertise” (Makerspace, 2013, p. 1). Makerspaces in education build on the extensive research on the effectiveness of hands-on activities. For example, a science education study at the University of Virginia found that "students who engaged in hands-on activities every day or once a week scored significantly higher on a standardized test of science achievement than students who engaged in hands-on activities once a month, less than once a month, or never" (Stohr-Hunt, 1996, p. 1). Also, a comprehensive review of math education research studies found that students who participated in project-based learning were better at solving word problems than students in traditional settings (Boaler, 2002).

Makerspaces can provide an inclusive environment for all students to learn and can empower students with special needs. One example is the Intermediate Unit 1 (IU1) Fab Lab program in Pennsylvania which serves as a motivational environment to encourage engagement with technology for students who are unsuccessful in traditional classrooms. Director Don Martin states that the IU1 Fab Lab “breaks barriers down and creates trust, which is important for kids” (Morris, 2018, p.3). Patrick Waters, a maker educator who also focuses on special needs students, promotes makerspaces for engaging students in projects that develop executive function, planning, organization, and learning real-world skills. He states, “School makerspaces also provide a unique opportunity for teachers to leverage the strengths and interests of students with special needs to increase their engagement and learning” (Waters, 2014, p. 2).

Purpose of the Study

The purpose of this study was to determine the effectiveness of participation in an afterschool makerspace program on the academic achievement of middle school students. Despite finding qualitative research supporting the success of makerspaces in education, the researcher found very few empirical studies on the influence of makerspaces on academic achievement. For this study, the independent variable was the number of days of participation in the afterschool makerspace program, and the control variable was non-participation in the afterschool makerspace. The dependent variables were NWEA math scores, math grades, NWEA science scores, science grades, school day attendance, and gender for sixth-eighth grade students.

This study was completed in a predominantly rural county in the southeastern United States with a population of 65,353. The county encompasses three small rural towns and two unincorporated communities. The public school district serves 10,298 preK-12th grade students in 15 schools organized into five attendance zones, each with a middle school that serves sixth-eighth grade students. With 24.4% of the population under 18 years old, education is a primary concern for the county's citizens (US Census Bureau, 2020).

The school district Title I survey consistently indicates that parents want afterschool academic enrichment, particularly STEM programs, for their children. However, the rural nature of a large part of the county affects its residents through isolation and limited resources. Data from the 2020 US Census indicates that 12.6% of the population lived below the poverty level, and the average daily commute to work is 26 minutes. Therefore, many children need financial support and transportation to participate in organized afterschool programs.

The makerspace program was administered through a 21st Century Community Learning Centers (CCLC) program that served students in five middle schools. Each program provided high-quality, engaging programming free of charge to students, as well as a nutritional snack, tutoring, and transportation home. The program focused on training students to use high-tech equipment, including laser engravers, 3D printers and pens, a vinyl cutter, a poster printer, a sublimation printer, a pottery wheel, an embroidery machine, and robotics kits. Additional low- or no-tech activities were incorporated to improve students' 21st Century skills, especially perseverance, communication, critical thinking, problem-solving, creativity, and collaboration.

Research Questions

1. Did the number of days of participation in an afterschool makerspace program affect math achievement test scores for sixth-eighth grade students?
2. Did the number of days of participation in afterschool makerspace affect math grades for sixth-eighth grade students?
3. Did the number of days of participation in an afterschool makerspace program affect science achievement test scores for sixth-eighth grade students?
4. Did the number of days of participation in an afterschool makerspace program affect science grades for sixth-eighth grade students?
5. Did the number of days of participation in an afterschool makerspace program affect school-day attendance for sixth-eighth grade students?
6. Did gender affect the impact of an afterschool makerspace program on achievement for sixth-eighth grade students?

Significance of the Study

While hands-on and experiential learning concepts are not new to education, the availability of low-cost, high-tech creation tools has ushered in the new term “makerspace.” The makerspace program that was studied provided afterschool makerspace programming for an average of 97 students per year in five middle schools. Evaluating program success is important in determining the future focus and direction of the afterschool makerspace program.

An abundance of anecdotal and qualitative data was found to support the implementation of maker learning. However, empirical data supporting the effect of makerspace participation on student academic achievement and learning was scarce. This study filled the need for a quantitative study on the effect of out-of-school makerspace participation on student academic achievement.

Definitions, Terms, Symbols, Abbreviations

Digital fabrication – a production process in which computer software creates digital files to drive equipment to create a physical object. The three main types of digital fabrication are 3D printing, CNC machining, and laser cutting.

Makerspace – room or space with technology tools to design, build and create physical objects from a digital design.

Maker Movement – a grassroots effort by people who like to tinker, create, design, and build, often using 21st Century tools. Makers include inventors, designers, artisans, craftsmen, and tinkerers.

NWEA - Northwest Evaluation Association. NWEA is a research-based assessment measuring growth and proficiency and providing insights to help tailor instruction.

PBL – problem-based learning. The teaching method in which real-world problems are used to teach concepts.

STEM– Science, technology, engineering, and math. With the addition of arts in recent years, the acronym STEAM is often used.

Summary

Implementing makerspaces in school districts, libraries, and universities requires the investment of millions of dollars in equipment, materials, and staff. To help inform stakeholder decisions about makerspace implementation, this study provided a quantitative analysis of student achievement data to determine the effectiveness of an afterschool makerspace program.

Chapter II: Literature Review

This chapter outlines the historical background and concepts related to the implementation of makerspaces, particularly in education. As with any innovation, each makerspace described was multifaceted and complex, and each had different goals, staffing, funding, tools, materials, and participants. Most of the research described in this literature review was qualitative and sought to analyze and describe makerspaces and perceptions of makerspace effectiveness.

The Maker Movement

The Maker Movement refers to the grassroots movement of people who creatively produce physical or digital artifacts. The Maker Movement has often been associated with other initiatives and movements, such as the resurgence of do-it-yourself (DIY), the interest in science, technology, engineering, and math (STEM) education, the promotion of engineering and computer science in K-12 education, and the trend of distributed design and creation (Halverson & Sheridan, 2014).

The Maker Movement advanced to the forefront of innovation, manufacturing, entrepreneurship, and education when President Obama hosted the 2014 White House Maker Faire and National Week of Making. Additionally, federal agencies, including the US Department of Education, expanded funding and support for making and makerspaces in education. Businesses and industries joined federal agencies in supporting maker educators, entrepreneurs, and manufacturers (White House, 2014).

Making and Makerspaces

According to Martin (2015), “Making is a class of activities focused on designing, building, modifying, and/or repurposing material objects, for playful or useful ends, oriented toward making a ‘product’ of some sort that can be used, interacted with, or demonstrated” (p. 2). Making also includes digital creations often found in virtual reality, digital graphic design, and computer programming. A secondary but essential part of making is the social act of sharing processes and products with others (Halverson & Sheridan, 2014).

Makerspaces are places where people intersect with projects, tools, and expertise to design solutions, create ideas, and make objects or digital creations (Makerspace, 2013). Essentially, makerspaces are where making happens. Initially, makerspaces were private spaces with paid memberships, similar to gyms, which gave members access to high-end and often expensive digital fabrication and workshop tools. As the cost of maker tools and technologies decreased and the appeal of innovating and creating expanded, makerspaces have spread to libraries, museums, and education (Halverson & Sheridan, 2014).

The first formalized educational makerspace, the Fab Lab, was formed in 2001 by Neil Gershenfield at the Center for Bits and Atoms at the Massachusetts Institute of Technology. Because Gershenfield wanted students to become creators, not just consumers, he started a class entitled “How to Make (Almost) Anything.” He taught students to use digital fabrication tools such as 3D printers and laser engravers to build and create personal projects. The class remains the basis of maker training for Fab Labs, which are now found worldwide (Nascimento & Po´lvora, 2018).

Although makerspaces have different goals, participants, locations, and equipment, they are most commonly found in formal and informal education. Successful makerspaces build a sense of community that keeps participants returning. A meta-analysis of makerspace research found that over half of the studies investigated makerspaces in education and libraries (Mersand, 2021). Additionally, a Maker Ed survey of youth-oriented makerspaces revealed that 42% were located in schools, and 53% served students aged 11-15. In an analysis of school maker programming, 85% offered maker classes, 65% offered open makerspace time, and 25% offered summer programming. The data also suggested that most youth-oriented makerspaces aligned more with STEM, with 58% offering activities in computer science and engineering, 48% in math, and 38% in science (Peppler et al., 2017). These findings indicate the importance of makerspaces in education.

Makerspaces often have a mixture of high-tech and low-tech options for making (Cross, 2017). Although each differs, most makerspaces have some form of 3D printing, vinyl cutting, physical micro-computing, computer programming, and laser engraving. Very few studies examine low or no-tech maker activities, although many organizations include traditional arts and crafts in their definition of making (Mersand, 2021). As the definition of making has expanded, many makerspaces have added sewing and embroidery machines, pottery wheels, and woodworking tools.

Making in Informal Education

Libraries

Libraries have often been known for their changing landscape. Libraries were initially established to provide all people access to books and other reading materials. In the late 20th Century, libraries expanded services to provide access to personal computers and films on VHS and DVD. In their most recent iteration, libraries incorporate makerspaces to provide access to activities, tools, and materials previously unavailable to the public.

By offering maker activities in an informal setting, libraries offer an opportunity to offer maker learning without the constraints of a prescribed curriculum. Participants learned new tools, software, and creativity in one qualitative study of 307 third-fifth grade students in an afterschool library makerspace program. In the self-evaluations, thematic development analysis found that students felt they learned new technology, became more creative, and developed confidence. Students also learned to help each other and wanted to go to the makerspace because it was fun. Many programs had waiting lists due to high demand (Pijls et al., 2022).

Library makerspace facilitators were trained through professional development and on-the-job training. Although they usually promote autonomous and open-ended learning, librarians often design activities to help children become makers. Even with training, makerspaces are sometimes challenging to manage because of overscheduling, children's behavior, and children who need extra guidance (Pijls et al., 2022).

Libraries use a mixture of library goals, stakeholder initiatives, and community needs to determine makerspace goals. For example, one U. S. public library with 20 locations had three goals; provide access to technology, foster entrepreneurship, and nurture creativity. Additional purposes defined by community members included strengthening their communities by making objects for fundraising or personal reasons. Library patrons made personalized gifts, experienced the intrinsic joy of making, and saved money by making something they needed. Each patron has a unique reason for attending a makerspace (Teasdale, 2020). This cross-section gives a good indication of the uses in most library makerspaces.

The success of a library makerspace requires careful planning, preparation, and implementation. Staff implementing maker activities need training on the maker tools, software, and concepts. Unfortunately, many librarians feel that the lack of formalized training affects the quality of makerspace implementation, leaving librarians unprepared to train patrons to use the makerspace tools and software effectively. As libraries navigate this complex process, the goal of access for all remains the same (Moorefield-Lang, 2015).

University Libraries

The growth of makerspaces in college and research libraries has risen dramatically. Davis (2018) found that 46% of college and research libraries in the New England area had or were planning to build makerspaces that offered a combination of planned programs and open access. Reasons for implementing makerspaces were promoting literacy and learning, representing the library as relevant in the digital age, providing access to expensive machines, and promoting the maker culture.

Making in Formal K-12 Education

In a suburban-rural Southern school district, 16 first–fifth grade teachers and two library media specialists interested in maker learning implemented standards-based Mobile Maker Kits into classroom instruction. Teachers faced tension between traditional learning activities and maker activities. Implementing maker activities required teachers to shift their focus to student-directed learning, standards-based outcomes, and altered classroom setup. Successful implementations required a mindset shift from requiring control to accepting chaos, requiring structure to allowing creativity, and requiring completion to learning from failure. The qualitative study concluded that teachers successfully combined the open-ended, collaborative, and interdisciplinary nature of maker learning with standards-based, content-driven learning (Jocius et al., 2020).

Administrative Support

Two Ontario makerspace teacher leaders, one a librarian and the other a makerspace leader, indicated that involving the entire school in maker culture is beneficial to the success of maker educators. They found that support from the school administration alleviated teacher overload and encouraged teacher collaboration in implementing maker learning. Finally, as instructional leaders, administrator support for professional learning was necessary to ensure teachers have the training and pedagogical tools to implement maker learning successfully (Hughes et al., 2022).

A qualitative longitudinal study in a Midwest U. S. K-12 laboratory school followed 7-14 teachers as they designed and implemented a new makerspace. The teachers indicated that school culture was critical to embracing changes resulting from school makerspace implementation. During the second year of the study, school leadership support for a school-wide Design Thinking Model was decreased when a new prescriptive STEM curriculum was introduced. Teacher subcultures developed where some teachers preferred design thinking, heavily incorporating maker pedagogies, some primarily used the prescriptive STEM curriculum, and others integrated both. Collaboration with administrators and teachers was necessary to integrate a makerspace into the school culture. Sustainability plans included continuous professional learning for teachers, funding for supplies and equipment, and feedback from teachers, students, and parents (Shively et al., 2021).

Teacher/Facilitator

Educational innovations like makerspaces require teachers to adapt their teaching strategies. In the previously mentioned study, Shively et al. (2021) analyzed teachers' perceptions of makerspace and maker pedagogy. The study found that teachers had to remain flexible in changing their classrooms to a design and project-based culture. Successful teachers embraced change using collaboration and professional support to incorporate maker learning strategies and overcome challenges.

For teachers to truly understand making, they must experience it themselves. In a study of 43 in-service teachers in the southeastern United States with little experience in maker education, researchers found that the most effective training required teachers to become students by using maker tools and technology in hands-on activities under the guidance of a facilitator. When teachers took on the role of a student, they experienced failure and productive struggle, and they subsequently used these experiences to develop scaffolding for their students. As teachers gained knowledge and skills, they were more confident utilizing classroom maker activities (Chen & Cao, 2022).

A qualitative study of 44 library professionals from 21 states who oversaw makerspaces focused on the role of the facilitator in managing, teaching, and organizing the makerspace environment. Overseeing a makerspace requires specialized training to organize equipment, support participants, and implement activities effectively. Librarians felt their education was only somewhat relevant in running a makerspace. The competencies they felt they needed were technology and tools, management, teaching and programming, and community advocacy. The library staff often learned these skills on the job or from networking with other makerspace coordinators (Koh & Abbas, 2016).

Teachers must learn to become facilitators working collaboratively with students to construct knowledge and solve interdisciplinary problems (Jocius et al., 2020). Because making is often new to students, teachers may be required to scaffold instruction. A study of 24 K-second grade teachers in three metropolitan schools analyzed the procedures teachers felt were most effective in assisting students to complete maker projects and identified constraints to implementing maker activities. Successful maker-learning activities required teachers to use explicit instruction, modeling, open-ended inquiry, offline tasks to assist with online design, questioning strategies, scaffolding, strategies to leverage student enthusiasm, and reflective journals (Bower et al., 2020).

Another study of 20 early childhood teachers in a Massachusetts laboratory school found that teachers must also be prepared to help students choose appropriate leveled projects and monitor difficulties with projects (Strawhacker & Bers, 2018).

Incorporating maker pedagogy into a content-based curriculum requires teachers to rethink traditional teaching strategies. In a design-based research study in a K-7 school in Alberta, Canada, a teacher conducted three makerspace curriculum development cycles to deliver academic content. Successfully incorporating maker principles required the teacher to develop four design teaching practices: student voice and choice of topic and materials, student research to support making, implementing structured feedback, and modeling risk-taking. Maker pedagogy also required subject-area integration and encouraged learning at home and in the community (Becker & Jacobsen, 2020).

Mersand (2021) recommended that maker educators learn to value student expertise by encouraging students to take ownership of their learning and problem-solving. Even when curriculum restraints prevented complete student autonomy, maker projects provided students with choices in materials and tools, resulting in higher student interest and increased student effort (Mersand, 2021).

Student Benefits

A qualitative study of 18 third-grade students from a small public school in a rural area in the northeastern Mediterranean analyzed the relationship between maker activities and collective creativity. The study found that students participating in group maker activities develop collective creativity. Group participation also helped students develop skills in self-regulation and acceptance of others' solutions and ideas. Based on the Collective Creativity Dialogic Framework and Coding Scheme (CC Dialogic), students displayed divergent and convergent thinking as they brainstormed, evaluated, and selected solutions to problems in a group setting. Finally, group maker activities fostered positive and productive social interaction with other students. The research found a significant relationship between collective creativity and the successful completion of projects (Timotheou & Ioannou, 2021).

One benefit of a makerspace environment is the increase in student self-efficacy. One study of 100 third-sixth graders who participated in a design-based makerspace course in their Southern California school analyzed how self-efficacy can change throughout an extended makerspace project. Self-efficacy was moderately high during the study, showing the positive motivational benefits of design-based learning. The highest level of self-efficacy at the beginning was likely due to excitement and curiosity about working in a makerspace environment. Students dealt with the struggle and frustration inherent in maker projects at the project's midpoint, causing lower self-efficacy. From the midpoint to the end, self-efficacy did not change, indicating a stable environment of productive struggle. Compared to early elementary students, older students had lower self-efficacy. The researchers believe this could be due to older students choosing a more complex project resulting in higher frustration and lower self-efficacy. As a result, many older students needed more time to finish their projects (Vongkulluksn et al., 2018).

In the previously mentioned Alberta, Canada study, students developed ideation, risk-taking, communication, collaboration, and problem-solving skills by working on long-term maker projects. Also, because students were given a choice of topic and projects, they showed high interest and continued to work on their projects outside of school (Becker & Jacobsen, 2020).

Constraints to Maker Implementation

Although teachers may have access to a makerspace, challenges can cause difficulties in successful classroom implementation. A study by Bower et al. (2020) of three urban schools that implemented maker modules in the classroom listed technical difficulties with equipment, internet connectivity, software usability, student misconceptions, student learning capabilities, time constraints, and behavioral issues as significant constraints to successful makerspace implementation. Obstacles listed in other studies included funding, space, and time (Cross, 2017).

To aid in developing and implementing a makerspace, teachers are often given extra time to plan lessons with maker activities embedded to support content standards. The extra time allows teachers to collaborate, plan lessons, and prepare materials. After initial implementation, teachers are usually given less time; therefore, only teachers who dedicated extra time and effort continued to provide makerspace activities for students (Shively et al., 2021).

Due to funding, many schools have a shared makerspace in which teachers schedule time. Scheduling becomes an accessibility barrier when too many teachers share one space. In one school studied by Shively et al. (2021), many teachers ultimately stayed in their rooms to conduct maker activities. Perceived ownership of maker culture and continued collaboration helped many teachers overcome these barriers.

Makerspaces in Colleges and Universities

Universities nationwide are opening makerspaces as innovation hubs to address increasing global competition. Many university makerspaces are found in engineering programs, allowing students to use technology-rich resources to participate in innovative design experiences. At a large public university in the southwest, 186 makerspace participants showed statistically significant increases in innovation orientation, design self-efficacy, innovation self-efficacy, technology self-efficacy, sense of belonging within the makerspace, and sense of belonging within engineering (Andrews et al., 2021).

One study analyzed the use of a large research university makerspace by surveying 260 electrical and mechanical engineering students. Results showed that the most common use was as a collaborative space to work on projects. The most popular tools used were electronic board fabrication, the 3D printer, the lathe, the milling machine, and the laser cutter. When asked about the effect of using the makerspace on their personal growth, almost 50% of electrical and 25% of mechanical engineering students reported a positive impact. Also, 60% of electric and 65% of mechanical engineering students indicated they were confident they could complete all design tasks using makerspace tools (Lagoudas et al., 2016).

Another goal is to provide equal access for all students to expensive tools, technologies, and software. Engineering makerspaces are also used to develop the 21st Century skills of collaboration, communication, creativity, and critical thinking. These skills are necessary for the real world of work that students are entering (Lanci et al., 2018).

One study surveyed engineering students at three United States universities, a Hispanic-serving university in the southwest, a liberal arts university in the east, and a research university in the southeast. Engineering students were surveyed to determine the effect of university makerspaces on students' engineering design self-efficacy. The makerspaces provided a shared learning environment for students from multiple disciplines to work on projects. Makerspaces were viewed as one way of providing students with hands-on design experience similar to internships. The study found that students who participated in a campus makerspace improved their confidence, motivation, and expectation of success in engineering design. Consistent makerspace participation also improved design, prototyping, and building skills. (Hilton et al., 2020).

STEM and Making

Making and STEM are often seen as synonymous initiatives. However, STEM is content that is taught, and making is how concepts are taught. Therefore, making and makerspaces are only one set of techniques and tools for teaching STEM.

The National Science Foundation is credited with the first use of the STEM acronym. STEM education generally denotes any preschool through a postdoctoral educational activity that involves teaching and learning any combination of science, technology, engineering, and math (Congressional Research Service, 2018).

Makerspace STEM learning allows students to design, build, and iterate physical or digital representations of STEM concepts. Most STEM maker activities use the design process to build knowledge based on students' experiences building and finding solutions to problems. Often STEM makerspaces are found in formal education where explicit connections are made to a curriculum (Bevan et al., 2015)

Makerspace Pedagogy

Constructivism and Constructionism

Maker education and makerspaces are built on the foundations of early 20th Century educators who focused on experiential learning. John Dewey and Maria Montessori were early proponents of constructivism, which states that knowledge is gained through experience that reaffirms or revises conceptual understandings. Building on constructivists' early works, Seymour Papert proposed constructionism, which states that students learn through interaction with building or the physical world. Physical artifacts demonstrate conceptual knowledge gained through the process of learning (Sheridan et al., 2014; Blikstein et al., 2017).

Using the principles of constructionism, Brennan (2015) proposed four actions learners use to approach learning; designing, personalizing, sharing, and reflecting. Students use design activities to build creativity and critical thinking, constantly iterating knowledge to refine concepts. Students personalize learning based on engagement and interests to build new knowledge on existing knowledge. Students share their knowledge and use social aspects of learning to clarify their understandings further. Students reflect on their learning to make sense of their learning process.

Project Based Learning

Project-based learning (PBL) involves students finding and synthesizing answers to a problem. PBL, often used in STEM, uses a situation or a vignette of a real-world problem with limited information to set the stage for learning. PBL engages students in active learning to find one of many solutions to a problem. Active learning, such as PBL, has repeatedly been shown to improve student learning and performance on achievement tests (Beier et al., 2018).

The three essential characteristics of PBL are that the teacher is a facilitator, learners are self-directed in their learning, and instruction is based on loosely structured inquiry-based problem-solving. PBL requires significant planning by the teacher to scaffold and support student learning and problem-solving. (Savery, 2015, as cited by Chan & Blikstein, 2018).

Multiple models of PBL exist; however, the one used by the Fab Lab is the four-phase model of problem presentation, problem investigation, problem solution, and process evaluation. In a makerspace, most activities result in a physical or digital product or prototype. However, PBL views the process as more important to learning than the product. Makerspaces and maker pedagogies can be incorporated to support and expand PBL in the classroom (Chan & Blikstein, 2018).

A case study involving two teachers in Southern Ontario implementing maker learning indicated that project-based maker learning required changes in teacher practice. Teachers often consolidated standards from multiple subjects to create an authentic project that students worked on for several weeks. Also, teachers altered their assessment practices to capture the student learning process throughout the project. Teachers developed an understanding that making is not the goal but a strategy to accomplish learning content. To effectively implement these practices in the classroom, teachers needed professional development in cross-disciplinary instructional planning and evaluation (Hughes et al., 2022).

Growth Mindset

Carol Dweck is credited with the idea of growth and a fixed mindset. A growth mindset believes people can build their knowledge and skills and strengthen their abilities through hard work and perseverance. A fixed mindset suggests that intelligence is static and that people cannot change how smart they are. Most people have a mixture of fixed and growth mindsets (Dweck, 2016).

The National Study of Learning Mindsets studied the effect of an online growth mindset intervention meant to help students understand that intelligence is not fixed but can be developed. The online intervention was developed from a face-to-face multiple-session workshop determined by researchers to be unscalable. Students were pretested before participating in two intervention sessions, one to four weeks apart. End-of-year grades were collected for 6,320 low-achieving ninth-grade students across the United States. Analysis showed significant improvement in grades in core subjects and a significant increase in math and science grades (Yeager et al., 2019).

Makerspaces use student-centered learning to develop a growth mindset. Activities in makerspaces often follow the iterative design process of design, building, testing, and redesigning. This process teaches students to use productive failure to continue growing their knowledge and skills and promotes a growth mindset (Nadelson, 2021).

In research by Vongkulluksn et al. (2021), 110 third-sixth grade students from a private elementary school in Southern California were exposed to design-based making activities during regular classroom instruction. Using the pretest-posttest method, students' growth mindset was assessed by measuring the level of disagreement with fixed mindset statements. Growth mindset was measured at the beginning and end of the first year and the beginning and end of the program's second year. Researchers found that students' growth mindset significantly increased over two years. Further analysis, however, showed an initial decrease in growth mindset during the program's first year. Between years one and two, students showed an increase in their growth mindset, which continued to increase during year two. The delay in developing a growth mindset could be because this study did not use an overt growth mindset intervention and the younger age of the participants.

21st Century Skills

Maker education is often linked with the development of 21st Century skills in students. The 21st Century skills were compiled by several organizations that sought to address the competencies students needed to be successful in a 21st Century workplace and economy. Although several versions of these skills exist, the most commonly cited skills are critical thinking, communication, collaboration, and creativity, also known as the 4C's (Bower et al., 2018; Lecorchick et al., 2019; Saorın et al., 2017 as cited in Shively et al., 2021). K-12 educational institutions have been encouraged to focus on developing these skills in students (Iwata et al., 2020).

A survey of 20 in-school and 28 out-of-school educational makerspaces by Maker Ed found that more than half of the makerspaces conducted maker activities multiple times per week that fostered creativity, developed and communicated new ideas, incorporated collaboration, and embraced failure. These activities align with the development of 21st Century skills. (Peppler et al., 2015).

In a Finnish research study, five teachers and 41 seventh-ninth grade students participated in integrated learning activities supported by a local university makerspace. The makerspace provided digital fabrication tools, including 3D printers, a laser engraver, vinyl cutters, an electronics workbench, and a computer numerical controlled (CNC) milling machine. The study supported the relationship between incorporating digital fabrication in learning and developing 21st Century skills, particularly creativity, collaboration, critical thinking, communication, and problem-solving (Iwata et al., 2020).

Most makerspaces encourage students to work in collaboration with their peers. Collaboration can expand the scope and complexity of maker projects while allowing students to expand their verbal and thinking skills. While some collaboration between children may happen organically, maker educators should encourage positive relationships between students and foster creativity and confidence in children (Norouzi et al., 2019).

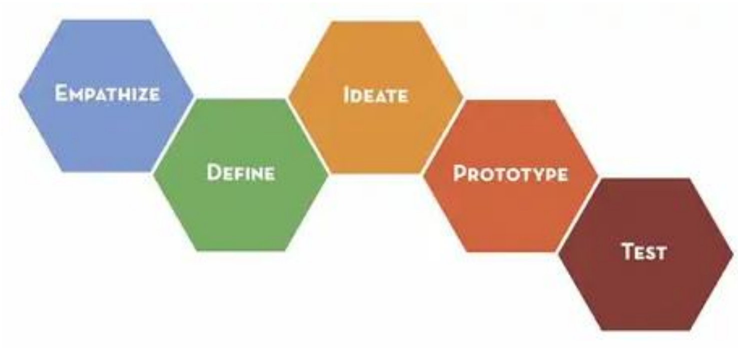
Design Thinking/Process

Design thinking and the design process are integral parts of maker culture. Design thinking is centered on solving open-ended problems through the cyclical process of designing, creating, testing, iterating, and redesigning. Student exposure to design thinking expands their learning beyond simple rote memorization of facts and figures. Design thinking can be applied to many areas of life and school (Becker, 2016).

Most makerspaces use various versions of the design process, which provide students with a step-by-step guide to anchor thinking. The Stanford d.school model of design thinking seen in Figure 1 is an overall process used to foster creativity and problem-solving. This model is often seen in creative problem-solving, artistic design, and business processes.

Figure 1

Design Thinking Model

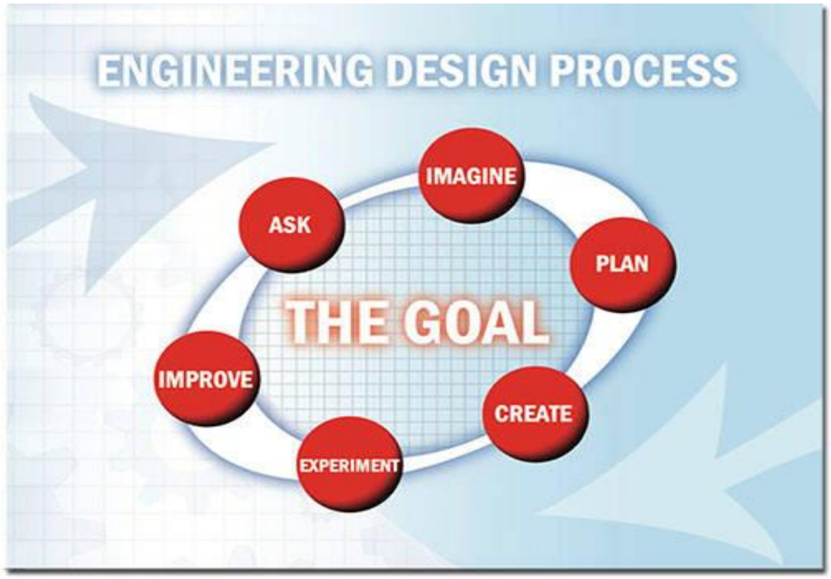


Note. Stanford d.school model of design thinking. From *Design Thinking Bootleg* (https://dschool.stanford.edu/resources/design-thinking-bootleg)

Many makerspaces have engineering elements, such as robotics and snap-together building systems. These makerspaces often used an engineering design process. Figure 2 illustrates one of the most popular engineering design processes, NASA's BEST, used in NASA's K-8 STEM activities.

Figure 2

Engineering Design Process



Note. NASA's BEST Engineering Design Model. From *Engineering Design Process* (https://www.nasa.gov/audience/foreducators/best/edp.html)

A qualitative longitudinal study in a midwest U. S. K-12 laboratory school found that teachers needed high-quality professional development to guide design thinking and maker learning. Teachers also needed continuing support after initial implementation to ensure the sustainability of design thinking and maker pedagogies. Having teachers observe each other, watch videos of exemplary maker teachers, and visit other makerspaces helped them continue to improve their practice (Shively et al., 2021). Teachers need a deep understanding of the design process and maker pedagogies to facilitate projects in the classroom successfully, especially when working with students with no makerspace experience (Mersand, 2021).

Equity in Makerspaces

Underrepresented Minorities

Racial and ethnic disparities in makerspaces often mirror the disparities in STEM education. The causes of these disparities are complex and multifaceted. One suggested cause is the stereotypes that label makers as genius, nerdy types often associated with robotics and engineering (Starr & Leaper, 2019). Another is the prevalence of makerspaces in middle or upper-class neighborhoods that are inaccessible to low-income, often minority children (Sang & Simpson, 2019). The Maker Ed survey of educational makerspaces showed this disparity, with participants identifying as 45.5% White, 21.6% Black/African-American, 18.9% Hispanic/Latino, 8% Asian, and 6.7% multiracial. Embedding maker learning opportunities in K-12 education removes many of the barriers of cost, transportation, and access found in community makerspaces (Peppler et al., 2017).

One makerspace at a large public university in the southwest surveyed 213 undergraduate students who completed projects in a makerspace as a part of engineering coursework. Students identified as foreign, multiracial, and Black had statistically lower development of innovation self-efficacy than White students and did not develop a sense of belonging to the makerspace. These findings are similar to findings for marginalized students in STEM, indicating makerspaces did not improve these students' innovation self-efficacy or a sense of belonging. However, Hispanic/Latinx students experienced the most significant gains in the sense of belonging to the makerspace compared to all groups, indicating the possible benefits of makerspace participation for these students (Andrews et al., 2021).

A study by Hilton et al., described earlier in this review, analyzed underrepresented minority students' differences in experiences. At the primarily Hispanic-serving university, minority students had similar confidence, motivation, or expectation of success as other students; however, they had significantly higher anxiety levels when completing engineering design projects. At the eastern liberal arts and Southeastern research universities, this result was not replicated, indicating the need for further study (Hilton et al., 2020).

Women

A study of engineering students indicated that an engineering-based makerspace had a higher impact on female students' GPA, engineering outlook, design skills, communication, and teamwork than male students. Female Hispanic students reported a higher impact on GPA, engineering outlook, communication, and teamwork. However, both reported lower levels of confidence in pursuing design tasks. More research is needed to understand these disparities (Lagoudas et al., 2016).

Gender differences were also found at an engineering makerspace at a large public university in the southwest. All students who participated in the makerspace program as a part of their engineering coursework increased their design, innovation, and technology self-efficacy. However, male students had statistically higher levels of each form of self-efficacy than females (Andrews et al., 2021).

One study about three university makerspaces, described earlier in this review, found differences in female and male experiences. Students who participated in makerspace programming at all three universities improved their engineering design self-efficacy; however, females' engineering design self-efficacy remained lower than males. At the primarily Hispanic-serving university, females had the same motivation levels, expectations of success, and anxiety as males; however, they had significantly less confidence when completing engineering design projects. At the Eastern liberal arts university, females had significantly less confidence than males. Finally, at the southeastern research university, females had significantly lower expectations of success and higher anxiety than males. More research is needed to analyze factors at the university that could account for the gender differences in makerspace experiences. (Hilton et al., 2020).

A study of third-sixth graders showed that girls have a higher growth mindset level than boys before, during, and after participation in design-based making activities. The student-driven projects are designed to engage girls in making (Vongkulluksn et al., 2021). Because a growth mindset is essential to STEM success, more research is needed to determine if continuous participation in makerspace learning can mitigate the loss of interest in STEM for girls during the middle and high school years.

Makerspaces in libraries and schools can serve as an entry point into STEM for females. Although much has to be done to narrow the gap, the maker movement is still skewed in favor of male participation. Studies indicated that societal constructs assigning gender to maker tools and activities could account for this disparity (Mersand, 2021). An effort is being made to bring equity to the maker movement. First, female makers are breaking stereotypes and becoming role models for girls. Second, retailers, makerspaces, and media are providing an increasing number of maker products that encourage female participation. Finally, social or familial groups support many females in developing maker skills. Many females praise fathers, brothers, and male peers for encouraging participation in all forms of making (Tomko et al., 2019).

Efforts to increase diversity in making have resulted in the development of activities that appeal to females. One project in Australia paired STEM undergraduates with year five and six elementary girls to complete an origami flower with LEDs. Survey results indicated the project's success, with over 90% of the girls responding that they enjoyed the activity and wanted more maker activities. Over 80% of the girls also indicated their understanding that circuits and electricity were the science concepts taught in the activity. The personal interest in making encouraged the participants to learn scientific concepts. To promote the attainment of knowledge, maker activities that support curriculum standards should be deliberately designed to appeal to a wide range of students (Sheffield et al., 2017).

Conclusion

No easy fix or clear answer exists for correcting disparities in makerspace participation. Makerspaces have the potential to promote equity and inclusion because the focus on the process instead of the product allows all students to be engaged and learn collectively. Maker learning, with its opportunities for collaboration and student input, improves a sense of belonging for all students (Nadelson, 2021).

Successful efforts begin with the needs and characteristics of the communities served by maker schools, libraries, and organizations. As the maker movement expands, more organizations and agencies should provide funding for equitable maker learning opportunities for underrepresented minorities and women. However, more quantitative research is needed to determine the statistical benefits of makerspaces in schools.

Gaps in Literature

The maker movement, makerspaces, and making are relatively new to the world of education; therefore, most of the available research attempts to describe and categorize the associated principles and concepts. These qualitative studies are essential to form a basis for further quantitative research.

Making suffers from a similar problem with the closely related area of STEM education. Major stakeholders and government entities currently have no standard definition for making and makerspaces. The lack of a concise definition has caused the public to jump on the bandwagon of making by including arts, crafts, and any creation of a physical object. More work must be done to reach a consensus and clarify the definition of making, makers, and makerspaces. More research on how makerspaces and maker learning affect student academic achievement is needed to justify the monetary investment in people, equipment, and time. Once a standard set of maker principles for learning are developed, their effect on learning in English language arts, math, and social studies could be studied.

Post-COVID-19, concerns about students' social-emotional well-being in K-12 education have been raised. Student voice, choice, and empowerment can improve students' feelings of belonging in schools. These characteristics, which are present in maker activities, give students more control over their learning. More research is needed to better determine the relationship between maker activities and social-emotional learning to inform educators, administrators, and parents' decision-making.

Chapter III: Methodology

Research Design

The design of this study was quasi-experimental, with an experimental group consisting of voluntary participants in an afterschool makerspace program. The threshold for inclusion in the study was participation in 25% of the program days for the designated year. A control group was selected using stratified random sampling of students from the same schools and grades who did not participate in the afterschool makerspace program. This study included 435 students, 237 participants, and 108 nonparticipant control students for the 2019-2020, 2020-2021, and 2021-2022 program years.

Purpose of the Study

The purpose of this study was to determine the effect of participation in an afterschool makerspace program on the academic achievement of middle school students. Math and science end-of-course grades and NWEA scores were analyzed to determine the program's effectiveness.

Research Questions and Hypotheses

1A. Did the number of days of participation in an afterschool makerspace program affect math achievement test scores for sixth-eighth grade students?

H_0: Participation in the afterschool program did not affect math achievement test scores.

H_{1A}: Students who participated at least 25% of available days in the afterschool makerspace had higher math achievement test scores than nonparticipants.

1B. Did the number of years of participation in the afterschool makerspace program affect math achievement test scores for sixth-eighth grade students?

H_0: Participation in the afterschool program for more than one year did not affect math achievement test scores.

H_{1B}: Students who participated for two or more years of afterschool makerspace had higher math achievement test scores than nonparticipants.

2A. Did the number of days of participation in the afterschool makerspace program affect math grades for sixth-eighth grade students?

H_0: Participation in the afterschool program did not affect math grades.

H_{2A}: Students who participated at least 25% of available days in the afterschool makerspace had higher math grades than nonparticipants.

2B. Did the number of years of participation in the afterschool makerspace program affect math grades for sixth-eighth grade students?

H_0: Participation in the afterschool makerspace program for more than one year did not affect math grades.

H_{1B}: Students who participated for two or more years of afterschool makerspace had higher math grades than nonparticipants.

3A. Did the number of days of participation in the afterschool makerspace program affect science achievement test scores for sixth-eighth grade students?

H_0: Participation in the afterschool program did not affect science achievement test scores.

H_{1A}: Students who participated at least 25% of available days in the afterschool makerspace had higher science achievement test scores than nonparticipants.

3B. Did the number of years of participation in the afterschool makerspace program affect science achievement test scores for sixth-eighth grade students?

H_0: Participation in the afterschool makerspace program for more than one year did not affect science achievement test scores.

H_{1B}: Students who participated for two or more years of the afterschool makerspace program had higher science achievement test scores than nonparticipants.

4A. Did the number of days of participation in the afterschool makerspace program affect science grades for sixth-eighth grade students?

H_0: Participation in the afterschool makerspace program did not affect science grades.

H_{1A}: Students who participated at least 25% of available days in the afterschool makerspace program had higher science grades than nonparticipants.

4B. Did the number of years of participation in the afterschool makerspace program affect science grades for sixth-eighth grade students?

H_0: Participation in the afterschool makerspace program for more than one year did not affect science grades.

H_{1B}: Students who participated for two or more years of the afterschool makerspace program had higher science grades than nonparticipants.

5. Did the number of days of participation in the afterschool makerspace program affect school-day attendance for sixth-eighth grade students?

H_0: Participation in the afterschool makerspace program did not affect school-day attendance.

H_1: Students who participated at least 25% of available days in the afterschool makerspace had fewer school day absences.

6. Did gender influence the effect of the afterschool makerspace program on achievement?

H_0: Gender did not affect math and science achievement test scores.

H_1: Male students had higher math and science achievement test scores than females.

Description of Population

Participants were sixth-eighth grade students who participated in a 21st Century Community Learning Centers afterschool makerspace program during the 2019-2020, 2020-2021, and 2021-2022 school years. The voluntary experimental group consisted of 237 students who participated in at least 25% of the program days, and the control group consisted of 108 nonparticipant students.

The school district in which the afterschool makerspace program runs used an achievement gap analysis to determine the focus of the afterschool makerspace program. Table 1 shows the disability and economically disadvantaged achievement gaps for students in the studied school district and the gap difference from 2017 to 2018.

Table 1

2017 and 2018 Achievement Gap Analysis

	Pass % 2017	Achievement Gap 2017	Pass % 2018	Achievement Gap 2018	Gap Difference
All Students	50.20%	**	57.40%	**	**
Students without Disabilities	55.30%	**	63.30%	**	**
Students with Disabilities	14.80%	-40.50%	20.80%	-42.60%	2.10%
Not Economically Disadvantaged	62.00%	**	68.10%	**	**
Economically Disadvantaged	38.60%	-23.40%	46.80%	-21.30%	-2.10%

Note. Data does not include a school consolidated in 2018-2019.

Students with disabilities and economic disadvantages scored lower than those without on the achievement tests. Economically disadvantaged students gained slightly from 2017 to 2018; however, the gap for students with disabilities increased. Based on this data, the school district identified students with disabilities and economically disadvantaged students as the targeted populations for the afterschool makerspace program. Students were recruited for the program based on teacher and principal recommendations.

Because the program was a voluntary afterschool program, no risk was involved. Measures were taken to remove all identifying information to protect the identity of experimental and control group students. The study was determined to be IRB-exempt.

Data

The experimental group data were collected from records of students participating in at least 25% of the afterschool makerspace program. Data collected included grade, gender, and daily program attendance. The researcher collected science and math NWEA scores, science and math grades, and daily school attendance from the student data management system.

A control group of students who attended the same schools, were in the same grades and had the same special education designation were randomly selected. The control group consists of students who had no participation in the afterschool makerspace program. Special education stratification was necessary because the afterschool program targeted these students for participation in the program. Due to all five middle schools being identified as Title I high-poverty schools, the researcher did not stratify data based on economic disadvantage. The researcher collected science and math NWEA scores, science and math grades, and daily school attendance for the control group from the school district's student data management system.

Variables in the study

For this study, the discrete predictor variable was the number of days of participation in the afterschool makerspace. The predictor control variable was non-participation in the afterschool makerspace. One categorical value was the gender of the study participants. Predicted variables were

- Math grades for sixth-eighth grade students.
- NWEA math scores for sixth-eighth grade students.
- Science grades for sixth-eighth grade students.
- NWEA science scores for sixth-eighth grade students.
- School day attendance for sixth-eighth grade students.

Data Analysis

Data for questions 1-5 were analyzed using a *t* test with a 95% confidence level. This study used a Welch *t* test procedure to determine the probability of observing the collected data, given that no difference exists between the population means. The degrees of freedom associated with the *t* tests fall between a minimum of the smaller sample size of the two samples minus one and a maximum of the sum of the two sample sizes minus two. The nearer the variances of the two samples are to one another, the nearer the degrees of freedom will approach the maximum value of (n1+n2)-2. The degrees of freedom of the two sample t tests are often less than the (n1+ n2)-2 therefore, an adjustment was needed since pooled variances are used when the two populations are known to have identical variances. A Pearson correlation was calculated to analyze the relationship between afterschool makerspace participation and school attendance. The gender and participation data were analyzed with a two-way ANOVA. A Scheffé test was used to determine the effect level for two-way ANOVA tests that showed a significant effect.

Chapter IV: Findings and Analysis

Introduction

This study investigated the effect of participation in an afterschool makerspace program on student academic achievement and school attendance. Quantitative data for the participants and the control group were collected from afterschool programs and student management records. Data collected included NWEA science and math scores, science and math grades, program attendance, school attendance, special education designation, and gender of participants. Data were collected for three program years, 2019-2020, 2020-2021, and 2021-2022. This chapter discusses the findings and analysis of the data.

Research Question 1A

Did the number of days of participation in the afterschool makerspace program affect math achievement test scores for sixth-eighth grade students?

Table 2 shows the mean, standard deviation, and *t* test of NWEA math scores for participants and nonparticipants in the afterschool makerspace program.

Table 2

Mean, SD, and t test for NWEA Math Scores

	n	M	SD	t test
		2019-2020		
Participants	108	223.51	15.52	$t(216) = -1.42$ $p = .9213$ 95% CI [-7.30, 1.19]
Nonparticipants	110	226.56	16.26	
		2020-2021		
Participants	67	223.31	15.92	$t(135) = 0.51$ $p = .3066$ 95% CI [-4.10, 6.93]
Nonparticipants	70	221.90	16.74	
		2021-2022		
Participants	98	228.46	17.57	$t(193) = -0.38$ $p = .6477$ 95% CI [-5.75, 3.89]
Nonparticipants	98	229.39	16.65	

For the 2019-2020, 2020-2021, and 2021-2022 school years, the two-sample *t* test indicated that students participating in the afterschool makerspace program did not have significantly higher NWEA math scores than nonparticipants ($p > .05$).

Research Question 1B

Did the number of years of participation in the afterschool makerspace program affect math achievement test scores for sixth-eighth grade students?

Table 3 shows the mean, standard deviation, and *t* test of NWEA math scores for multiyear participants and nonparticipants in the afterschool makerspace program.

Table 3

Mean, SD, and t test for Multiyear NWEA Math Scores

	n	**M**	**SD**	**t test**
Participants	40	229.70	17.47	$t(70) = 0.096$ $p = .4617$ 95% CI [-6.14, 6.76]
Nonparticipants	98	229.39	16.65	

A two-sample *t* test indicated that students who participated in the afterschool makerspace program for two or more years did not have significantly higher NWEA math scores than nonparticipants ($p = .4617$).

Analysis of the data for Research Question 1 found that participation in the afterschool makerspace program for one year or multiple years had no significant effect on math achievement test scores. These results are consistent with findings by Andria (2020), in which student participation in a library makerspace did not significantly improve eighth grade math achievement test scores.

Research Question 2A

Did the number of days of participation in the afterschool makerspace program affect math grades for sixth-eighth grade students?

Table 4 shows the mean, standard deviation, and *t* test of math grades for participants and nonparticipants in the afterschool makerspace program.

Table 4

Mean, SD, and t test for Math Grades

	n	M	SD	t test
		2019-2020		
Participants	110	81.93	8.37	*t*(217) = -1.90
Nonparticipants	110	84.13	8.80	*p* = .9706 95% CI [-4.48, 0.08]
		2020-2021		
Participants	68	85.59	9.39	*t*(135) = 0.80
Nonparticipants	70	84.33	9.07	*p* = .2123 95% CI [-1.85, 4.37]
		2021-2022		
Participants	98	85.11	9.47	*t*(194) = 0.60
Nonparticipants	98	84.30	9.70	*p* = .276 95% CI [-1.89, 3.52]

For the 2019-2020, 2020-2021, and 2021-2022 school years, the two-sample *t* test indicated that students participating in the afterschool makerspace program did not have significantly higher math grades than nonparticipants ($p > .05$).

Research Question 2B

Did the number of years of participation in the afterschool makerspace program affect math grades for sixth-eighth grade students?

Table 5 shows the mean, standard deviation, and *t* test of math grades for multiyear participants and nonparticipants in the afterschool makerspace program.

Table 5

Mean, SD, and t test for Multiyear Math Grades

	n	M	SD	t test
Participants	40	82.15	8.0	*t*(87) = -1.34
Nonparticipants	98	84.30	9.7	*p* = .9082 95% CI [-5.33, 1.04]

A two-sample *t* test indicated that multiyear participants in the afterschool makerspace program did not have significantly higher math grades than nonparticipants (*p* = .9082).

Analysis of the data for Research Question 2 found that participation in the afterschool makerspace program for one year or multiple years did not affect math grades. These results are consistent with findings by Gottfredson et al. (2010) that afterschool programming had no statistically significant effect on grades. However, another study found that regular attendance in an afterschool program significantly affected grades (Springer & Diffily, 2012).

Research Question 3A

Did the number of days of participation in the afterschool makerspace program affect science achievement test scores for sixth-eighth grade students?

Table 6 shows the mean, standard deviation, and *t* test of NWEA science scores for participants and nonparticipants in the afterschool program.

Table 6

Mean, SD, and t test for NWEA Science Scores

	n	M	SD	t test
		2019-2020		
Participants	102	209.18	11.85	*t*(203) = -0.06
Nonparticipants	110	209.27	10.64	*p* = .5247 95% CI [-3.15, 2.96]
		2020-2021		
Participants	68	209.91	13.45	*t*(102) = 0.79
Nonparticipants	70	207.04	27.09	*p* = .2153 95% CI [-4.32, 10.06]
		2021-2022		
Participants	98	212.39	12.46	*t*(152) = 0.95
Nonparticipants	98	209.94	22.40	*p* = .1728 95% CI [-2.67, 7.56]

For the 2019-2020, 2020-2021, and 2021-2022 school years, the two-sample *t* test indicated that students participating in the afterschool makerspace program did not have significantly higher NWEA math scores than nonparticipants (*p* >.05).

Research Question 3B

Did the number of years of participation in the afterschool makerspace program affect science achievement test scores for sixth-eighth grade students?

Table 7 shows the mean, standard deviation, and *t* test of NWEA science scores for multiyear participants and nonparticipants in the afterschool makerspace program.

Table 7

Mean, SD, and t test for Multiyear NWEA Science Scores

	n	M	SD	t test
Participants	40	210.35	12.35	*t*(124) = 0.14
Nonparticipants	98	209.94	22.39	*p* = .4454 95% CI [-5.50, 6.33]

A two-sample *t* test indicated that those who participated in the afterschool makerspace for two or more years did not have higher NWEA science scores than nonparticipants (*p* = .4454).

Analysis of the data for Research Question 3 found that participation in the afterschool makerspace program for one year or multiple years had no significant effect on science achievement test scores. These results can be contrasted with findings by Andria (2020), in which student participation in a library makerspace had a significant negative relationship with eighth grade science achievement test scores.

Research Question 4A

Did the number of days of participation in the afterschool makerspace program affect science grades?

Table 8 shows the mean, standard deviation, and *t* test of science grades for participants and nonparticipants in the afterschool program.

Table 8

Mean, SD, and t tests for Science Grades

	n	M	SD	t test
		2019-2020		
Participants	110	85.99	7.38	*t*(211) = - 0.43 *p* = 0.6657 95% CI [-2.65, 1.70]
Nonparticipants	110	86.46	8.90	
		2020-2021		
Participants	68	85.46	9.17	*t*(136) = - 0.36 *p* = 0.6385 95% CI [- 3.67, 2.55]
Nonparticipants	70	86.01	9.30	
		2021-2022		
Participants	98	88.32	8.92	*t*(192) = - 0.06 *p* = 0.9531 95% CI [-2.46, 2.32]
Nonparticipants	98	88.39	8.03	

For the 2019-2020, 2020-2021, and 2021-2022 school years, the two-sample *t* test indicated that students participating in the afterschool makerspace program did not have significantly higher science grades than nonparticipants ($p > .05$).

Research Question 4B.

Did the number of years of participation in the afterschool makerspace program affect science grades for sixth-eighth grade students?

Table 9 shows the mean, standard deviation, and *t* test of science grades for multiyear participants and nonparticipants in the afterschool makerspace program.

Table 9

Mean, SD, and t tests for Multiyear Science Grades

	n	M	SD	t test
Participants	40	84.85	9.37	$t(64) = -2.09$
Nonparticipants	98	88.39	8.03	$p = .9799$ 95% CI [-6.91, -0.16]

The two-sample *t* test indicated that those who participated in the afterschool makerspace for two or more years did not have higher science grades than nonparticipants ($p = .9799$).

The findings for Question 4 were inconsistent with the findings by Cutucache et al. (2018), which found that participation in at least 50% of days in STEM afterschool programming resulted in significant gains in science content knowledge. Additionally, another study found that regular attendance in an afterschool program significantly improved grades (Springer & Diffily, 2012).

Research Question 5

Did the number of days of participation in the afterschool makerspace program affect school-day attendance for sixth-eighth grade students?

Table 10 shows the mean, standard deviation, and *t* test of school absences for participants and nonparticipants in the afterschool makerspace program.

Table 10

Mean, SD, and t tests for School Absences

	n	M	SD	t test
		2019-2020		
Participants	98	5.88	5.31	*t*(201) = 0.13
Nonparticipants	110	5.78	5.05	*p* = .5527 95% CI [-1.33, 1.52]
		2020-2021		
Participants	68	8.75	6.00	*t*(129) = -1.13
Nonparticipants	70	10.08	7.81	*p* = .1306 95% CI [-3.68, 1.01]
		2021-2022		
Participants	95	11.21	6.29	*t*(186) = -1.66
Nonparticipants	98	12.89	7.69	*p* = .0492 95% CI [-3.67, 0.31]

For the 2019-2020 and 2020-2021 school years, the two-sample *t* test indicated that students participating in the afterschool makerspace program did not have fewer school absences than nonparticipants ($p > .05$). For the 2021-2022 school year, the two-sample *t* test indicated that students participating in the afterschool makerspace program had fewer school absences than nonparticipants (p = .0492).

A Pearson correlation was calculated to analyze the relationship between program attendance and school absences. Table 11 shows the Pearson correlation of afterschool program attendance to school day absences.

Table 11

Pearson Correlation for program attendance and school absences.

	2019-2020	**2020-2021**	**2021-2022**
Participants	-0.155	-0.27	-0.23

For all three school years, afterschool makerspace program attendance had a weak negative correlation to school day absences ($r < 0.3$).

Attendance in the afterschool makerspace program had mixed results. While the experimental group had significantly higher attendance than the control group for the 2021-2022 school year, there is only a weak negative correlation between afterschool makerspace program participation and school absences.

These findings are inconsistent with studies that found that regular attendance in an afterschool program decreased the number of school absences, especially for middle school students (Springer & Diffily, 2012; Cutucache et al., 2018).

Research Question 6

Did gender influence the effect of the afterschool makerspace program on achievement?

Table 12 shows the mean and two-way Analysis of Variance of NWEA math scores for 2019-2020, 2020-2021, and 2021-2022 school years for male and female participants and nonparticipants in the afterschool makerspace program.

Table 12

Two-Way ANOVA Results for Gender, Participation, and NWEA Math Scores

		n	M	Two Way ANOVA
			2019-2020	
Male	Participants	53	223.72	F interaction between Gender and Participation = 0.39 *p* = .5345
	Nonparticipants	52	224.35	
Female	Participants	55	223.31	
	Nonparticipants	58	228.55	
			2020-2021	
Male	Participants	29	222.66	F interaction between Gender and Participation = .36 *p* = .0225
	Nonparticipants	38	215.66	
Female	Participants	38	223.82	
	Nonparticipants	32	229.31	
			2021-2022	
Male	Participants	38	228.79	F interaction between Gender and Participation = 0.70 *p* = .4052
	Nonparticipants	55	227.8	
Female	Participants	60	228.25	
	Nonparticipants	43	231.42	

For the 2019-2020 and 2021-2022 school years, the two-way ANOVA indicated no statistically significant effect of the interaction between gender and participation on NWEA math scores ($p > .05$). For the 2020-2021 school year, the two-way ANOVA showed a statistically significant effect of gender and participation in the afterschool makerspace program on the math achievement test scores ($p = .0225$).

A Scheffé post hoc test was calculated for 2020-2021 math scores to determine the specific level of interaction between gender, participation, and NWEA math scores. Table 13 shows the Scheffé post hoc test for NWEA math scores.

Table 13

Scheffé Post Hoc Test for 2020 - 2021 NWEA Math Scores

	n1	n2	Mean 1	Mean 2	Pairwise Mean Difference	Comparison	Significant (Diff > Comp)
1v2	32	38	229.31	223.82	5.50	8.99	n
1v3	32	38	229.31	215.66	13.65	8.99	y
1v4	32	29	229.31	222.66	6.66	9.61	n
2v3	38	38	223.82	215.66	8.16	8.60	n
2v4	38	29	223.82	222.66	1.16	9.24	n
3v4	38	29	215.66	222.66	7.00	9.24	n

Note: 1 = female nonparticipants, 2 = female participants, 3 = male nonparticipants, 4 = male participants

Post hoc analysis using the Scheffé test indicated that the average NWEA math score for female nonparticipants was significantly higher than male nonparticipants, although not significantly higher than male and female participants.

Table 14 shows the mean and two-way Analysis of Variance of NWEA science scores for male and female participants and nonparticipants in the afterschool program.

Table 14

Two-Way ANOVA Results for Gender, Participation, and NWEA Science Scores

		n	M	Two Way ANOVA
		2019-2020		
Male	Participants	50	209.82	F interaction between Gender and Participation = 0.09 p = .768
	Nonparticipants	52	207.90	
Female	Participants	52	208.56	
	Nonparticipants	58	210.50	
		2020-2021		
Male	Participants	30	211.03	F interaction between Gender and Participation = 5.67 p = .0187
	Nonparticipants	38	200.16	
Female	Participants	38	209.03	
	Nonparticipants	32	215.22	
		2021-2022		
Male	Participants	38	213.32	F interaction between Gender and Participation = 2.68 p = .1030
	Nonparticipants	55	206.84	
Female	Participants	60	211.80	
	Nonparticipants	43	213.91	

For the 2019-2020 and 2021-2022 school year, a two-way ANOVA indicated no statistically significant effect of the interaction between gender and participation in the afterschool makerspace program on NWEA science scores ($p > .05$). For the 2020-2021 school year, a two-way ANOVA showed a statistically significant effect of gender and participation in the afterschool makerspace program on the science achievement test scores ($p = .0187$).

A Scheffé post hoc test was calculated for 2020-2021 science scores to determine the specific level of interaction between gender, participation, and NWEA math scores. Table 15 shows the Scheffé post hoc test results for NWEA science scores.

Table 15

Scheffé Post Hoc Test for 2020-2021 NWEA Science Scores

	n1	n2	Mean 1	Mean 2	Pairwise Mean Difference	Comparison	Significant (Diff > Comp)
1v2	32	40	215.22	207.93	7.29	8.67	n
1v3	32	37	215.22	205.38	9.84	8.83	y
1v4	32	30	215.22	211.03	4.19	9.29	n
2v3	40	37	207.93	205.38	2.55	8.34	n
2v4	40	30	207.93	211.03	3.11	8.83	n
3v4	37	30	205.38	211.03	5.65	8.98	n

Note: 1 = female nonparticipants, 2 = female participants, 3 = male nonparticipants, 4 = male participants

Post hoc analysis using the Scheffé test indicated that the average NWEA science score for female nonparticipants was significantly higher than male nonparticipants, although not significantly higher than male and female participants.

Summary

This chapter presents the findings and analysis of the data collected from the 2019-2022 middle school afterschool makerspace program. Two areas show a statistically significant effect. Data analysis indicated that students participating in the 2021-2022 afterschool makerspace had fewer absences than nonparticipants. Data analysis also indicated that the interaction of gender and participation in afterschool makerspace had a statistically significant effect on the science and math achievement test scores during the 2020-2021 school year. However, further analysis indicated that the effect was for nonparticipants of the study.

Chapter V: Conclusions and Discussion

This study aimed to determine the effect of participation in an afterschool makerspace program on middle school students' achievement test scores, grades, and school-day attendance. The research findings resulted from analyzing three years of data for students in the afterschool program. These students were compared to a control group selected using stratified random sampling from the same schools, grades, and special education designation who did not participate in the afterschool makerspace program.

Conclusions

Question One

Research question one analyzed the NWEA math scores of students who participated in at least 25% of the days of an afterschool makerspace program and a control group of students who did not participate. For 2019-2020, 2020-2021, and 2021-2022, the afterschool makerspace program participants did not have significantly higher NWEA math scores than nonparticipants. Therefore, the null hypothesis was not rejected.

Part B of the question analyzed the effect of multiple years of attendance. Participants who attended multiple years of the afterschool makerspace program did not have significantly higher NWEA math scores than nonparticipants. Therefore, the null hypothesis was not rejected.

Question Two

Research question two analyzed the math grades of students who participated in at least 25% of the days of an afterschool makerspace program and a control group of students who did not participate. Participants in the afterschool makerspace program did not have significantly higher math grades than nonparticipants. Therefore, the null hypothesis was not rejected.

Part B of the question analyzed the effect of multiple years of attendance. Participants who attended multiple years of the afterschool makerspace program did not have significantly higher math grades than nonparticipants. Therefore, the null hypothesis was not rejected.

Question Three

Research question three analyzed the NWEA science scores of students who participated in at least 25% of the days of an afterschool makerspace program and a control group of students who did not participate. For 2019-2020, 2020-2021, and 2021-2022, the afterschool makerspace program participants did not have significantly higher NWEA science scores than nonparticipants. Therefore, the null hypothesis was not rejected.

Part B of the question analyzed the effect of multiple years of attendance. Participants who attended multiple years of the afterschool makerspace program did not have higher NWEA science scores than nonparticipants. Therefore, the null hypothesis was not rejected.

Question Four

Research question four analyzed the science grades of students who participated in at least 25% of the days of an afterschool makerspace program and a control group of students who did not participate. For 2019-2020, 2020-2021, and 2021-2022, the afterschool makerspace program participants did not have higher science grades than nonparticipants. Therefore, the null hypothesis is not rejected.

The second part of the question analyzed the effect of multiple years of attendance. Participants who attended multiple years of the afterschool makerspace program did not have higher science grades than nonparticipants. Therefore, the null hypothesis was not rejected.

Question Five

Research question five analyzed the school-day attendance of students who participated in at least 25% of the days of an afterschool makerspace program and a control group of students who did not participate. For 2019-2020 and 2020-2021, participants in the afterschool makerspace program did not have fewer absences than nonparticipants. Therefore, the null hypothesis was not rejected. For the 2021-2022 school year, participants in the afterschool makerspace program had significantly fewer school absences than nonparticipants (p = .0492). Therefore, the null hypothesis was rejected.

Question Six

Research question six analyzed the interaction between gender and makerspace participation on achievement test scores for students who participated in at least 25% of the days of an afterschool makerspace program and a control group of students who did not participate. For 2019-2020 and 2021-2022, the gender of students and participation in the makerspace program had no statistically significant effect on NWEA math or science scores. Therefore, the null hypothesis was not rejected.

For 2020-2021, the two-way ANOVA indicated that gender and makerspace attendance had a statistically significant effect on NWEA math scores (p = .0225) and science scores (p = .0187). Therefore, the null hypothesis was rejected. Post hoc analysis using the Scheffé test indicated the average NWEA math and science scores of female nonparticipants were significantly higher than male nonparticipants, although not significantly higher than male and female participants. Therefore, makerspace participation and gender do not positively affect math and science achievement test scores.

Discussion

Making and makerspaces are relatively new to K-12 education; therefore, research studies have focused on describing makerspaces and provided qualitative support for implementing making and makerspaces in education. The afterschool makerspace program in this study was implemented based on the need for an afterschool program to provide engaging hands-on activities, incorporate STEM/STEAM, and develop 21st Century skills. Additionally, makerspaces hold great promise for providing rich educational experiences for students with disabilities and economic disadvantages (Morris, 2018; Waters, 2014).

Afterschool makerspaces are popular for supporting student engagement in STEM and STEAM. For example, an afterschool STEM program for middle school students in two rural low-income schools in Southwest Virginia provided students with 90 minutes of afterschool programming per day for one semester. Data analysis showed that students who participated developed positive perceptions of science and were more likely to pursue science as a career (Chittum et al., 2017).

Multiple studies have shown that makerspaces are ideal for developing 21st Century skills. Because makerspaces promote imagination and building physical creations, students develop creativity (Pijls et al., 2022: Timotheou & Ioannou, 2021). Also, making and makerspaces use the principle of working together to solve problems and sharing solutions; therefore, students develop the critical future job skill of collaboration (Mersand, 2021; Jocius et al., 2020). Additionally, a study by Iwata et al. (2020) supports the use of makerspaces in developing creativity, collaboration, critical thinking, communication, and problem-solving.

The current research study showed little effect of afterschool makerspace programming on student academic achievement. This is not surprising, considering studies on the effectiveness of afterschool programming in improving academic achievement have been mixed.

Several principles and pedagogies found in makerspaces have been shown to improve academic achievement. For example, makerspaces primarily use hands-on pedagogy for activities and projects. Based on the support of many quantitative studies on the effectiveness of hands-on pedagogies, it was expected that makerspaces would positively affect students' math and science learning (Stohr-Hunt, 1996). Another pedagogy used in makerspaces, project-based learning, has been shown to improve student learning and performance on achievement tests (Beier et al., 2018).

Many studies recommend afterschool programming as a method for improving academic achievement. For example, a study of a Boys and Girls Club in Dallas found that increased afterschool program attendance was positively related to an increase in student GPA from the beginning to the end of a school year (Springer & Diffily, 2012). Another study of a large urban city in Nebraska used a pretest and posttest design to determine the effect of an afterschool program on STEM content knowledge. Students who participated in at least 50% of the lessons significantly improved their STEM content knowledge compared to a control group (Cutucache et al., 2019).

However, a meta-analysis of afterschool research found that only high-quality programs positively affected educational outcomes and called for a more standardized method for evaluating afterschool programming. One suggestion was to use a pretest-posttest method during the same academic year to determine effectiveness (Lester et al., 2020).

Only one quantitative study of makerspaces and academic achievement was found. This study analyzed data from school libraries in New York to determine the relationship between library makerspaces and academic achievement. The findings found either no statistically significant or a negative effect of participating in the library makerspace on English Language Arts, math, and science assessments (Andria, 2020). The current empirical study supports these findings.

Another goal of the afterschool program was to decrease school absences. For example, a study of a Boys and Girls Club in Dallas found that increased afterschool attendance resulted in a significant decrease in school absences (Springer & Diffily, 2012). The statistically significant effect of afterschool makerspace on school attendance during the 2021-2022 school year supports this finding.

Findings for the 2019-2020 school year could be caused by the early ending of the school year due to the COVID-19 pandemic. The pandemic also affected the 2020-2021 school year because of a delayed start and many students attending hybrid or virtual school. The 2021-2022 school year was the first normal year post-pandemic in which students were required to return to regular school attendance. Because afterschool participants must attend school during the day to attend makerspace, these students were likely more motivated to come to school regularly. Therefore, makerspace participation significantly decreased school absences.

The interaction between makerspace participation, gender, and academic achievement showed an effect only during the 2020-2021 school year. However, further analysis showed that this effect was unrelated to makerspace participation.

Practical Significance

As federal, state, and local agencies continue to provide funding for makerspaces in libraries, K-12 schools, and postsecondary institutions, more studies are needed to determine the effectiveness of these programs. The afterschool program investigated in this research study was funded through the 21st Century Community Learning Centers federal grant administered by states. To seek additional funding through grants or community support, the afterschool makerspace program was required to show success. However, little quantitative evidence exists to indicate that participation in makerspace programs has a significantly positive effect on academic achievement, especially in STEM subjects.

Anecdotal and qualitative evidence exists to suggest the success of makerspaces on the self-efficacy, 21st Century skills, and motivations of students. However, to be accepted as a mainstream education initiative, more quantitative studies are needed to determine the best makerspace pedagogies, practices, and activities that directly support student learning.

P-20 Implications

The Maker Movement has expanded tremendously since the early 21st Century. The US government supports making through organizations such as the Congressional Maker Caucus, the National Science Foundation, and the US Department of Education. Many national nonprofit organizations are expanding the support of makers and makerspaces. Most notable are the Nation of Makers, which grew out of President Obama's White House maker initiatives, Digital Promise, and Maker City. In education, the Massachusetts Institute of Technology's Fab Lab Network promotes making in education worldwide. In education, nonprofits like Fab Labs and MakerEd leverage sponsorships with companies like Chevron, Volkswagen, and GE to bring makerspaces to K-12 students. Also, large cities and urban areas use makerspaces for job training, entrepreneurship opportunities, and community collaboration. Through rapid grassroots expansion, makerspaces can now be found in community spaces, libraries, museums, universities, corporations, and K-12 schools.

Making also has the potential to increase the number of nontraditional students in STEM fields at a time when broadening participation is needed to continue the United States' competitive, entrepreneurial, and innovative economy. Making can introduce P-20 students to problem-solving and skills development using tools and methods that appeal to nontraditional students. Continued funding of openly available makerspaces and a broad range of making activities can provide a much-needed way to provide diversity and inclusion to communities and schools.

Making as an academic pedagogy could be combined with similar initiatives such as problem-based learning, hands-on activities, problem-based learning, growth mindset, and 21st Century skill development to change the face of P-20 education. Ultimately, making is a P-20 and community phenomenon supporting learning for people of all ages and educational levels. Making allows people at any knowledge level to participate in the broader maker community and is a perfect example of authentic lifelong learning.

Limitations of the Study

This study is limited to students in one school district who were in sixth-eighth grade during the years 2019-2020, 2020-2021, and 2021-2022. The experimental group of students voluntarily attended the afterschool makerspace program. This study did not consider the influence of classroom teachers on students' academic achievement but attempted to alleviate bias by using a stratified random sample control group.

The school district in which the study took place comprises five middle schools with different socioeconomic levels, demographics, and cultures. This study did not analyze results for individual schools.

Recommendations for Future Research

As a relatively new educational pedagogy, making and makerspaces offer many unexplored topics. While this study compared the participant group with a control group, this study should be repeated with a pretest-posttest method for determining the effect of makerspace participation on students' academic growth during a single academic year. This method would control for teacher differences and could better show how makerspace participation directly affects student growth during the school year.

For this study, students had to participate in 25% or more of available makerspace days to be included in the data set. Afterschool research by Cutucache et al. (2019) used a participation level of 50% available days. Repeating this study with a higher level of participation could reveal interactions and effects not shown at the current participation level.

The afterschool makerspace program investigated in this study was funded for the 2022-2023 school year. Adding an additional year of data, post-COVID-19, could provide additional support for the effect on school attendance found for the 2021-2022 school year. A fourth year of data would also increase the sample size.

This study collectively analyzed the effect of makerspace participation on academic achievement for all five middle school makerspaces. However, the five middle schools have very different socioeconomic levels, cultures, and demographics; for example, two schools are considered rural, two are housed in small towns, and one is suburban. Two schools have high levels of poverty, and three are very diverse. Further data analysis is needed to analyze each school individually to determine if the demographics of schools and makerspace participation will show interactions not evident in the collective data set.

Of the students who participated in two or more years of the program, 30% were special education students. This percentage is higher than any one year of participation. The 21st-Century program specifically recruited these students based on research that indicated makerspaces provided these students with ideal learning conditions. More research is needed to understand what factors caused these students to participate for multiple years and what benefit they received from this multiyear participation. A survey of these students and their families could give a better picture of the factors affecting these students.

Developing 21st Century skills is necessary for students to be fully prepared for college and careers. Many studies have provided qualitative evidence that makerspace participation develops 21st Century learning skills, specifically communication, collaboration, creativity, and critical thinking (Sheffield et al., 2017; Iwata et al., 2020). A single assessment has yet to be designed to show the growth of 21st Century skills. Current assessments rely on multiple pieces of evidence and specific tests to measure critical thinking. Creating a picture of a student's 21st Century skills is complex (Lai, 2012). More research is needed to develop a standardized assessment to show the growth of 21st Century skills in a makerspace environment.

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Appendix

MURRAY STATE UNIVERSITY

Institutional Review Board

328 Wells Hall
Murray, KY 42071-3318
270-809-2916• msu.irb@murraystate.edu

TO: Mardis Dunham, Counseling and Assessment Center

FROM: Jonathan Baskin, IRB Coordinator JB

DATE: July 14, 2022

RE: Human Subjects Protocol I.D. – IRB # 23-002

Project Title: *Effect of Makerspace Participation on Academic Achievement*.
Principal Investigator(s): Mardis Dunham, Teresa Lampe
Determination: Individuals not Identifiable - Activity does not involve human subjects as defined in 45 CFR 46.102(e)(1)

The Murray State University IRB has reviewed the information you supplied for the project named above. Based on that information, it has been determined that this project does not involve activities and/or subjects that would require IRB review and oversight. The IRB will keep your determination form on file for a period of 3 years.

Please note that there may be other Federal, State, or local laws and/or regulations that may apply to your project and any changes to the subjects, intent, or methodology of your project could change this determination. You are responsible for informing the IRB of any such changes so that an updated determination can be made. If you have any questions or require guidance, please contact the IRB Coordinator for assistance.

Thank you for providing information concerning your project.