Summer 2020

Improving Computational Thinking: Action Research Implementing a School Makerspace With Elementary Students

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Recommended Citation

Swick, T. C.(2020). *Improving Computational Thinking: Action Research Implementing a School Makerspace With Elementary Students.* (Doctoral dissertation). Retrieved from https://scholarcommons.sc.edu/etd/6011

IMPROVING COMPUTATIONAL THINKING: ACTION RESEARCH IMPLEMENTING A SCHOOL MAKERSPACE WITH ELEMENTARY STUDENTS

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2020

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DEDICATION

This dissertation work is dedicated to my wife, Amy, and our children, Bobby, and Joey. Their support, encouragement, and sacrifice over the last three years has made this project possible. Without your constant support, I would have never completed this work. Thank you for giving up many weekends and countless nights for me to complete this research. I also dedicate this to the many mentors and friends I have had the privilege of learning under in my career as an educator. These include Beth Elliott, Dr. Katie Barber, Dr. Sabina Mosso Taylor, and Connie May, among many others. Your support and leadership were vital in my growth as an educator.

ABSTRACT

The purpose of this action research was to evaluate the implementation of making experiences to support computational thinking through the development of makerspaces for fifth grade students at an elementary school in South Carolina. This action research explored the following three central questions: (1) To what extent did the implementation of a makerspace improve computational thinking skills for fifth grade students at an elementary school in South Carolina?, (2) How did these students' perceptions of using computational thinking as a problem solving method change based on makerspace experiences? and (3) How did their problem solving skills change through the use of computational thinking in makerspaces?

The innovation for my action research was the implementation of a makerspace to support computational thinking skills across five weekly design challenges. Sixteen student-participants took part in this study. Quantitative data was collected through pre- and postintervention assessment results using the computational thinking skills (CTS) survey developed by Korkmaz, Cakir, and Ozden (2015). Qualitative data was collected through observations, semi-structured focus group interviews, and participant artifacts. Data was analyzed by incorporating a mixed methods approach using a paired sample *t*-test for the pre- and postassessments, and an inductive thematic analysis of the qualitative data using the constant comparative method. Five themes evolved from the data: 1) developing problem solving skills, 2) effective tinkering and makerspace approaches as a method of thinking, 3) implementing computational thinking skills, (4) improving motivation and perseverance, and (5) developing effective communication, teamwork and collaboration skills.

Findings indicate that the development of a makerspace improved problem solving through effective making approaches. Students were able to demonstrate effective tinkering characteristics alongside the use of the design thinking process in increasingly complex ways. Implications of findings for integrating computational thinking into makerspace learning and for future research are discussed. Limitations of this study included the study design, the participant population, and my possible influence as a participant observer.

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CHAPTER 1

INTRODUCTION

National Context

Starting in 1999, the National Research Council (NRC) began publishing concerns that technological education must include the development of computational fluency, since technology is changing too fast for a skills-based approach to be effective (NRC, 1999 & 2002). This suggests that students should have more experience with computational thinking skills. Adversely, the increased development of standardized tests has hurt the pace, content and type of instruction taking place in classrooms (Hynes, Hira, Joslyn & Hynes, 2014). This has resulted in tested subjects being seen as more important than non-tested areas. As a result, computational thinking skills are not receiving adequate attention in elementary classrooms.

The 2007 Partnership for 21st Century Learning (P21) described the skills, knowledge, and expertise that students must know in order to succeed in the 21st century. Their framework found that students today would need innovation skills for work environments that don't yet exist. The partnership stated that to be able to prepare students for an increasingly complex world, the skills of critical thinking, communication, collaboration, and creativity (4Cs) should be addressed in schools.

In 2009, President Obama brought national attention to the possibilities of designing new digital learning environments for schools, when the White House hosted its inaugural MakerFaire. During the event, the President encouraged young people to create, build, invent, and become makers of things rather than just consumers (The White House, 2009). Following these remarks, the National Academy of Science has expressed an emerging interest into developing makerspaces and making as possible school learning environments. (Blikestein, 2013; Jarret, 2016; Moorefield-Lang, 2015; Rosenfeld & Erson, 2014).

Researchers in the field feel that the solution is to teach computer science in grades K-12 (Carter, 2006; National Research Council, 2012; Tucker et al., 2003). Since the 1980s, studies have looked at the positive characteristics of teaching children computational thinking skills, such as debugging, scaffolding, and problem transfer (Clements & Gullo, 1984; Klahr & Carver, 1988; Kurland, Pea, Clement, & Mawby, 1986; Pea, Soloway, & Spohrer, 1987). However, more recently, the field has begun to look at how to include teaching young children computing through coding, robotics, and modeling software (Galloway, 2015; Kafai, Fields & Burke, 2011; Polly & Rock, 2016), and to integrate the skills into other subject areas (Harel & Papert, 1990; Kafai, Ching, & Marshall, 1997; Metcalf, Krajcik, & Soloway, 2000).

This data indicates that despite existing efforts to improve Science Technology Engineering and Math (STEM) instruction through a focus on the 4Cs, there is still a growing national need to address computational thinking skills within the advancement in digital learning environments.

In 2016, the International Society for Technology in Education (ISTE) updated its standards for students by including a strand on computational thinking (ISTE, 2016). Intended as a way of leading changes in learning with technology, the strand on computational thinking encourages teachers to instruct students to use technology to solve problems by developing and testing solutions (ISTE, 2016). With the increasing use of technology in all careers, today's students must begin to use computational thinking concepts while in the K-12 environment (Barr & Stephenson, 2011). Computational thinking skills are no longer just for engineers and programmers, so all teachers must understand that teaching these skills have become a necessary part of our lives, and that learning how to use computers to extend our capabilities through computer-aided solutions is a necessary skill for students today. (Barr, Harrison, & Conery, 2011).

Moving forward with preparing students for future careers, it is important to expand the development of new technology careers for elementary school students. New environments, like makerspaces, and new skills, like computational thinking, are important elements for students to have access to and to explore. However, as stated by technology leaders in the 2017 Digital Learning report from the SpeakUp Digital Research Project, the greatest roadblock we face in expanding technology use is motivating schools to change their traditional practices to use technology in more meaningful ways (Project Tomorrow Speak Up, n.d.).

Local Context

This action research took place at a suburban elementary school in southeastern United States. The school is located in the fifth largest public school district of South Carolina. The school's fall 2019 enrollment had a student population of 673. The majority of the ethnic make-up for the school was African American (75.1%). The other major diversity groups included White (8.4%), Hispanic (8.12%), and Asian (2.3%). During the spring of 2019, the school was chosen to host the district's new computer science magnet program. As a magnet, the school's mission is to provide its students with learning experiences that integrate computer science concepts into regular classroom instruction. All students attending the school take part in all magnet opportunities. This includes an hour of integrated computer science instruction every week across all grade levels.

This site was purposely chosen due to its unique nature as the district's new magnet school for computer science. However, none of the students had previous experiences with a makerspace. Therefore, most of participants had minimal preexisting opinions, or experiences that could influence their impressions of making activities. This clean slate approach provided a richer and deeper opportunity for the researcher to describe the impact makerspaces have on students that have never used technology to solve problems through computational thinking.

My experience, observations, and discussions with professionals in the field of education indicates to me that there is a great concern with how to teach computational thinking through the development of innovative digital learning environments like those provided by a makerspace. Currently, my school district lacks a framework to guide elementary school teachers in computer science instruction. Despite the introduction of state computer science standards, teachers lack necessary resources needed to implement methods for developing computational thinking. Based on my discussion with other educators, elementary teachers see the need for developing computational thinking skills, however, the pressure to keep up the pace of instruction in order to be prepared for mandated standardized tests keeps innovation from taking place. The result is that school leaders are concerned about the time, effort, and management needed to teach computational thinking skills. Planning innovative problem based learning is time consuming, and teachers worry that implementing new experiences will take time away from teaching tested subject areas.

This can be seen in the issue of teaching computational thinking to elementary school students. For example, the elimination of computer science classes in elementary classrooms is taking away opportunities for students to practice computational thinking. As my school district has adopted one-to-one computing, traditional computer instruction has begun to disappear. Several elementary schools in my school district have dismantled their computer classrooms, and principals have begun to remove computer science as a weekly instruction activity. For example, one school site, Jackson Creek Elementary, does not offer computer instruction to students at any age, and in fact, does not have a computer lab established in the building.

In order to counteract this pattern, new innovative learning experiences need to be implemented to offer students experiences with computational thinking. However, across my school district, I have regularly found that elementary teachers are reluctant to adopt innovative approaches, such as with teaching computational thinking skills to their students, because they either feel it is a skill only required of engineering or content that should not be taught until high school. Those that are interested tend to either be intimidated by the challenge or work on projects in isolation within their schools.

The lack of computer science instruction, and limited knowledge of the field for elementary school teachers will be magnified as South Carolina begins the adoption of computer science standards. South Carolina Computer Science and Digital Literacy (SCCSDL) standards adopted in 2017 ask students as early as third grade to begin using the computational thinking skills of algorithms and programming (South Carolina Department of Education, 2017).

While my school district is currently in the development of an Institute of Innovation for juniors and seniors across the district, there is not yet a plan to expand this model to younger students in the district. According to Donna Teuber, the district's Innovation Program Designer, one of the challenges they have encountered is making the center's efforts accessible to students across the district (personal communication, February 14, 2017). Because of the growing concern that teaching strategies focus only on maintaining high test scores, the district needs to develop successful models of innovative learning experiences with younger students.

Currently, my school district lacks a framework or strategy to address the instruction of digital literacy through computational thinking. Lastly, in order to increase the implementation of problem solving learning experiences through the use of educational technology, schools my district must consider expanding learning spaces and increase the types of technology tools available.

Statement of the Problem

The issue that I addressed with this study is the lack of instructional opportunities for students to experience computational thinking skills in real-world applications in my context. Advances in computing have made possible incredible opportunities for innovation and imagination, and these changes are establishing a need for schools to bring the power of computational thinking skills to a larger group of students (Barr & Stephenson, 2011).

Only a handful of studies (e.g., Blikstein & Krannich, 2014; Chu, Quek, Bhangaonkar, Ging, & Sridharamurthy, 2015; Davis & Mason, 2016) have examined the use of makerspaces in education. Few have looked into the use in an elementary school setting. Additionally, most of the published studies center around middle and high school aged learners. Based on this pattern, I felt there is a need to study the effective use of makerspace inspired learning with younger students.

To address this problem, I explored the implementation of making activities to support computational thinking using technology in ways that develop and test solutions through the development of makerspaces for fifth grade students at my elementary school.

Purpose Statement

The purpose of this action research was to evaluate the implementation of making experiences to support computational thinking through the development of makerspaces for fifth grade students at an elementary school in South Carolina.

Implementing a maker approach in education extends upon the theoretical approach of constructivist social learning theory, which develops the idea that the child actively builds knowledge through experience (Martin & Dixon, 2013). As the makerspace movement spreads into schools, libraries and communities, my experience leads me to believe that there is increased importance on new studies to define and document the characteristics and usefulness of the environment. For this reason, I aimed to explore how makerspaces can be used to provide experiences for elementary students to practice computational thinking skills.

Research Questions

This action research explored the following three central questions: (1) To what extent did the implementation of a makerspace improve computational thinking skills for fifth grade students at an elementary school in South Carolina?, (2) How did these students' perceptions of using computational thinking as a problem solving method change based on makerspace experiences? and (3) How did their problem solving skills change through the use of computational thinking in makerspaces?

Researcher Subjectivities & Positionality

I am a twenty-year elementary classroom teaching veteran that is currently working as an elementary school computer science magnet lead teacher. As a 47-year-old Caucasian male that grew up with a middle socioeconomic background, I acknowledge that there are certain biases that I bring with me to my research.

Growing up in home where both my parents were in the field of education, my first instinct was to avoid becoming a teacher. However, after a brief career in photojournalism, I found myself returning to earn a teaching degree. I grew up in a house that valued education, and it was only a matter of time before gave in to the call to teach. Since that moment, I have worked as a classroom teacher for fourth and fifth grade students in a variety of settings. Over the course of my teaching career, I have worked with one-to-one computing classrooms for more than a decade, spent five years in a Montessori program teaching through the integration of innovative learning strategies, two years as a technology learning coach, and the past year as a computer science magnet lead teacher.

Thinking over the philosophical foundations of my work as a teacher and how these beliefs will impact my work as an action researcher, I have come to the realization that this process will give form and voice to something that has driven my work for many years. Even looking back at a past study and reflection from a master thesis written more than 22 years ago, I find deep roots in developing meaning from direct experiences (Duemer & Zebidi, 2009). This compels me to choose pragmatism as my educational research paradigm, because from my viewpoint learning “arises out of actions, situations and consequences” (Creswell, 2014, p.10).

I see a connection to the worldview of pragmatism, in the manner in which it will assist me in understanding human needs, interests and the purposes foremost in action, such as making (Garrison & Neiman, 2003). Based on this belief, it follows that I feel the needs of the student become most important. This is accomplished by following their interests through meaningful active experiences. I believe in seeing the mind as an always active entity. I believe the mind is continuously processing data and that it attempts to assimilate new experiences with past experiences. Because of this, the search for knowledge is ongoing (Duemer & Zebidi, 2009). I find that this belief is reflected in the origins of the maker movement. I believe the maker movement places importance on the nature of the individual. Each makerspace experience is unique and is dependent upon the perspectives each participant brings to the experience. The actions, learning, and experiences are different for each participant. Based upon their prior knowledge and how they assimilate new experiences, each individual will come away with something different from the learning experience.

One of the challenges that my personal background presents is my long-term connection with developing active learning experiences for students in the classroom. As a proponent of developing new active and engaging modes of instruction, I do not always feel educational technology is implemented in ways that enhances student learning. My experiences with implementing one-to-one computing classrooms and teaching using the Montessori method have helped me develop an understanding how to infuse technology in ways that engage students in critical thinking.

Through this action research, I am interested in learning more about how elementary age students can utilize critical thinking skills, such as computational thinking, in real-world problem-solving situations, such as those created in a makerspace. I believe this is an often-missed opportunity as more and more districts seek to integrate technology into the classroom.

As a computer science magnet lead teacher, my responsibilities are to assist teachers at my site in integrating technology into the curriculum. I work as a mentor that co-teaches, models and plans in an effort to improve instructional practices. This offers me the positionality to conduct research as an insider collaborating with other insiders (Herr & Anderson, 2005). As an insider, I will be an active participant in the development of the makerspace intervention. Therefore, I will be conducting research into my own practice and setting. Due to my close proximity to the implementation of this action research, I will need to be cautious of my insider perspective by sharing this information with all participants and stakeholders. The main concern here is that by studying my own program I must be aware of the tendency to only self-promote. I must be mindful to separate my practice from the actions that take place within the study. Due to this close positionality, it is important to ensure that all findings, both positive and negative, get reported, and that all data analysis receives additional review from outsiders.

It is my belief that my participation in this action research strengthens the quality and meaning of the data collected. I feel that the nature of action research calls for the practitioner to take part in the process and self-reflect. I believe that by bringing my experiences with innovative learning activities and computational thinking I can use my professional expertise to further the impact of the study.

Definition of Terms

Computational Thinking is defined by Cuny, Snyder, and Wing (2010) as "the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent" (p.32).

Creation is defined as the exercise of focusing on the central function of a task to produce a whole product (Simpson, 2016).

Design Thinking is defined in this action research as a process that helps people discover and implement solutions to problems that relies on individual creativity, effective teamwork, and a willingness to fail and try again, repeatedly, until the optimal solution is identified (Jarret, 2016).

Experimentation is defined in this action research as the procedure of learning and the creation of knowledge based on highly iterative proceedings (Rauth, Koppen, Jobst & Meinel, 2010).

Invention is defined as producing an object to effect a solution to a problem (Blikstein, 2013).

Makerspaces are defined by the Institute of Museum and Library Services (2014) as "part of a growing movement of hands-on, mentor-led learning environments to make and remake the physical and digital worlds. They foster experimentation, invention, creation, and STEM learning" (p. 1).

Making is defined by Martinez and Stager (2013) as an active process of building, designing, and innovating with tools and materials to produce shareable artifacts in a naturally rich environment.

Perceptions are defined as the mental impression for regarding and understanding by which students become aware through the use of their senses.

STEM learning is defined as engaging in the opportunities to explore concepts of science, technology, engineering and math (Clapp & Jimenez, 2016.

CHAPTER 2

LITERATURE REVIEW

The purpose of this action research is to evaluate the implementation of making experiences to support computational thinking through the development of makerspaces. The review of related literature focuses on the research questions of my study: (1) To what extent did the implementation of a makerspace improve computational thinking skills for fifth grade students at an elementary school in South Carolina?, (2) How did these students' perceptions of using computational thinking as a problem solving method change based on makerspace experiences? and (3) How did their problem solving skills change through the use of computational thinking in makerspaces?

Based on these questions, two main variables were used to guide the initial literature search: makerspaces as learning environments and the importance of computational thinking in the 21st century curriculum. From this initial phase, additional literature searches were conducted based on emerging themes that were identified from this first group of studies using the following keyword phrases: (a) design thinking, (b) learner-centered environments, (c) authentic learning environments, (d) constructivism, (e) student engagement, (f) problem solving, (g) critical thinking, and (h) social action. Due to the emerging nature of this research area, keyword phrases were used in combination with the initial variables in order to fully explore related areas that impact the nature of this review. This was done in an effort to capture a wide range of all possible relevant research studies that may impact this developing research area. Electronic databases, such as *ERIC, Education Source, PsycINFO,* and *ProQuest* were used to search for published articles. Based on the articles found using these resources, additional materials were collected by scanning bibliographies in order to trace particular authors' lines of research. The *Google Scholar* website proved to be a useful resource to locate and cross reference these resources.

The review of this literature is organized into two major sections. The first section takes an in-depth look at developing makerspaces as learning environments. The second section examines the importance of computational thinking for 21st century learning. I will explore the impact these roles have on student perceptions, and how they can be utilized in an elementary school setting to improve learning experiences.

Developing Makerspaces as Learning Environments

For this study, the use of makerspaces as school learning environments is examined as an opportunity for promoting a variety of skills. These include (a) definition of a makerspace as a learning environment, (b) opportunities and challenges for makerspaces, (c) theoretical foundations, (d) developing the maker mindset, (e) the importance tinkering and creative play, and (f) makerspace learning characteristics.

Definition of a Makerspace as a Learning Environment

As the maker movement, which is best characterized as an attitude of ingenuity and the do-it-youself (DIY) mentality (Blikstein, 2013), has spread in recent years, educators have begun to explore its implementation and use as a school learning environment. These spaces often go by a number of different names, such as FabLabs, Hackshops, and Innovation Stations, but can be best identified and grouped by the name of makerspace (Litts, 2015). Research in this area addresses how schools can create locations where users can learn through experimentation and play spaces. Halverson and Sheridan (2014) describe makerspaces as places for creative production in art, science, and engineering where people of all ages blend digital and physical technologies to explore ideas, learn technical skills, and create new products. Martin (2015) provides a working definition of makerspaces as a space for a class of activities centered on the designing, building, modifying, and repurposing of material objects for play or useful ends aimed at developing some sort of product. Blikstein, Kabayadondo, Martin, and Fields (2017) further explain that makerspaces focus on the convergence of computation, tinkering and engineering. Additionally, other recent studies build on these definitions, and in summary agree that at minimum they should be developed as a space where learners can develop collaboration skills, and establish attitudes for creation and innovation needed for the 21st century learners (Bers, Strawhacker, & Vizner, 2018; Chu, Quek, Bhangaonkar, Ging, & Sridharamurthy, 2015; Galloway, 2015; Kafai, 2018; Moorefield-Lang, 2014).

Since studies examine the use of makerspaces in slightly different ways, a number of different components have been identified, however, many experts show that in order for a makerspace to become an educational space the following five key components must be demonstrated: identifying problems, building models, applying skills, revising ideas, and sharing new knowledge (Sheffer, 2018; Hira, Joslyn, & Hynes, 2014; Kafai, 2018; Moorefield-Lang, 2014; Sheridan et al., 2014). To test the importance of these factors, Sheffer (2018) surveyed the best practices of K-12 makerspace directors across 39 different locations and found that a design thinking approach is the most important element to a successful curricular goal in a makerspace. Additionally, in a case study of elementary school library makerspaces, Moorefield-Lang (2014) describes having established procedures for students of what to do in a space as a critical consideration for success. Without these components, the free and open nature of a makerspace can become overwhelming for younger students.

Lastly, literature in this area suggests additional research is needed in order to identify the importance a makerspace provides for learners as they develop an ownership of ideas (Davis & Mason, 2016). A series of recent studies suggest that by creating an external representation of an idea through the use of intermediate tools that assist in developing technological fluency, students are able to demonstrate learning and developmental growth (Harel & Papert, 1991; Kurti, Kurti, & Flemming, 2014; Sheridan et al., 2014). To test this link between makerspace learning experiences and developmental growth, Lahana (2014) developed the Developmental Assests Profile (DAP) survey to measure the external and internal assets of students in a mixed methods case study of low socioeconomic (SES) school students in a New York middle school. The results indicated that makerspace experiences had no effect on how students are able to demonstrate growth in a makerspace, therefore, these conclusions support the notion that additional research is needed in this area.

Opportunities and Challenges for Makerspaces

In order for makerspaces to have an impact as learning spaces, a series of different challenges and opportunities must be met. These include: (a) opportunity for blending arts and engineering, and (b) challenges to classroom makerspaces.

Opportunity for blending arts and engineering. A number of studies demonstrate the opportunity makerspaces provide in contextualizing science learning. Experts show that in order to solve real-world problems, learners must have first-hand experience, and this has led researchers to propose that makerspaces must provide for the integration of STEM in meeting standards (Harel & Papert, 1991; Hira et al., 2014; Lahana, 2014). However, other studies by Sheridan et al.(2014), Vossoughi and Bevan (2014), and Moorefield-Lang (2014) have questioned this assertion, and propose that makerspace learning is an opportunity to break down the different learning disciplines and is instead an opportunity for blending arts and engineering skills. When Sheridan et al. (2014) conducted a comparative case study of three makerspaces, their data suggested a multidisciplinary approach fueled student engagement and innovation. They collected more than 150 hours of observations and field interviews over the course of one year. The authors noted that a key theme in their findings was that skills and knowledge were treated as tools to create new things and new opportunities which went beyond merely developing STEM skill and became more about valuing the process of the making. Additionally, other research by Vossoughi and Bevan (2014) also caution about focusing too narrowly on STEM objectives and recommend opening the makerspace to artistic pursuits. Additionally, the study notes that the majority of studies taking place are done qualitatively and mainly in after-school settings which indicates the need for further study and a broadening of study methodology. In addition, Moorefield-Lang (2014) echoes this finding on the lack of research into the development of makerspace as learning environments by noting that while research continues to grow, there remains a limit to scholarly and peer-reviewed research in this field.

Challenges to classroom makerspaces. Hira et al. (2014) identified a number of different challenges that face the development and use of makerspaces: the need to overcome "No Child Left Behind" accountability, teacher preparation, technology and resource management, and diversity as main hindrances to the creation of classroom makerspaces. Based on their collective experience, the authors of the report expand on these issues, but of key interest to this study are their findings in two areas: (a) the need to overcome high-stakes testing, and (b) teacher preparation.

High-stakes testing. Recent research shares that as high-stakes standardized testing becomes the system of modern accountability, the result is less and less time devoted to innovative teaching methods in order to save time (Oliver, 2016; Scheer & Plattner, 2011) This is likely related to the relaxed sense of control that teachers adopt in creating makerspace interactions which is an inherent element of the constructivist/ constructionist background (Scheer & Plattner, 2016). In the absence of a teacher-centered curriculum, it becomes essential that the resources of the space provide for productive and impactful work that connects students to meaningful experiences (Lahana, 2015). This in turn magnifies the importance of the next challenge.

Teacher preparation. Another significant issue is the amount of time teacher preparation requires in order to implement a makerspace program. makerspaces can be leveraged as a powerful space for students to tinker, create, design and explore, but the constructivist principles that bolster a makerspace can be difficult for students and teachers to embrace (Sheffer, 2018). Martinez and Stager (2013) found this to be consistent with their case study observations of makerspaces where they argue that successful implementation relies on the facilitation techniques of the instructor.

Educational makerspaces benefit from instructors that have a basic understanding of design principles which makes possible the integration of academic and sociocultural themes (Blikstein, Blikstein & Krannich, 2014; Rosenfeld & Erson, 2014). These findings suggest the need for further empirical study into the implementation of makerspaces as learning environments. The current body of work is not conclusive about its usefulness outside of STEM related subjects as well as the issues of teacher preparation amid high-stakes testing environments.

Theoretical Foundations

While makerspaces can be grounded in a number of different learning theories, this study focuses on tracing its foundations as a learning environment through the lenses of constructivism and constructionism. The two theories are closely related but there are differences and distinctions that merit explanation.

Constructivism. Constructivism is a complex theory with different connotations depending on the perspective of the researcher. As a learning theory, it dates back many decades. This study will trace constructivism back to its roots with Piaget in the 1950s who establishes that children build knowledge from experience (Piaget, 1954). As a progressive pedagogy that stresses social construction of knowledge, the theory stipulates that learning takes place as students modify their understanding aided by experimentation and explanations stemming from different learning resources (Kafai & Resnick, 1996). As a result, the role of the teacher is often described as a facilitator (Wilson, 1996). In this way, a constructivist learning environment encourages students to test out and improve upon their ideas on their own.

Research indicates a makerspace can become an integral component of constructivist learning. Several studies explore this connection and suggest a stance that supports the argument that critical thinking development can be improved using constructivist principles. (Bers, Flannery, Kazakoff, & Sullivan, 2014; Papert, 1980; June, Yaacob, & Kheng, 2014). June et al. (2014) evaluated the development of critical thinking in their qualitative action research study involving 50 students over a course of 14 weeks. Their findings indicate constructivists methods uses engaging instruction as a means for provoking critical thinking. The authors indicate that the students' knowledge construction is facilitated by the student-centered active process of the constructivist learning model.

When knowledge is constructed and reconstructed through direct interaction with the environment, makerspace learners are able to gain knowledge by engaging in personally meaningful experiences (Litts, 2015). Viewing constructivism as a related theory underpinning the interactions of a makerspace strengthens its place as a classroom learning space. Several studies suggest this occurs because makerspaces focus on meeting the fundamental and universal needs of people. This is seen as the need for competence, autonomy, and relatedness which is necessary for developing a connection to new knowledge (Cetin-Dindar, 2016; von Glasersfeld, 1989; Jonassen, 1991; Litts, 2015).

Constructionism. Constructionism has emerged as a related theory based on Piaget's work. It has been derived from the work of Piaget and Vygotsky in constructivism (Clinton & Reiber, 2010; Harel & Papert, 1991). Attributed to the work of Seymour Papert, the constructionism framework states children can learn deeply from making their own meaningful projects. An early pioneer for the impact of technology on learning at the MIT Media Lab, Papert's work with Piaget in the 1950s influenced his ideas (Blikstein, 2013). In his book, *Mindstorms*, Papert takes constructivism’s notion of building knowledge, but adds to it a context where the learner is consciously engaged in constructing a public entity or usable artifact (Bers et al., 2014; Galloway, 2015; Kafai & Resnick, 1996; Kafai & Vasudevan, 2015; Litts, 2015; Papert, 1980; Martinez & Stager, 2013).

Constructionism advances the notion that learners are more likely to make new ideas when they are actively engaged in making some type of external artifact (Clinton & Reiber, 2010; Kafi & Resnick; 1996). While constructionism is closely related to constructivism, a key difference between the two is explained by the importance Papert's theory places on the physical object. It focuses student learning on concrete objects where playing with a real creation generates the most knowledge with the least amount of instruction (Papert, 1991). Because of the important role concrete creations play in constructionism, Papert’s theories are related to the idea of makerspaces as learning spaces that provide the opportunity to drive inquiry through construction of a tangible project. (Harel & Papert, 1991). Therefore, constructionism becomes the theoretical framework behind creating makerspaces as student-centered learning environments. According to Kurti et al. (2014), the development of makerspaces in education has the potential to revolutionize teaching and learning. As students move to construct their own knowledge alongside of others through the philosophy of hands-on learning by building things they become actively engaged on both learning and teaching (Kurti et al., 2014).

Developing the Maker Mindset

At the heart of educational makerspaces is the potential for reframing how students approach the learning process. The maker mindset sees learning as a holistic participatory process that can happen in all types of activities regardless of what technology is used. It is viewed as fundamentally tied to the social contexts in which it occurs, and can be valued as an educative experience (Brahms, 2014; Calderon, 2009; Chu et al., 2015; Davis & Mason, 2016; Dougherty, 2013; Litts, 2015; Martin & Dixon, 2013; Martin, 2015). Brahms (2014) evaluated the importance of the maker mindset in an exploratory investigation of the makerspace learning process. The qualitative study examined the interactions of families with young children who participated in a museum-based makerspace through the collection of 20 video-based observations over the course of 12 weeks. Based on their collected data, the study suggests that by taking part in a community of practice learners increased their engagement which allowed for increased meaningful learning by measuring the instances of community learning practices and changes in relation to observations of meaningful learning. This study demonstrates the importance of a community of practice for increased engagement in an after-school, museum-based setting (Brahms, 2014). However, additional studies in school-based makerspaces will be required to determine the generalization of these findings, suggesting the need for further research in school-based settings.

Research into the maker mindset suggests that what people learn becomes linked to how and where they learn. These studies report that when the socially determined practices of makerspace are situated within a given activity setting, students are more likely to integrate different knowledge skills (Brahms, 2014; Chu et al., 2015; Litts, 2015). Therefore, the maker mindset becomes an important component of the makerspace learning environment when learning is integrated to participation. By participating in a community of practice, makerspaces assist the development of self-efficacy, motivation, and interest which establishes the idea of knowing through doing (Litts, 2015).

A number of studies have recently suggested that a series of emerging themes and core principles are key to developing the maker mindset with data developed from a descriptive qualitative case study of 12-18 year olds, Martin and Dixon (2013) describe the key factors of the maker mindset as having an open community; encouraging active participation, and actions that integrate across different contexts. Chu et al. (2105) echo this in their findings during a qualitative study of children ages eight to eleven participating in a one-time Saturday workshop. Making is described as necessary for the integration of different knowledge skills and should be designed for the purpose of self-efficacy, motivation, and interest (Chu et al., 2015). Brahms (2014) identifies this as core learning practices and explains that the maker mindset should lead learners to explore, question, tinker, test, and iterate (Brahms, 2014). Lastly, a phenomenological qualitative study by Davis and Mason (2016) presents data about makerspace participation through interviews of middle school girls in Texas. Their findings suggest the potential benefits of a maker mindset are to induce greater interest and participation with formal and informal STEM related content (Davis & Mason, 2016). It is therefore argued that educational makerspaces should include efforts to develop a maker mindset to allow students to increase participation by motivational exploration in tinkering and testing out ideas.

The Importance Tinkering & Creative Play

In addition to the maker mindset, tinkering and creative play are seen as equally important skills in a makerspace learning environment. Tinkering is described as a branch of making that emphasizes creative improvisational problem solving that the draws upon the design process (Bevan, Petrich, & Wilkinson, 2014). It centers on open-ended design and construction of objects, and generally uses both high- and low-tech tools (Bers et al., 2014; Ryoo, Bulalacao, Kekelis, McLeod, & Henriquez, 2015; Vossoughi & Bevan, 2014). Tinkering allows for persisting in unexpected challenges. This can allow for learners to pursue multiple pathways which can encourage diverse ways of thinking. By allowing for a multitude of approaches, a variety of learner solutions are celebrated, and practices/concepts are made transparent so that thinking can be made visible (Ryoo et al., 2015). Tinkering looks at how creativity can be fostered in a progressive learning environment. It replaces the usual standards of instruction and can be mediated through design education to help develop an understanding for innovation (Derosa, 2016; Rauth, Koppen, Jobst, & Meinel, 2010).

Tinkering allows children to build and experiment with manipulative materials. A number of research reports suggest tinkering develops deeper understandings of computational thinking concepts through design activities (Harel & Papert, 1991; Kafai, 1995; Resnick, 1998; Papert, 1993; Resnick & Rosenbaum, 2013; Soloway, Guzdial, & Hay, 1994). Their study findings indicate that learning activities are meant to engage children as active participants. makerspace learning environments contrast to traditional school activities in which teachers aim to transmit new information to the students by giving students a greater sense of control over the learning process. A case study by

Bevan, Gutwill, Petrich, and Wilkinson (2015) documents the tinkering activity of youth participants through the development of a tinkering learning dimensions (TLD) framework. The study was designed to target the effective use of tinkering, and found that tinkering is a possible, powerful context for learning and defines four dimensions necessary for effective use of tinkering. However, little empirical data is yet known about the impact of tinkering and making experiences in school-age learning. Design principles and pedagogies are still emerging in this area (Vossoughi & Bevan, 2014), further implementation of TLD framework is needed. This study proposes that makerspace programs offer interest-based engagement to practice creativity and tinkering while mastering content objectives in self-guided activities that allow the opportunity to follow emerging interests (Azevedo, 2013; Derosa, 2016).

Makerspace Learning Characteristics

With the development of makerspaces as school learning environments, successful implementation of these spaces has become associated with a variety of different characteristics. There are currently three significant characteristics that apply to the scope of this study. These include (a) authentic collaborative learning experiences, (b) learner-centered experiences, and (c) supports student engagement.

Authentic collaborative learning experiences. One of the proposed benefits of makerspace activities is to foster collaborative learning. Recent studies suggest that knowledge results from the combination of grasping and transforming the experience (Jagielski, 2016; Richard & Giri, 2017; Sheridan et al., 2014; Simpson, 2016, Yanez, Okada, & Palau, 2015). Key findings of a comparative case study by Sheridan et al. (2014) of three makerspaces in Pittsburgh emphasize that makerspaces seem to break down disciplinary boundaries in ways that facilitate process and product-oriented practices. The study identifies ways that makerspace learning activities lead to innovative work with a range of tools, materials, and processes through collaborative and authentic practice (Sheridan et al., 2014).

Authentic learning provides students the chance to get a taste of the real world. While undertaking the kinds of tasks required by careers, researchers believe authentic learning improves student employability (Simpson, 2016). An analysis of recent literature suggests authentic learning should focus on real-world, complex problems and their solutions (Jagielski, 2016; Lombardi, 2007; Simpson, 2016). By using role-playing exercises, problem-based activities, case studies, and participation in virtual communities of practice, authentic collaborative experiences develop a shared experience and enhance the learning process. However, in discussion of authentic collaborative experiences, one issue has been the emphasis on testable content areas. Innovative learning experiences, such as a makerspace, must battle against methods that use easily scored questions to replace problem solving ability (Simpson, 2016). Schools must face sacrificing innovative teaching methods for the need to focus on better test scores (Jagielski, 2016).

Learner-centered experiences. Educational makerspace learning and constructivist learning theory have always encouraged that learning should be based in everyday activity. Literature in this area explains that knowledge is part a product of the activity, context and culture in which it is developed and used. (Brown, Collins, & Duguid, 1989; Clinton & Reiber, 2010; Devlin, Feldhaus, & Bentrem, 2013; Howard, Ma, & Yang, 2016). A seminal case study of two different math classes conducted by Brown et al. (1989) argue that learning should be situated in everyday activity. Their approach to problem solving investigates the claim that conventional schooling ignores the aspects of situated learning, and in order for learners to gain access to knowledge they must act meaningfully and purposefully (Brown et al., 1989). The authors of the study call for establishing what they call cognitive apprenticeships to alter the delivery of knowledge, which my study argues can be a key characteristic of a makerspace.

Additionally, more recent studies further this argument by calling for the development of a completely different paradigm of education from the current, industrial-age, teacher-centered system (Aslan & Reigeluth, 2016; June et al., 2014). With the availability of the Internet, teachers are now having greater opportunity to access various educational tools which can be used to enhance the practice of student-centered learning in the classroom and to engage in a lot of interactions with students (Bevan et al., 2014). Based on a mixed methods case study of more than 100 students in grade six through twelve, Aslan and Reigeluth (2016) propose a system of functions for improving educational technology to support a learner-centered paradigm. While some are convinced that educational technology can support a learner-centered approach, others are convinced educational technology is not being leveraged towards this goal (Austin, 2017). In a qualitative study of K-12 teachers enrolled in a master's degree program, Kayler and Sullivan (2008) contend that teachers incorporating technology tended to use it mainly for knowledge transmission. The study questioned that teachers lacked experience in applying technology to support and enhance teaching and did not use technology in ways that supported higher level learning through learner-centered experiences (Kayler & Sullivan, 2008). This data suggests an opportunity for further research into this area. This study assumes that makerspace learning offers the opportunity for practicing teachers to tie ideas from their classroom practice and content area to the theoretical frames of constructivism in order to promote student-centered learning, while at the same time leveraging new educational technology tools.

Supporting student engagement. Another implication of makerspaces and Constructivist theory is that face-to-face instruction alongside hands-on activities is linked with increased student engagement. In order to avoiding passive learning experiences that students receive in the traditional classroom environment, student engagement needs to be a primary concern of the learning environment (Brown et al., 1989; Carroll et al., 2010). Several recent studies suggest the correlation between students' engagement and performance to be rather significant (Chu et al., 2015; Cetin-Dindar, 2016; Clark, 2016; Kostaris, Stylianos, Sampson, Giannakos, & Pellicone, 2017). Additionally, The National Assessment of Educational Progress (NAEP) reported concerns in the Trends in International Mathematics and Science Study (TIMSS), and the Program for International Student Assessment (PISA) which all reveal most students educated in American schools lack the ability to comprehend and apply mathematical concepts (National Center for Education Statistics, 2012). One possible implication of this lack of mathematical concept comprehension may be that American students learning experiences in these academic areas are not engaging or based in real-world experiences. A quantitative study of elementary school students in Turkey by Cetin-Dindar (2016) supports this claim. The quantitative study, which developed the use of two different student motivation questionnaires, asserts that when learning is related to real world issues, student motivation may increase to learn science and math, since they own these issues and dilemmas (Cetin-Dindar, 2016). Kostaris et al. (2017) observed similar instance in their study of the flipped classroom model (FCM). The authors of the study provide evidence for the potential of increasing cognitive learning outcomes when students are motivated to engage in real world issues. While this study extends the argument for supporting student engagement, there is reason to question its implications for other subject groups. Due to the study design, generalizing results outside of the direct subject population is limited. Additionally, there is not a clear correlation between student engagement with real world issues as it relates to an educational makerspace. This suggests the need for further study in this area. This study argues that developing educational makerspaces provides a possible framework for improving student engagement through a constructivist learning environment that promotes real world issues.

The Importance of Computational Thinking for 21st Century Learning

In order to thrive in a digital world, educational innovation has begun to focus on the necessity of the problem-solving skills of computational thinking. There are several elements, concepts, and skills that identify computational thinking as a potential component of makerspace learning environments. These include (a) definition of computational thinking, (b) defining the 21st century learning curriculum, (c) promoting problem solving with design thinking in a makerspace, (d) characteristics of computational thinking in a makerspace, and (e) the potential for makerspace learning in education.

Definition of Computational Thinking

While the idea of computational thinking is not new, new thinking has revealed it as an idea whose time has come. Recent research in the area agrees that Jeanette Wing's article "computational thinking," which appeared in the March 2006 issue of *Communications of the ACM*, has influenced a call to action for a wide-ranging influence of the pedagogical aspects of computational thinking (NRC, 2010). Wing's argument that 21st century computer science (CS) is a universal skill for everyone and not just for computer scientists is now the focus of a growing body of research (Aho, 2012; Brennan & Resnick, 2012; Cuny, Snider, & Wing, 2010) According to Wing (2006), "computational thinking involves solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science" (p. 33). Essentially, computational thinking is about teaching learners to think about solving problems in the way that a computer would. Current studies contend computational thinking is an essential skill for the next generation of workers and citizens, and the integration of computational thinking at all educational levels (Brennan & Resnick, 2012; Grover & Pea, 2013; Perkovic, Settle, Hwang, & Jones, 2010; Wing, 2006). Early notions that computational thinking is about procedural thinking and simply programming (Papert, 1981), are being revisited to include core concepts that will take computer science beyond programming.

Based on Wing's premise, new research has begun to clarify this stance and restates the definition as the thought processes involved in formulating problems so their solutions can be represented as computational steps and algorithms in a form that can be effectively carried out by an information-processing agent to assist in problem solving (Chen et al., 2017; Kanbul & Uzunboylu, 2017; NRC, 2010; Wing, 2006). A particular interest to my study is recent research that states elementary students, who are often only on the receiving end of technology, lack experiences with computational thinking. As a result, students are unable to develop problem solving skills that could enhance their understanding of mathematics (Kafai & Burke, 2014; Estapa et al., 2015; Kanbul & Uzunboylu, 2017). To probe the development of computational thinking in elementary students, Chen, Shen, Barth-Cohen, Jiang, Huang, & Eltoukhy (2017) developed a framework to contextualize its use with elementary school students. Their computational thinking framework identified six dimensions: (1) formulating problems in a way that machines can help to solve, (2) processing data in a logical way, (3) representing data abstractly, (4) algorithmizing the automated solutions, (5) solving problems in an efficient way, and (6) transferring knowledge and skills in solving other problems (Chen et al., 2017). Using the framework as part of a robotics curriculum, the researchers measured student improvement in computational thinking following the robotics curriculum. The scope of this study is still limited to computational thinking's applications to programming curriculum.

Of particular interest to this study is Korkmaz, Cakir, and Ozden's (2015) Computational Thinking Skills (CTS) questionnaire. The CTS was designed to measure a student's knowledge, skill and attitudes towards being able to use computers in the solution of the life problems for production purposes. The questionnaire was originally developed to determine the computational thinking skills of undergraduate students in Turkey and collects data in the form of five different factors: creativity, algorithmic thinking, cooperativity, critical thinking, and problem solving. Items for the CTS were selected from a variety of other previously published scales and were purposely aligned with the ISTE (2015) computational thinking standards. Korkmaz, Cakir, and Ozden (2017) published a validity and reliability study for the computational thinking scale. The validity and reliability of the scale has been studied by conducting exploratory factor analysis, confirmatory factor analysis, item distinctiveness analyses, internal consistency coefficients and constancy analyses. As a result of the conducted analyses, the authors concluded that the scale is a valid and reliable measurement tool that could measure the computational thinking skills of the students. In a related study, Korucu, Genturk, and Gundogdu (2017) used the CTS in their examination of computational thinking skills of secondary students in Turkey. Based on data collected from the questionnaire, their study found that computational thinking skills positively affect the use of computers and technology towards 21st century abilities such as problem solving, analytic thinking, and creative thinking (Korucu et al., 2017)

The question still remains about how elementary age students use computational thinking's influence beyond traditional CS courses or activities. This study is interested in exploring the relationship makerspaces have with computational thinking for young learners. Unlike a robotics curriculum, a makerspace learning environment provides the opportunity to observe computational thinking in a more diverse application setting that may be more reflective of broader 21st century skill applications.

Defining the 21st century Learning Curriculum

Many in education acknowledge that the changing 21st century society demands students to be equipped beyond cognitive knowledge. To accomplish this, research proposes an increase of constructivist learning in education, which empowers teachers as the facilitators of the movement to foster 21st century skills (Aslan & Reigeluth, 2016; Calderon, 2009; Perkovic et al., 2010; Scheer, Noweski, & Meinel, 2012; Yadav, Hong, & Stephenson, 2016; Yanez et al., 2015).

The need for evolving classrooms arises from teaching in the 21st century classroom. The emphasis must be placed on active learning using a student-centered approach in order to meet the demands of a technological and globalized future (Carrol et al., 2010; Derosa, 2016; Devlin et al., 2013; Yanez et al., 2015). Research further identifies these 21st century skills that students will need as the ability to think critically, problem solve, adapt and innovate (Acedo & Hughes, 2014; Aslan & Reigeluth, 2016). This developing 21st century skills framework has been derived from Partnership for 21st century (P21) which identifies three types of skills necessary for success in future global technology fields. P21 describes the skills as creativity and innovation, critical thinking and problem solving, and communication and collaboration. P21 further argues the need for the 21st century public education system to prepares student in the global skills race, and that the skills of innovation, creativity, critical thinking, problem solving, communication and collaboration are essential to prepare students for the future (P21, 2008).

With these future ready skills in mind, makerspace learning research has recently suggested that adding creativity to critical thinking highlights the intersections of problem solving, argument analysis and decision-making (Acedo & Hughes, 2014; Derosa, 2016). By addressing the issue of creativity, researchers believe makerspaces are capable of developing the habits of mind that students need to address high levels of complexity, challenge and unfamiliarity (Jarret, 2016; Joslyn et al., 2014). In a qualitative exploratory case study of students attending a makerspace classroom at an international school in China, Derosa (2016) asserts that creativity is an essential skill needed to meet the demands of a technological future. The study establishes the notion that creativity instills in students a need for the ability to think critically, problem solve, adapt and innovate. Studies such as these imply that the 21st-century citizen needs to analyze situations critically, reason and draw conclusions in a world where corporations and individuals saturate the public domain through information technology (Acedo & Hughes, 2014). The impact that makerspace learning experiences will have on enhancing creativity to develop 21st century skills for students in elementary school is not yet clear. Small scale qualitative case studies with limited sampling are not yet strong enough to offer wide scale generalizations. In order to address the implication that one of the key principles of a makerspace is to address collaboration, creation and innovation needed for the 21st century learner further research is needed (Galloway, 2015).

Promoting Problem Solving with Design Thinking in a Makerspace

In order to give structure to the principles of 21st century skills, it is essential to find ways to emphasize how new innovative methods are able to demonstrate how to build concrete solutions to complex problems. To accomplish this, recent research investigates at how design thinking focuses on the need to create ideas and find viable and novel solutions for problems by leveraging the learning aspects of a makerspace which are to encourage cognitive, spatial, motor, social, and aesthetic skills (Akins & Burghart, 2006; Bers et al., 2018; Douglass, 2016 Kangas, Seitamaa-Hakkarainen, & Hakkarainen, 2013; Rauth et al., 2010; Scheer et al., 2012). At the middle school level, design thinking leads New York eighth graders to improvement of math scores on annual assessments in math and science in relation to implementing the design thinking processing (Akins & Burghardt, 2006). Results were especially positive for students in students in the lower quartiles who demonstrated an improvement of more than 125%

(Akins & Burghardt, 2006). The qualitative case study acknowledges how design thinking develops a better understanding of how technology can support student learning in the new paradigm. Design thinking has the potential to impact learning to learn in a wide variety of areas (Rauth et al., 2010). A recent qualitative study argues design thinking fosters the ability to imagine without boundaries and constraints (Carrol et al. 2010). My study aims at investigating the claim of these studies in regard to the effectiveness of design process. This is a key method that may help students become more empowered in their own learning during experiences in makerspace learning environment.

However, reports are limited about how elementary age students use problem solving with respect to design thinking (Carroll et al. 2010). There is a need to examine how innovative ways to address 21st-century skills can promote critical thinking and problem solving. One paper addresses the engineering design requirements in the next generation science standards (NGSS) using a picture book with kindergarten students as the inspiration for problem solving activities in the classroom. The narrative account seeks to demonstrate design thinking is a useful tool for classroom use for elementary age students (Douglass, 2016), but does not offer empirical evidence to support any claims. Since an educational makerspace is supported by a culture of prototyping, a "show don’t tell" mentality with a bias towards action, and collaboration, design thinking becomes a natural part of the experience (Kangas et al., 2013; Rauth et al., 2010). Since research in this area is limited in scope towards younger age students, there is a need for additional research in this area.

Characteristics of Computational Thinking in a Makerspace

In order to utilize the concepts of computational thinking within a makerspace, three different characteristics need to be addressed to ensure effective development of its concepts and skills. These include (a) developing critical thinking skills, (b) developing coding skills, and (c) acquiring problem solving approaches.

Developing critical thinking skills. Critical thinking is defined by Dewey (1910) as the active, persistent, and careful consideration of any form of knowledge in the light of the grounds that support it. Recent studies of critical thinking focus on using it as a set of problem solving skills for why the concept of a principle is correct (June et al., 2014; Kanbul & Uzunboylu, 2017; Nold, 2017). As a characteristic of computational thinking, critical thinking involves identifying, analyzing, synthesizing, and evaluating information to yield actionable knowledge to make effective decisions (Douglas, 2016). It is supported by makerspace learning experiences which utilize effective design principles. In traditional computer science classes, students view computer programming as a purely technical activity rather than a set of combined problem-solving skills (Kazimoglu, 2012). However, if critical thinking is included in the design process this will involve tasks that require identifying, analyzing, synthesizing, and evaluating information to yield actionable knowledge to make effective decisions (Kazimoglu, Kiernan, Bacon, & Mackinnon, 2012; Nold, 2017). Nold (2017) conducts an action research study with three business classes that demonstrates the importance of critical thinking skills for success beyond the classroom. Using a modified Motivated Strategies for Learning Questionnaire (MSLQ), which was initially developed by Pintrich, Smith, Garcia, and McKeachie (1991), the study was able to identify improvements in 14 out of 15 learning constructs during a college level business class which was then correlated with grades to identify effective critical thinking constructs. Since the study population focuses on adult learners, the implications for younger age students is not clear. Additionally, the scope of this study is not directly correlated with makerspace implementation, so any generalizations outside the direct interventions taken by the study are yet to be explored and demonstrates a need for further research in this area.

A limited amount of studies show how developmentally appropriate programming and robotics tools can engage kindergartners in learning computational thinking (Brennan & Resnick, 2012; Sanford & Naidu, 2016). When it comes to robotics and programming concepts, some evidence suggests an improvement of problem-solving and reasoning skills even within observations of young children. Two case studies by Bers et al. (2018) of kindergarten makerspaces in Denmark highlight the potential for design thinking in the makerspace learning environment. Their work endorsees the potential for learning by integrating programming and robotics in the early childhood classroom through the use of the Positive Technological Development (PTD) framework used to evaluate how design thinking environments can promote positive behaviors through technology (Bers et al., 2018). When it comes to the overall impact critical thinking can have on young students, there is still need for additional empirical studies (Sainford & Naidu, 2016). Given the location and population differences of present case studies, there is not enough data about low socio-economic status elementary age students. This suggests the need for additional research argued by this study.

Developing coding skills. Computer programs and robotics tools in a constructivist approach can be developed to engage children in computational thinking, robotics, programming and problem-solving. Recent studies indicate that this is an example of a successful way to introduce technological fluency and computational thinking (Bers et al., 2014; Kafai et al., 2007; Kafai & Vasudevan, 2015; Liu, 2010). These studies have shown the learning of robotics can give students an opportunity to design and create new applications (Bers et al., 2014; Kafai et al., 2007; Kafai & Vasudevan, 2015; Liu, 2010). Efforts are progressing to bring computing into primary and secondary schools to aid students in taking their first steps in developing computational thinking. Research states that young children can actively engage in learning from computer programming when applied to the field of robotics. (Bers et al., 2014; Kafai & Vasudevan, 2015; Liu, 2010). The potential for increasing student computational thinking fluency through programming is becoming a key part of developing the way youth view the computer culture. Through a series of observations of minority students ages 8-18, Kafai et al. (2007) conducted ethnographical research of an after-school computer clubhouse. The study argued that the use of a visual programming platform supported greater idea diffusion which broadened student perceptions towards the previous held narrow notions of programming (Kafai et al., 2007). There exists a limited amount of research in primary education to use coding education and robots (Sanford & Naidu, 2017). Further studies are required to be able assert a connection of abstract knowledge to the actual world through the integration of coding. There is a need for additional research into programming as an aspect of technology fluency (Kafai et al., 2007; Kanbul & Uzunboylu, 2017)

Integrating programming into schools, however, poses a challenge because flexible work arrangements and interest-driven collaboration choices do not fit well within the more structured organization of collaboration traditionally favored in school classrooms (Fields, Vasudevan & Kafai, 2015; Kafai et al., 2017). Fields et al. (2015) demonstrate the importance of changing the conventional approach to teaching programming in isolated courses or after-school clubs in their review of student programming collectives of a northeastern United States high school. The authors state the collectives provide open source communities for developing learning about specific programming concepts that shifted from mere computation towards participation in computational practices tied to the creation of learning activities (Fields et al. 2015). Research shows implications for the advancement of coding skills in relation to computational thinking, and points towards further implications for the need of makerspaces in elementary school settings to promote programming within the regular school day.

Acquire problem solving approaches. Problem solving skills must be connected to a student's actual world (Brown et al. 1989). Recent research suggests that in order to accomplish the development of new abstract knowledge, student learning must be manifested in everyday activity so that it connects with their real-world experiences (Brown et al., 1989; Norris, 2014). It is evident that current conventional school programs fail to provide opportunities for learners to connect abstract knowledge with their actual world (Roy, Kihoza, Suhonen, Vesisenaho, & Tukiainen, 2014). Given the present state of the literature, there is a need for students to acquire skills for producing solutions for problems (Kanbul & Uzunboylu, 2017). Since students need both the skills and the tools to participate actively in a society where problems are increasingly complex, this study argues the point that makerspace learning environments can serve to mediate this concern. Norris (2014) states it is important to determine that students' interest for making digitally mediated projects which developed new and critical literacies.

The Potential for Makerspace Learning in Education

Researchers suggest that when given age-appropriate technologies, curriculum and pedagogies, young children can actively engage in learning from computer programming as applied to the field of robotics (Bers et al., 2014; Richard & Giri, 2017; Sheridan et al., 2014). However, valuable opportunities are missed to build knowledge in specific content areas through superficial subject engagement in conventional classroom practices (Richard & Giri, 2017). Recent research indicates that by identifying and purposefully facilitating STEM opportunities, schools can potentially induce greater interest and participation with formal and informal STEM fields (Clapp & Jimenez, 2016; Davis & Mason, 2016; Fan & Yu, 2017; Martinez & Stager, 2013). Often makerspace environments are seen as only STEM teaching platforms and solely designed towards making significant improvements in math testing (Akins & Burghardt, 2006). A quasi-experimental quantitative study of two classes in STEM students in Taiwon demonstrated these students obtained greater conceptual knowledge, increased higher-order-thinking skills, and improved engineering design skills more than other students in the study (Fan & Yu, 2017). The implication for using makerspace environments to support STEM advancement is supported by this research, however, Clapp and Jimenez (2016) suggest going further by intentionally integrating the Arts into STEM using the makerspace experience. Their findings from a review of 60 randomly sampled maker activities demonstrated mainly a superficial engagement in the arts for most makerspace activities.

The key to promoting makerspace learning as more than a STEM related initiative is to incorporate appropriate design activities that should consist of an open-ended, highly iterative process that can provide context for a variety of learning experiences (Clapp & Jimenez, 2016; Fan & Yu, 2017). While scientific, mathematical, and technological concepts are a piece of the environment, it should also be used to increase students' systems thinking by modeling, testing, evaluating, modifying designs aimed at higher-order thinking abilities which can be integrated to broader curriculum areas. Implicit benefits arise from participants' increased engagement with complex technical content in a voluntary, authentic context (Davis & Mason, 2016; Martinez & Stager, 2013).

Summary

To summarize, 21st century society demands that today's students have more than basic knowledge. Computational thinking is seen as one of the most important skills for the next generation, which suggests educational efforts at all levels need to design and implement for the integration of computational thinking (Brennan & Resnick, 2012). Because makerspace learning components are focused on problems-solving, building models, applying skills, revising ideas and sharing new knowledge, they offer a potential fit for successfully meeting these issues. Of particular interest is the role of tinkering which allows children to build and experiment with manipulative materials. Experiences such as these can provide the ability for students to develop deeper understandings of computational thinking concepts (Vossoughi & Bevan, 2014). Because of this, it is important to explore the relationship between makerspaces and computational thinking.

The development of makerspaces in elementary school environments is still an emerging research field. Much of the current research focuses on qualitative case studies of after school or high school projects (Bevan et al., 2014; Brahms, 2014; Sheridan et al., 2014). There is a clearly identified need for additional research for its use with elementary age students, and of specific need further examination of use with low socio-economic populations. Additionally, while empirical research describes several different types of computational thinking measurement instruments (Blikstein et al., 2017; Brennan & Resnick, 2012; Korkmaz et al. 2015; Korucu et el. 2017), this has yet to be demonstrated empirically in elementary school settings. Consequently, the effectiveness of a makerspace learning environment on computational thinking skills for elementary students has yet to be demonstrated by an empirical study.

CHAPTER 3

METHOD

As previously mentioned, the purpose of this action research was to evaluate the implementation of making experiences to support computational thinking through the development of makerspaces for fifth grade students in an elementary school in South Carolina. Three central questions were explored by this action research: (1) To what extent did the implementation of a makerspace improve computational thinking skills for fifth grade students at an elementary school in South Carolina?, (2) How did these students perceptions of using computational thinking as a problem solving method change based on makerspace experiences?, and (3) How did their problem solving skills change through the use of computational thinking in makerspaces?

Research Design

Using an action research approach was appropriate for this study because it allowed me to gain a better understanding of how students approach critical thinking and problem solving through engineering design thinking, tinkering, invention, and fabrication while focusing specifically on the characteristics of the population at my elementary school. While this study aimed to examine generalized outcomes of a makerspace approach, my purpose was to examine the immediate impact on students in my local school. In this manner, action research was chosen for this study, because it allowed an effective means for achieving desirable educational outcomes in a real school situation (McMillan, 2004; Schmuck, 1997).

Further, action research is defined as inquiry conducted by educators for the purpose of gathering information about how their particular school operates and is characterized as an inquiry into one's own practice (Johnson, 2008; Mills, 2011). Due to my close proximity to implementation of the study experiences, the reflective nature of action research will also benefit my dual role as instructor and researcher. Since action research is about examining one's own practice, I utilized this aspect of the study to reflectively explore my role as an active observer in the learning process (McLean, 1995; Mertler, 2017). Additionally, my viewpoint was that this study develops a practical approach that will foster change in my immediate school location. For these reasons, I feel my study connected appropriately with the framework of action research.

The action research approach taken by this study allowed the researcher to improve overall student performance, eliminate achievement gaps and enhance their own efficacy and morale in an ever-increasingly complex world by examining the approaches for what really works (Sagor & Williams, 2016). While the goal of quantitative research is to understand phenomena through the measurement of data related to factors that affect the outcome of a study (Morales, 2016), action research allows for unique steps of data analysis so that the researcher can be free to study the individuals and explore the processes, activities and events central to the study in a natural setting with an emerging design (Creswell, 2014). This flexibility underlies one of the key advantages of action research – its cyclical, spiraling approach. As Stringer (2007) points out the framework consists of a look, think, and act routine which leads to observations, reflections, and actions that inform each new stage of the study. By doing so, action research enabled me to follow an inductive process that focuses on a reflexive holistic account centered around the participants meanings (Maxwell, 2005). Since this study focuses mainly on the personal experiences of the participants, it was important that the chosen inquiry approach was less restrictive and reflects this interactive nature.

This study used a convergent parallel mixed methods design. By using this design, the researcher concurrently conducted the quantitative and qualitative elements in the same phase of the research process, weighed the methods equally, analyzed the two components independently, and interpreted the results together (Cresswell, 2014).

As the qualitative form has expanded in recent years, one of its noted strengths is that it allows the researcher the ability to collect multiple sources of data in the field by gathering observations, interviews and artifacts directly from the people involved within the context of a natural setting (Hatch, 2002; Ivankova & Wingo, 2018). In particular, a qualitative research design fit this study well because it allowed me to better understand the context and environment of the data collected. As Wilson (2017) and Marshall and Rossman (2011) state the qualitative approach allows for reflexivity and holistic reporting. Since the focus of qualitative research is on participants perceptions and experiences (Lincoln, 1995; Creswell & Miller, 2000), then I was free to focus on multiple forms of data using participants words, observations and artifacts to assemble a narrative for the implementation of a makerspace at my elementary school.

Setting

The research took place in the school’s makerspace, which was located within the school's science lab. The lab included space for flexible seating and working environments. The science lab featured 12 modular tables that were arranged into four groups. At each table, group materials were arranged inside a large storage bin. These bins included several laptop computers for each table as well as any resource materials and instruction support documents for the week's challenge. The support documents included reference sheets to the design process and computational thinking reference sheets as well as any instructions specific to the tools being used that week. In addition to the group bins, a materials station was assembled in the center of the room. Students were able to borrow and use any materials located at this station as needed. The materials station included collections of paper, tape, cardboard, office supplies, and any extra materials specific to the weekly challenge. Additionally, this space included materials for four categories of exploration. Those categories included construction, electronics, robotics, and coding challenges. This included a set of 12 Ozobot robots, 12 Makey Makey programming boards, and six LittleBits STEM kits.

Participants

For the purpose of this study, the participants included a purposely selected group of 16 fifth grade students that took part in the school's 21st Century Community Learning afterschool program. The purpose of the afterschool tutoring and enrichment clubs was to provide students with afterschool support in the area of academics while also providing exposure to a variety of enrichment activities and social emotional learning. The afterschool activities were funded by a federal grant designed to support students in poverty. These funds were used to purchase materials and funded bus transportation. Students were selected for afterschool tutoring and enrichment because they were identified as needing additional afterschool support. Students first qualified for participation if they were classified as receiving free or reduced lunch. Because the program did not receive enough initial participation, a second set of criteria for qualification was developed. Based on the new criteria, students qualified for the program if they scored as "Does not meet," or "Approaches" expectations on state standardized testing. Additionally, students were also able to qualify for the program if they did not meet growth goals using the district's Measures of Academic Progress assessment. The size of the sample groups was determined by the effective size of a focus group (Creswell, 2014). Only 16 fifth grade students chose to participate in afterschool tutoring and enrichment, so all fifth grade students were invited to participate in the study. None of the originally selected participants chose to not take part in the study, so no additional participants were invited to participate. In this study, the 16 students were arranged into four heterogeneous groups (See Table 3.1). Participants are referenced using pseudonyms to protect confidentiality. Ten of the participants were female and six were male. Of the 16 participants, 13 were African American, two were Asian, and one was White. Two students left the afterschool program and were unable to complete the innovation.

The most compelling reason fifth grade students were selected for this group was because of the increasingly important role computational thinking (CT) plays in upper elementary grades. South Carolina Computer Science and Digital Literacy (SCCSDL) standards for 2017 ask students as early as fifth grade to begin using the computational thinking skills of algorithms and programming (South Carolina Department of Education, 2017). This assertion mirrors the broad world-wide acknowledgement that CT now exists in all aspects of the global economy and as such deserves a place in the mandatory elementary school curriculum (Grover & Pea, 2013). CT thinking concepts have an important implication in computer sciences as well as in almost every other field and should be taught in elementary schools (Buitrago Florez et al., 2017). Often, students in elementary school experience only the receiving end of technology, and lack experiences with understanding what actually happens inside the box (Burke & Kafai, 2014). This lack of production limits the effectiveness of technology (Estapa et al., 2017). Based on this premise, CT has become a considered to be a necessary 21st-century skill that all individuals should acquire to be able to solve problems efficiently even when they are not seeking careers in computers science (Barr & Stephenson, 2011). Additionally, this study targeted fifth grade students at this site, because younger students would not have the same access to technology, since only upper elementary students have one to one computer access.

Table 3.1 *Makerspace Participants*

Group	*Participant*	*Gender*	*Race*
Group A	Asjia	Female	African American
	Israel	Male	Asian
	Adriana	Female	African American
	Cameron	Male	African American
Group B	Marcus	Male	African American
	Audrianna	Female	African American
	Kaiden	Male	African American
	Anina	Female	African American
Group C	Layke	Female	African American
	Dashay	Female	African American
	Jevaeh	Female	African American
	Carl	Male	White
Group D	Taman	Female	Asian
	Khloe	Female	African American
	Ashlynn	Female	African American
	Daniel	Male	African American

As the school's magnet lead teacher, my role was to ensure successful implementation of technology standards and to assist in the effective implementation of technology integration. As the magnet lead teacher, I was involved in developing makerspace instruction, and I was personally involved with the development of the learning space challenges and learning experiences.

Innovation

The innovation for my action research was the implementation of a makerspace to support computational thinking skills. Prior to beginning the innovation, students completed a preassessment using the Computational Thinking Scale (CTS). Students were then guided through a series of five design challenges that integrated makerspace learning characteristics with computational thinking skills. Following the 5-week makerspace implementation, students retook the CTS assessment in order to evaluate the innovation's influence on computational thinking skills.

Justification for the innovation. The use of this strategy within a makerspace has been developed by Blikstein (2013) to encourage authentic learning through innovation and engineering practices like design thinking, tinkering, invention, and fabrication. Additionally, the importance of computational thinking has gained interest with Wing's (2006) call to action to emphasize the importance of having students represent solutions as a series of computational steps or algorithms. Harel and Papert (1991) originally framed a theory of constructionism that emphasized the role production-based experiences play in how people learn. This movement has recently been developed by Martinez and Stager (2013) to expand making experiences into the classroom by seeking to develop formal educational settings where students learn by constructing knowledge through the act of making something. A makerspace is a place where students are free to explore interests through the use of tools both physical and virtual to develop creative projects (Blikstein, 2013; Sheridan et al., 2014). My makerspace model focused on providing engineering, circuitry, design, and computer programming activities. These activities were chosen because they provided the best opportunity to observe students computational thinking skill development in a makerspace setting, since they gave students the opportunity to demonstrate creativity, algorithmic thinking, critical thinking and problem solving (Bevan et. al. 2014; Cross, 2017; Martin 2015; Resnick, 1998).

Preassessment. Each student completed the CTS scale (Appendix A) that was originally developed by Korkmaz, Cakir, and Ozden (2015). Students completed the survey one week prior to the start of the makerspace innovation. The CTS is a five point likert type scale that consists of 29 items that determines the computational thinking skills of students in five different factors. The factors of the scale include the following: creativity, algorithmic thinking, cooperativity, critical thinking, and problem solving. I delivered the assessment to each of the four groups of students orally. Prior to the administration of the survey, a review of unfamiliar vocabulary was conducted with the students. During the administration of the assessment, students had access to a glossary of terms. Additionally, the meanings of difficult words were explained as the survey was completed by students to ensure understanding of survey question items. Following the survey, a general introduction to the makerspace was be given where a review of rules, and expectations of the space was provided. At this time, students were also introduced to the five-step design process that we used during the innovation. Students were also introduced to the variety of tools and applications available to them during makerspace activities.

Weekly Design Challenges. The implementation of the innovation included a five-week makerspace intervention. The makerspace was included as an afterschool enrichment club. Because of scheduling conflicts with other afterschool enrichment clubs, the makerspace sessions took place over a ten week period with meetings taking place every other week for five weeks. When students were not involved with the makerspace, they attended golf and swim lessons at a nearby country club. Students participating in the action research took part in daily hour-long makerspace sessions for each of the five weeks. The sessions took place between 4:30 and 5:30 p.m. every afternoon. The sessions featured open-ended problem-solving challenges based on real-world situations. Each week highlighted a set of makerspace tools, and posed a new design challenge for the students to solve as indicated in Table 3.2.

During these sessions, students were encouraged to experiment, design, fix errors, persevere, and collaborate using a variety making tools, such as Makey Makey boards, LittleBits building blocks, Ozobots, Scratch programming, and other various materials. These tools were chosen because of their ability to support creativity, algorithmic thinking, cooperativity, critical thinking, and problem solving (Bevan et. al. 2014; Cross, 2017; Martin 2015; Resnick, 2010). Makey Makey boards allowed students to experiment with creative solutions through a plug and play interface. These boards allow students to design different input that control different types of computers and devices. The board creates an electronic bridge so that real world objects can interact with digital components which provides students the ability to control a computer through anything

Table 3.2 *Weekly Makerspace Design Challenges and Tools*

Week	*Design Challenge*	*Makerspace Tools*	*Computational Thinking Skills*
Week 1	Young students at our school are getting bored in class. Develop an interesting video game to teach something to a younger student.	Scratch	Creativity, Algorithmic Thinking, and Problem Solving
Week 2	Not all students in our school were able to play your video game. Design a new controller that gives greater accessibility to your video game	Scratch, Makey Makey, and various tools and materials as needed	Creativity, Algorithmic Thinking, Critical Thinking and Problem Solving
Week 3	Students and teachers are getting lost in our school. Design a system that helps everyone get to class more efficiently.	Ozobots, and various tools and materials as needed	Creativity, Algorithmic Thinking, Cooperativity, Critical Thinking, and Problem Solving
Week 4	Student motivation is low at our school. Design and build a prototype for an invention to address this problem.	Littlebits, Makey Makey, Scratch, and various tools and materials as needed	Creativity, Cooperativity, Critical Thinking, and Problem Solving
Week 5	On your Own: Think of a problem that a machine can solve. Design and test your own solution to this problem.	Various tools and materials as needed	Creativity, Algorithmic Thinking Cooperativity, Critical Thinking, and Problem Solving

that conducts electricity. LittleBits building blocks supported the development of ideas into inventions. The bits allowed for prototype development through the use of snap together electronic building blocks that offer a variety of different input and output controls. This allowed students to test problem solving ideas with realistic inventions. Since the bits snap together, students created complex machines with the need for advance circuitry skills. Ozobots are pocket-sized robots that offer a variety of ways for students to code, create, and connect computing concepts with real world situations. Ozobots can be controlled screen free through color code stickers and markers, or online with OzoBlockly. Ozoblockly is a block coding language designed specifically for use with Ozobots. These small robots allowed students to visualize the different aspects of algorithmic thinking and provided an easy to learn introduction to robotics for younger children. Scratch is a free online programming language developed by the MIT Media Lab. Scratch gave students the opportunity to learn how to program interactive stories, games, and animations. Through the platform, students practiced systematic reasoning in a creative environment. During the weekly challenges, students used each day of the week to focus on a different step of the design process. Table 3.3 displays the daily expectations of the design process.

Table 3.3 *Daily Design Process Expectations*

Monday	*Tuesday*	*Wednesday*	*Thursday*	*Friday*
Define	Ideate, Prototype	Ideate, Prototype, Build	Build, Analyze	Share

Students practiced developing and testing solutions in a hands-on learning environment through the manipulation of digital and physical tools. Additionally, at the end of each challenge, students shared their solutions by explaining the thought processes involved in formulating the problem and how it is expressed in their solution during weekly debriefing focus group interviews. During the focus group interviews, students were questioned about how they used the makerspace learning characteristics of design thinking, tinkering, invention, and fabrication to demonstrate using the computational thinking skills of creativity, algorithmic thinking, cooperativity, critical thinking and problem solving.

Post-assessment. After the five-week innovation period, each student retook the CTS scale. A testing format that was identical to the preassessment took place. Additionally, a final group interview session was conducted. During this session, students also presented a portfolio of their learning to their focus group. In their portfolios, students highlighted two or three of their favorite products from the design challenges. The portfolio was used to highlight how they demonstrated creativity, cooperativity, critical thinking, and problem solving. This allowed students to reflect about how they used design thinking, tinkering, invention, and fabrication in the development of the physical artifacts.

Data Collection

In this mixed methods study, the data was analyzed in two sections. In the first section, results of the quantitative data will be presented. This will be followed with results of the qualitative data. These data sources were triangulated to provide reliability and validity by combining findings from the quantitative and qualitative data sources (Creswell, 2014). Table 3.4 summarizes the alignment of the research questions with the data sources and methods of analysis.

Computational Thinking Skills Survey

Quantitative data was analyzed by comparing pre- and postintervention results using the Computational Thinking Skills (CTS) questionnaire developed by Korkmaz, Cakir, and Ozden (2015). The CTS is a five point likert type scale of 29 items developed to determine the levels of computational thinking of students. The questionnaire collects data in the form of five different factors: creativity, algorithmic thinking, cooperativity, critical thinking, and problem solving. The options are arranged and scored as: (1) never, (2) rarely, (3) sometimes, (4) generally, and (5) always.

Table 3.4 *Research Questions, Data Sources and Methods of Analysis*

Research Questions	*Data Sources*	*Methods of Analysis*
RQ1: To what extent will the implementation of a makerspace improve computational thinking skills for fifth grade students at an elementary school in South Carolina?	Observations (Field Notes) Participant artifacts Focus group interviews	Inductive thematic analysis by constant comparative method
RQ2: How do these students' perceptions of using computational thinking as a problem solving method change based on makerspace experiences?	Observations (Field Notes) Focus group interviews Computational Thinking Skills questionnaire	Inductive thematic analysis by constant comparative method Wilcoxon signed rank test
RQ3: How do their problem solving skills change through the use of computational thinking in makerspaces?	Observations (Field Notes) Participant artifacts Focus group interviews	Inductive thematic analysis by constant comparative method

Items for the CTS were selected from a variety of other previously published scales. These included the creativity scale developed by Whetton and Cameron (2002) which was adapted by Aksoy (2004), the cooperative learning attitude scale by Korkmaz (2012), the scale of California critical thinking tendency, and the logical-mathematical thinking scale developed by Yesil and Korkmaz (2010). The section on creativity includes eight questions and asks students questions such as: I believe I can solve most of the problems I face if I have sufficient amount of time and I show effort. The section on algorithmic thinking includes six questions and asks students questions such as: I can digitize a mathematical problem expressed verbally. The cooperativity section includes four questions and asks students questions such as: I like experiencing cooperative learning together with my group friends. The critical thinking section includes five questions and asks students questions such as: I am proud of being able to think with a great precision. The problem solving section includes seven questions, and asks students questions such as: I have problems in the demonstration of the solution of a problem I have in mind. A complete list of questions by section can be found in Appendix A.

Korkmaz, Cakir, and Ozden (2017) published a validity and reliability study for the computational thinking scale. The validity and reliability of the scale has been studied by conducting exploratory factor analysis, confirmatory factor analysis, item distinctiveness analyses, internal consistency coefficients and constancy analyses. As a result of the conducted analyses, the authors concluded that the scale is a valid and reliable measurement tool that could measure the computational thinking skills of the students. The tests of Kaiser-Meyer-Oklin (KMO) and Bartlett were conducted on the data for the purpose of testing the construct validity of CTS and the results were determined as KMO = 0.880; Bartlett test value x^2 = 7727.897; sd = 406 ($p < .001$). The authors found the KMO value to be above 0.80 and interpreted this to demonstrated that the data set is in the excellent level for conducting factor analysis. Additionally, according to the Bartlett values, it was understood that the null hypothesis was rejected since a .05 meaningfulness level or lower was achieved. With the construct validity determined, the authors proceeded with a confirmatory factor analysis. The values of the goodness of fit were examined and have been found as x^2(sd = 362, N = 580) = 1169.932, p < .001. Observed fit values were determined to show an acceptable goodness. The reliability of the scale has been calculated with the use of the Cronbach Alpha reliability coefficient, the correlation value between two equal-half, Sperman-Brown formula and Guttmannsplit-half reliability formula. The two Split Half correlations of the scale was determined as 0.344; Sperman Brown reliability coefficient as 0.512; GuttmannSplit-Half value as 0.498; Cronbach Alpha reliability coefficient as .822. Based on these measures, the authors concluded that each factor in the scale in general could conduct consistent measurements.

The CTS assessment pre- and postmeans and standard deviations were calculated. Results from a normality test (Shapiro-Wilk) suggested significant results deviated from normality, therefore, a nonparametric Wilcoxon Signed-Rank test was conducted for all pre-and postdata from the questionnaire results. This test is appropriate for the study since the same group of students are exposed to the intervention (Ary, Jacobs, Irvine & Walker, 2018).

Because multiple tests were run under the same hypothesis, the Bonferroni type adjustment was applied to reduce type I error rate. When multiple comparisons are being made, the type I error rate will rise. Using the Bonferroni correction helps to avoid reporting false positives (Streiner & Norman, 2011). Since this study uses six similar tests that measure the outcome of computational thinking, multiple comparison corrections needed to be applied in order to control for type I error. For this study, an alpha level of .008 was used as the threshold for determining if the results of a test were statistically significant (Streiner & Norman, 2011).

Observations

Since many of the situations in a makerspace require seeing and hearing what is going on in the setting, the use of observations as a qualitative data collection technique was an important part of data collection for this study (Schmuck, 1997). Observations allowed me to gather data about students and see things they would not be able to report about themselves in interview sessions (Schmuck, 1997). So that I could record nonverbal reactions and better understand the interactions and communication within the small groups as I participated as both a practitioner and researcher, I collected observational data through intense periods of unstructured observations during makerspace learning experiences (Bailey & Bailey, 2017). In making unstructured observations, I focused on describing what occurred in as much detail as possible. During these intense periods, my observations attempted to collect an exact record of what was said and done by participants in as much detail as possible. Observations of the student groups were recorded in the form of field notes. Field notes were taken daily during each makerspace session using a two column format (Mertler, 2017). The left column recorded actual observations where I wrote what I saw and collected generic data such as time and place of observation (Johnson, 2008), and the right column was used for preliminary interpretations (Leedy & Omrod, 2005). During the observations, I looked for interactions related to key variable of makerspace learning and computational thinking that aligned with each of my three research questions. The makerspace learning characteristics included evidence of: design thinking, tinkering, invention, and fabrication. The computational thinking characteristics included evidence of: creativity, algorithmic thinking, cooperativity, critical thinking, and problem solving. A complete observation protocol guide can be found in Appendix B. Observation protocols were used as part of the qualitative data analysis framework as described at the conclusion of this section.

Semi-structured Focus Group Interviews

Individuals in the innovation participated in weekly focus group interviews. This type of format allowed me to make use of the limited time allotted for reflections for each group of students. (Mertler, 2017). Additionally, since the participants had similar experiences and backgrounds with the makerspace environment, it provided the possibility for better data collection as students feed off each other's comments (Creswell, 2013). Interviews allowed the participants to share their perspectives by adding their voice in relation to the implementation of the makerspace, and the development of computational thinking skills. Interviews were the best method of obtaining this perspective, and as a result have been determined to be an appropriate method. The interviews took place on Fridays at the conclusion of each week's challenge and lasted between 15 and 20 minutes. While conducting the focus group interviews, I had a copy of the interview protocol and took notes using a field notebook. A digital handheld recorder was used to record all interviews. During the interview sessions, I ensured that all students could hear each other's' responses, have time to reflect, and have the opportunity to share (Mertler, 2017). The interview protocol guide (Appendix C) is aligned to the research questions (See Table 3.5).

Table 3.5 *Interview Protocol Research Question Alignment*

Interview question alignment

- What making experiences did you find most useful? (RQ1)
  - Did using the steps of design thinking help you? How did you define the problem? What ideas did your group consider? What steps did you take in building the solution? What testing you conduct? (RQ1, RQ3)
  - Do you recall tinkering with any ideas or objects? Did you try things out? Were there any failures? What materials did you find helpful? Did you make any improvements along the way?(RQ1, RQ3)
  - Can you describe a time when you had to be inventive or use fabrication? Did you make something new or did you improve someone else's idea? What digital technology tools did you use or find helpful and why?(RQ1)
- Do you recall using any computational thinking? (RQ1, RQ3)
  - In what ways was your solution creative, new or different? (RQ1, RQ3)
  - In what ways did your solution use algorithmic thinking? Did you use any steps to solve the problem? How was your solution effective or efficient? Did any resources help you make improvements? (RQ1, RQ3)
  - Did your solution require any cooperation in the group? Did you find ways so that everyone could help? What roles did you each person take on? (RQ1)
  - Does you solution show any critical thinking? How did you analyze the situation? Did you prioritize anything? How did you evaluate your progress? (RQ1)
  - How did you solve the problem? Did any skills help you with this? What steps did you take? (RQ3)
- Have your makerspace experiences change how you think about problem solving? (RQ2)
  - Does computational thinking change how you solve problems? (RQ2)

The interview protocol followed a semi-structured interview format using a set of base and follow up questions. The semi-structured format questions were clear and brief to allow participants to help guide the process and share views and opinions (Bailey & Bailey, 2017; Creswell, 2014; Mertler, 2017). Following the interviews, I developed a transcription of the session. Field notes taken during the interviews were matched with transcriptions and be used as part of the qualitative data analysis framework as described at the conclusion of this section.

Participant Artifacts

Since one of the key elements of makerspace learning is the production of an artifact, it was important that the visual sources of data developed during this innovation be preserved and collected in order to assist in contributing to the understanding of what is occurring during this action research study (Mills, 2011). For this study, students collected and present artifacts in the form of a portfolio to be presented at the conclusion of the 5 week design challenge. This portfolio approach is widely recognized as an important part of the evaluation process of makerspace learning characteristics and has been used in a number of similar studies (Blikstein, 2013; Jarret, 2016; Litts, 2015; Sheridan et al., 2014). This approach allowed for formative assessment to take place over time which emphasizes the evolving nature of the development of a portfolio (Brennan & Resnick, 2012). For this study, student portfolios included the physical examples of weekly design challenges, and any student created documents that supported the development of the final product. Students developed their portfolios following the final design challenge and were collected the following week. A review of these documents provided limited information about the process of developing the projects but provided a good deal of insight into to development key makerspace learning characteristics and computational thinking development. A portfolio review instrument has been created to ensure that review of these documents is aligned with research questions one and three. It has been written to explore the nature and development of the key concept variables connected to these questions. The portfolio review instrument aided in identifying examples of design thinking, tinkering, invention, and fabrication based on makerspace learning experiences in student work, Additionally, it provided documentation of how the concepts of creativity, algorithmic thinking, cooperativity, critical thinking and problem solving which relate to computational thinking were utilized in the creation of the artifacts. The complete instrument can be found in Appendix D.

Qualitative Data Analysis Framework

Analysis of the qualitative data will follow an inductive thematic analysis approach by trying to make sense of the data by taking it apart, peeling it back, and putting it back together again (Creswell, 2014). The goal of the analysis was to represent the data in a rich, thick descriptive narrative set on identifying a few important themes that develop a picture of the innovation case study (Creswell & Brown, 1992). Data was analyzed by the constant comparative method using thematic analysis (Corbin & Strauss, 2008; Glaser & Strauss, 1967). The data will include observations, semi-structured focus group interviews, and participant artifacts.

Since the qualitative approach often produces large volumes of data, the effort of this analysis attempted to organize the various data into patterns and themes to develop a framework (Mertler, 2017). This was done following a spiraling approach. The process followed concurrently with data collection and analysis and did not follow a set of distinct linear steps. Instead, it engaged in the process of moving in circles of data collection, emergent ideas, coding themes, interpretations, and findings. This approach allowed the researcher the ability to make systematic comparisons across units of data as they are collected (Bernard, Wutich, & Ryan, 2017). These steps were intent on preserving the uniqueness of the data while generating specific analytic outcomes (Creswell, 2017). This process was iterative and was reviewed in several repeated rounds of analysis.

This documentary data process focused on identifying a few emerging themes that were aggregated from coding development of the data using an open coding approach (Johnson, 2008). The coding process was set to accomplish both a general descriptive narrative of the chronology of events, setting and participants as well as themes for constant comparative analysis (Schmuck, 1997). This process took advantage of computer aided qualitative analysis software (Delve), and began with open coding by collecting detailed descriptions from transcriptions of interviews, observations, artifacts, and video tapes within the context of the setting. Open coding has been chosen for its natural heuristic approach which allows the researcher to explore the data without assumptions (Bailey & Bailey, 2017). Coding preserved the participant data in sentence form highlighting the important and interesting information as comments in Delve. Text segments were collected in sentence form and given codes pulling exact words from the participants. These codes were organized into categories, and finally were linked to form emerging themes using Microsoft Excel (Creswell, 2017). Coding categories were reviewed and refined as necessary. Themes were identified by examining the data for uses of repetition, and similarities and differences (Bernard, Wutich, & Ryan, 2017). The relationship between codes, categories and themes were represented through a set of diagrams representing the relationships between codes and emerging themes. This qualitative data was used to compliment the quantitative data results.

Procedures

This study consisted of three phases. The timeline for the procedures of this action research is as follows: Phase 1: Participant Identification, Phase 2: Data Collection and

Phase 3: Data Analysis. Each phase is described in detail below. Table 3.6 is included to detail the timeline of all the procedures.

Table 3.6 *Timeline of Participant Identification, Data Collection & Data Analysis*

Phase	Expectation	Timeframe
Phase 1: Participant Identification	1. Identify Target Population 2. Select Sample Groups 3. Contact Participants 4. Review Consent Form	2 weeks
Phase 2: Data Collection	1. Computational Thinking Scale (CTS) Pretest 2. Weekly Problem-Solving Design Challenges 3. Field Note Collection 4. Session Video Recording 5. Weekly Focus Group Interviews 6. Artifact Collection 7. Initial Thematic Coding 8. CTS Posttest	14 weeks
Phase 3: Data Analysis	1.Transcribe Focus Group Interviews and Session Recordings 2. Open Coding 3. Constant Comparative Method 4. External Audit 5. Repeated Measures *t*-test (Modified CTS Scale) 6. Statistical Summary & Narrative Report 7. Member Checking 8. Share Findings	7 weeks

Phase 1: Participant Identification

Participant identification for this study began in the fall of 2019 using the selection criterion identified earlier (purposeful sampling). Four sampling groups of four students for a total of 16 participants were invited to participate. I collaborated with necessary faculty members in order to inform students of the opportunity and the innovation's objective. Student guardians were contacted I sent home a consent form for selected students to participate in this study. After reviewing consent forms and obtaining parental permission, students were divided into four heterogeneous groups representative of the overall makeup of the participants. Once focus groups were established, I began to meet daily with students for one hour sessions during their afterschool club sessions.

Phase 2: Data Collection

Prior to beginning the makerspace learning sessions, students completed a pretest using a modified version of the CTS scale initially developed by Korkmaz, Cakir, and Ozden (2015). Following the completion of this assessment, I met with the focus groups for a total of 5 weeks. Students participated in completing weekly design challenges to problem solve different real-world scenarios in sessions that occur five times a week. I worked with students in the makerspace to teach the design process to encourage creativity, tinkering, problem solving, and critical thinking. Students used the materials in the makerspace to promote an understanding of computational thinking. During the weekly challenges, I collected in-depth descriptive data using a variety of qualitative techniques. First, daily field notes were recorded using the previously described observation protocol developed for this study. Second, weekly semi-structured focus group interviews were conducted to debrief at the conclusion of each design challenge. Weekly interviews were recorded and lasted between 10 and 20 minutes. Lastly, participant artifacts were collected at the conclusion of each challenge in the form of photographs, written documents, and physical objects. In addition, following the data collection for each week, the researcher analyzed the observational, interview, and portfolio data for developing themes. These themes allowed the research to develop codes to analyze the emerging data. At the conclusion of the five-week study, participants completed a posttest using the modified CTS scale from the beginning of the study.

Phase 3: Data Analysis

After completing the makerspace focus groups, I transcribed each focus group interview and session recording. I began with transcription of these interviews, since it will require a large amount of time. From this data, emerging themes were identified through the *in vivo* open coding process. I used the constant comparative method (Corbin & Strauss, 2008; Glaser & Strauss, 1967) to analyze the descriptive data collected through observations, interviews, and artifacts. The researcher shared the collected data and codes with an external auditor. The external auditor for this case study was the school's principal. She reviewed the accounts of the case study to provide objective assessment of the themes to check for accuracy and ask questions about the aspects of the makerspace intervention. Following the review of an external auditor, I then analyzed the CTS scale pre-post test data using a Wilcoxon signed-rank test. To determine statistical significance, the test results were compared to a Cronbach's alpha level of .008. The researcher developed a statistical summary and narrative report of the case study description and themes and shared the findings with the participants prior to sharing a final report. The researcher met with the participants in grade level groups to determine whether the participants felt the case study narrative was accurate. Following the member checking, the researcher made revisions prior to sharing the findings and develop a final report.

Rigor & Trustworthiness

Since this mixed methods study will include both quantitative and qualitative research data, this section describes how this study provided for different measures of validity, reliability, and trustworthiness.

The quantitative data was examined by the measures of validity and reliability as previously described in this chapter.

The qualitative data was examined by other measures of trustworthiness. This was established through the use of triangulation, member checking, and peer debriefing. These characteristics were used to reinforce perceptions made by the researcher in an effort to ensure they are not misinformed and that they actually represent what was seen and heard (Fraenkel, Wallen, & Hyun, 2012).

Triangulation

The triangulation of results is the use a variety of instruments, methods and sources to support and enhance the validity of findings (Mertler, 2017). This study used methodological triangulation by using different data sources in the examination and building of themes. The convergence of this data from multiple perspectives added to the trustworthiness of this study (Creswell, 2014). This study used data from observations, focus group interviews, and participant artifacts. The analysis of these different forms was used to corroborate the development of themes during analysis. Multiple methods of data collection compensated for the limitations of any single source of data, and at the same time exploit their individual benefits (Brewer, & Hunter, 1989).

In this study, four sources of data were used to ensure triangulation: semi-structured observations, focus group interviews, participant artifacts, and the CTS survey.

This data was collected through the use of protocols, transcriptions and rubrics as previously described in this chapter. Additionally, this study provided further use of triangulation by incorporating both the quantitative results of the CTS survey alongside the qualitative findings.

Member Checks

Member checking, which Bailey and Bailey (2017) describes as asking participants to review the accuracy of findings in the research, was conducted with all participants to verify the overall accuracy of themes and findings. In this study, this was done using the themes identified during the focus group interviews. Following the transcription and analysis of this data, the descriptions were shared with each individual. I read the themes and descriptions from the interview to students, so they had a chance to clarify or provided extended explanation. This gave each participant the opportunity to reflect and verify that the themes follow accurately with their perceptions of the study. As described previously in chapter one, findings were communicated with participants during personal meetings. Doing so ensured the data collection includes the terms of the contextual meaning of the setting through both the researcher and participant (Shenton, 2004).

Peer Debriefing

Lastly, peer debriefing provided a measure of “external audit” (Mertler, 2017, p.143) that provides the researcher the opportunity to reflect on the study. By using peer debriefing to add to the validity of the account, the intent is to enhance the overall accuracy of the analysis by involving an outside expert (Johnson, 2008). For this study, meetings were held with two different groups. Several debriefing sessions were held with the my school's principal Connie May. These discussions were based on verifying the overall analysis of the codes, categories, and themes of the study, while ensuring this data described the participants and the setting accurately. These discussions occurred weekly throughout the implementation of my innovation and during the data analysis period that followed. Additionally, I met with my dissertation chair at the conclusion of the study to discuss analytic procedures. This conversation was intended to interrogate the initial findings and analysis through a process of questioning that led the researcher to abstract the data further. Additional discussion was held as needed to strengthen rigor throughout the research process. By including an external audit by peers this opportunity for scrutiny and feedback offered a fresh perspective that challenges assumptions in case my closeness to the project inhibits my ability to view it without detachment (Shenton, 2004).

Plan for Sharing

In order to decrease the divide that has existed in the field of education between research and the classroom teacher, I plan to share this action research study with both local and national venues (Mertler, 2017). However, since action research is primarily interested in empowering professional growth that enables changes through collaboration in local contexts, it will be important that the results of this study are shared with all stakeholders first (Johnson, 2008). To accomplish this, I included all study participants, participant guardians, teachers, and administrators in the sharing of this study. Prior to sharing the report publicly, I met with the participants and guardians of the participants of the study to share the findings of the report. This provided an opportunity for the student participants to review the conclusion of the report prior to any outside groups.

Next, the report will be shared with my school faculty and my school district's technology department staff members. I will share the results of this study with my colleagues because it is likely that no one is more interested in this study than the teachers at my school. I will present the findings of my study during informal grade level meetings in the fall of 2020. The meetings will be short, focused and brief, and provide a bulleted outline of the study's findings (Johnson, 2008). I will use these meetings as an opportunity for reflection and gather feedback from the other professionals in my setting. From these meetings, I will look for ways to amend the plan and take additional actions steps to update and revise the action research project (Schmuck, 1997). Following these informal meetings, I will present the findings of this study as a district innovation project with the my school district's innovation community during one of their monthly community meetings. The R2 Innovates group is an innovation incubator that provides teams with the support needed to implement new teachings strategies. By sharing with this community of teachers, I hope that others will look to expand on the findings this study presents on makerspaces and computational thinking.

Lastly, I plan to submit this project to the International Society for Technology in Education (ISTE) conference as a research paper. The ISTE standards for students include a strand computational thinking, so the results of this study may be of particular interest to this national community of educational technology professionals.

In order to protect the confidentiality and anonymity of my participants, when presenting the results of this action research study, I will limit the descriptions of individuals and setting so they are not identifiable (Mertler, 2017). Additionally, since much of the sharing of this data will take place in local settings, I will use pseudonyms in place of actual names. Also, since some of the data collected in this study features photos, and portfolio documents, any identifiable images will be approved for publication and sharing by informed consent from parents and assent from the participants themselves.

CHAPTER 4

ANALYSIS AND FINDINGS

The purpose of this action research was to describe the impact makerspace learning experiences have on the develop of computational thinking for fifth grade students. Both quantitative and qualitative data were collected to answer the following questions: (1) To what extent did the implementation of a makerspace improve computational thinking skills for fifth grade students at an elementary school in South Carolina? (2) How did these students' perceptions of using computational thinking as a problem solving method change based on makerspace experiences? and (3) How did their problem solving skills change through the use of computational thinking in makerspaces?

This chapter presents an overview and analysis of the data collected during a mixed-methods action research study. Sixteen student-participants took part in this study. These participants were administered a questionnaire before and after the innovation took place. They also took part in weekly interviews and submitted projects for a portfolio review. In addition, I collected daily observational notes throughout the course of the study. This chapter includes both my quantitative and qualitative findings. The quantitative findings are a breakdown of the Computation Thinking Skills (CTS) (Korkmaz, Cakir & Ozden, 2015) questionnaire results. The qualitative findings include participant descriptions, observations, interviews, and artifact reviews. These findings were analyzed to help accurately answer the research questions. From this data collection, I provided study themes and my interpretations.

Quantitative Analysis and Findings

Quantitative data was collected using the CTS (Korkmaz, Cakir & Ozden, 2015) as both a pre- and postquestionnaire for student participants. The CTS was developed to investigate the different variables associated with computational thinking and was adapted for use in secondary school levels (Korkmaz, Cakir & Ozden, 2015; Korucu, Gencturk & Gundodgu, 2017). The CTS is a five-point likert type scale and consists of 29 items that are broken down into five factors. Each participant answered questions as to their knowledge, skill, and attitude towards using computers to solve problems. Each of the items was scaled as: (1) never, (2) rarely, (3) occasionally, (4) usually, and (5) always. The factors of the scale include the following: creativity, algorithmic thinking, cooperativity, critical thinking, and problem solving. The published validity and reliability of this instrument were reported earlier. I conducted a reliability analysis on the pre-questionnaire values. Cronbach's alpha showed the questionnaire to reach acceptable reliability, $\alpha = 0.77$.

CTS Results

Descriptive statistics. For the CTS, pre- and postquestionnaire results ($n = 14$) are reported in Table 4.1. The table includes overall pre- and postquestionnaire means as well as pre- and postmeans for the different subscales of the survey. Pretest scores resulted in a mean of 106.00 with a standard deviation of 17.92. Posttest scores resulted in a mean of 114.64 with a standard deviation of 17.45.

Table 4.1 *Descriptive Statistics for Computational Thinking Skills Survey (n = 14)*

	Pre		**Post**	
	M	***SD***	***M***	***SD***
Overall Survey	106.00	17.92	114.64	17.45
Creativity	29.50	5.43	33.35	5.66
Algorithmic Thinking	20.64	5.90	23.21	4.66
Cooperativity	15.76	2.88	16.35	2.73
Critical Thinking	22.35	5.18	24.50	5.18
Problem Solving	17.71	6.17	17.21	5.88

Pre- and postcomparison. Results from a normality test (Shapiro-Wilk) suggested significant results deviated from normality. A *p* value less than .05 was used to determine if a significant deviation from the normal curve occurred. Based on this assumption, I determined the data sets for the overall CTS means and the subscales for creativity and critical thinking means to be non-normal data. Therefore, nonparametric Wilcoxon Signed-Rank tests were conducted for all pre-and postdata from the questionnaire results.

Because multiple tests were run under the same hypothesis, the Bonferroni type adjustment was applied to reduce type I error rate. When multiple comparisons are being made, the type I error rate will rise. Using the Bonferroni correction helps to avoid reporting false positives (Streiner & Norman, 2011). Since this study uses six similar tests that measure the outcome of computational thinking, multiple comparison corrections needed to be applied in order to control for type I error. To reduce the likelihood of discovering a false positive, the alpha level needs to be lowered to account for the number of comparisons being made (Streiner & Norman, 2011). For this study, an alpha level of .008 was used as the threshold for determining if the results of a test were statistically significant.

The Wilcoxon Signed-Rank test indicated that the CTS posttest ranks (*M* = 114.64) were statistically significantly higher than the CTS pretest ranks (*M* = 106.00, *p* = .005). The test also indicated that the creativity subscale posttest ranks (*M* = 33.35) were statistically significantly higher than the creativity subscale pretest ranks (*M* = 29.50, *p* = .001). The test also indicated that the critical thinking subscale posttest ranks (*M* = 24.50) were not statistically significantly higher than critical thinking pretest ranks (*M* = 22.35, *p* = .055). The Wilcoxon Signed-Rank test showed no statistical significance in the pretest algorithmic thinking ranks (*M* = 20.63) and posttest algorithmic thinking ranks (*M* = 23.21, *p* = .084). Additionally, there was no statistical significant difference in the pretest cooperativity ranks (*M* = 15.78) and posttest cooperativity scores (*M* = 16.35, p = 0.504). Lastly, there was no statistical significance difference in the pretest problem solving ranks (*M* = 17.71) and posttest problem solving ranks (*M* = 17.21, p = 0.500).

Overall, I found the respondents who took part (*n* = 14) increased in subscale of creativity, however, my other subgroups showed a high degree of variance. One interesting result I observed was for the subgroup of problem solving. In the postquestionnaire results, the mean score for the subgroup dropped slightly from pre (*M* = 17.71) to post (*M* = 17.21).

Qualitative Analysis and Findings

In this study, I collected qualitative data from three sources. These included semi-structured participant observations, semi-structured focus group interviews, and participant artifacts. Table 4.2 describes this data set. A total of 15 observations were conducted across five weeks of activities. A total of five focus group interview sessions were collected. A total of 10 participant artifacts were collected for review. This section includes a description of the qualitative data I collected, the analysis of my qualitative data, and themes and interpretations.

Table 4.2 *Summary of Qualitative Data Sources*

Types of Qualitative Data Sources	Number	Total Number of Codes Applied
Semi Structured Observations	15	226
Semi Structured Focus Group Interviews	5	335
Participant Artifacts	10	272
Totals	30	833

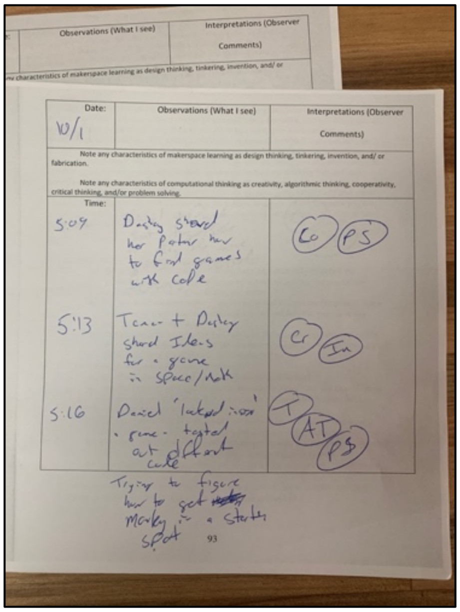
Participant Observations

My goal in analyzing the observation data was to describe the experiences of 16 participants in relation to the research I was conducting. I collected observations during each week of makerspace challenges. Notes were taken for the three days each week that students worked in groups (see Figure 4.1). I wrote descriptions of the learning characteristics I was seeing in relation to makerspace learning and computational thinking and included the participant actual language when possible. Included with these observations, I added observer comments to interpret actions of the participants. I transcribed these written observations into word processing software exactly as entries were written. Daily observation entries were combined into a week by week format. Each week was entered as a separate document. The original journals were retained for reference as needed had any questions arisen from the transcription.

Participant Interviews

Along with these descriptions, I also transcribed the focus group interviews I performed. Focus group interviews took place at the conclusion of each week's challenge. Participants were interviewed in two different groups with eight students in each group.

Interviews were recorded using a handheld recording device and typically lasted between fifteen and twenty minutes. Transcriptions were made from audio recording files using Temi, a web -based speech-to-text software program (see Figure 4.2). The automatic transcriptions were checked manually for accuracy using direct audio to text comparisons, and discrepant errors were corrected prior to coding in an effort to preserve the exact and authentic participant viewpoints.



Observations (What I see)	Interpretations (Observer Comments)

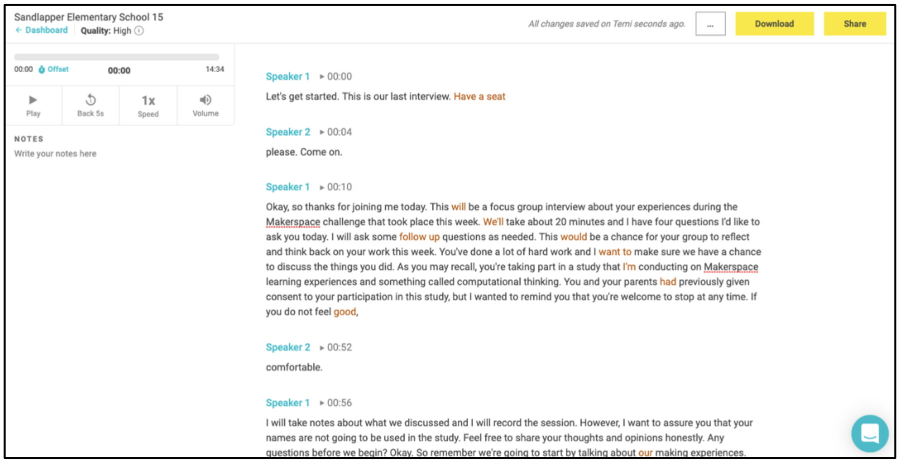
…y characteristics of makerspace learning as design thinking, tinkering, invention, and/ or

Date: 10/1	Observations (What I see)	Interpretations (Observer Comments)
Note any characteristics of makerspace learning as design thinking, tinkering, invention, and/ or fabrication. Note any characteristics of computational thinking as creativity, algorithmic thinking, cooperativity, critical thinking, and/or problem solving.		
Time: 5:09	Dasley showed her Partner how to find games with code	Co PS
5:13	Team + Dasley shared Ideas for a game in Space/Math	Cr In
5:16	Daniel 'looked into' a game - tested out different code	T AT PS

Trying to figure how to get ~~[illegible]~~ Monkey in a starting spot

93

Figure 4.1: An example of participant observations before online coding began.



Sandlapper Elementary School 15

Speaker 1 ▸ 00:00

Let's get started. This is our last interview. Have a seat

Speaker 2 ▸ 00:04

please. Come on.

Speaker 1 ▸ 00:10

Okay, so thanks for joining me today. This will be a focus group interview about your experiences during the Makerspace challenge that took place this week. We'll take about 20 minutes and I have four questions I'd like to ask you today. I will ask some follow up questions as needed. This would be a chance for your group to reflect and think back on your work this week. You've done a lot of hard work and I want to make sure we have a chance to discuss the things you did. As you may recall, you're taking part in a study that I'm conducting on Makerspace learning experiences and something called computational thinking. You and your parents had previously given consent to your participation in this study, but I wanted to remind you that you're welcome to stop at any time. If you do not feel good,

Speaker 2 ▸ 00:52

comfortable.

Speaker 1 ▸ 00:56

I will take notes about what we discussed and I will record the session. However, I want to assure you that your names are not going to be used in the study. Feel free to share your thoughts and opinions honestly. Any questions before we begin? Okay. So remember we're going to start by talking about our making experiences.

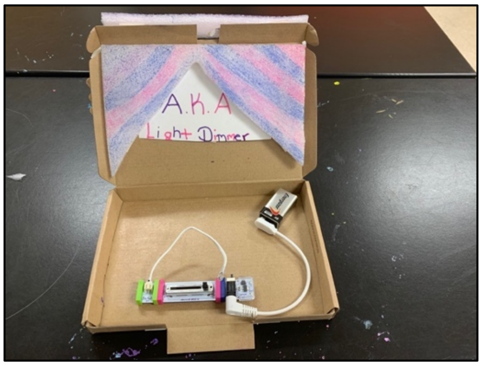
Figure 4.2: An example of audio transcription using Temi before online coding began.

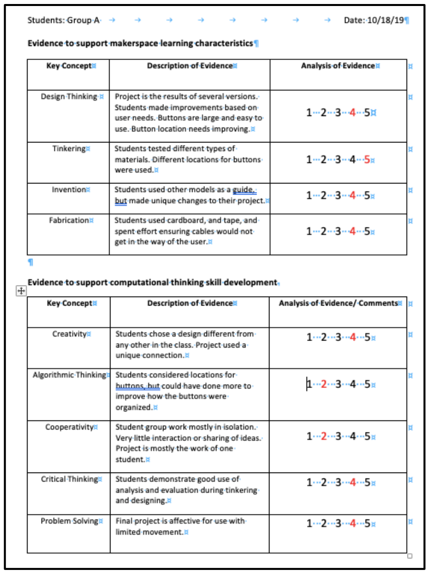
Participant Artifacts

Additionally, each week I collected work samples from two different groups of students for an artifact review. Different groups were selected each week to ensure that all groups were represented in the work samples. Photos were taken of the artifacts to use with the review protocol (see Figure 4.3). The review protocol included a description of the artifact's makerspace learning and computational thinking characteristics, as well as my own ratings for levels of analysis. The portfolio artifacts were used as supporting evidence for the characteristics identified in the previous qualitative data.

Analysis of Qualitative Data

After transcribing the interviews using Temi, a web -based speech-to-text software program, I entered them into Delve (2019), an online coding tool, to analyze the qualitative data. No codes were generated prior to analyzing this data. When analyzing the interview and observation data, I went day by day and sentence by sentence. Analysis of the qualitative data included three cycles of coding. The first cycle of coding used open coding techniques. In order to transition to the next cycle of coding, code mapping was used to assemble the codes to prepare for second cycle coding. The second cycle of coding used open coding techniques, and a final third cycle of coding implemented pattern coding. Because the portfolio artifacts were based solely on my own perceptions of the students work, they were not included in the first cycle of coding in order to allow student perceptions and actions to guide the process. When analyzing the portfolios, I followed a deductive approach using predefined codes that were developed from makerspace learning and computational thinking characteristics identified by previous research studies.





Students: Group A Date: 10/18/19

Evidence to support makerspace learning characteristics

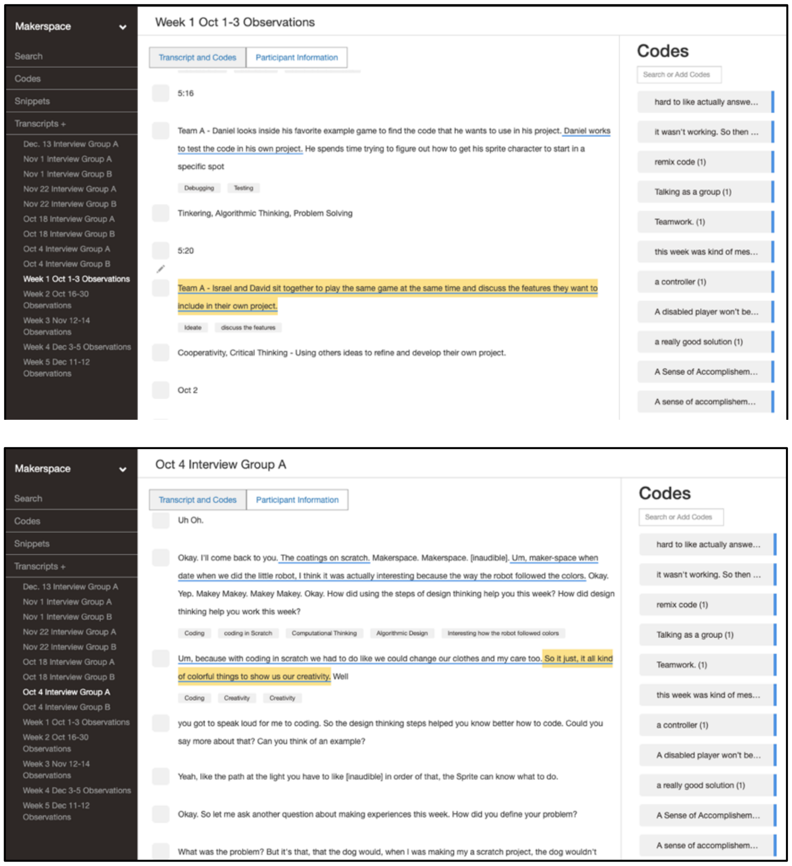
Key Concept	Description of Evidence	Analysis of Evidence
Design Thinking	Project is the results of several versions. Students made improvements based on user needs. Buttons are large and easy to use. Button location needs improving.	1 2 3 [✓ 4] 5
Tinkering	Students tested different types of materials. Different locations for buttons were used.	1 2 3 4 [✓ 5]
Invention	Students used other models as a guide, but made unique changes to their project.	1 2 3 [✓ 4] 5
Fabrication	Students used cardboard, and tape, and spent effort ensuring cables would not get in the way of the user.	1 2 3 [✓ 4] 5

Evidence to support computational thinking skill development

Key Concept	Description of Evidence	Analysis of Evidence/ Comments
Creativity	Students chose a design different from any other in the class. Project used a unique connection.	1 2 3 [✓ 4] 5
Algorithmic Thinking	Students considered locations for buttons, but could have done more to improve how the buttons were organized.	1 [✓ 2] 3 4 5
Cooperativity	Student group work mostly in isolation. Very little interaction or sharing of ideas. Project is mostly the work of one student.	1 [✓ 2] 3 4 5
Critical Thinking	Students demonstrate good use of analysis and evaluation during tinkering and designing.	1 2 3 [✓ 4] 5
Problem Solving	Final project is affective for use with limited movement.	1 2 3 [✓ 4] 5

Figure 4.3: An example of a participant artifact and review protocol.

I began the first cycle of coding by reading the transcripts of students interviews and observations over. In the first cycle of analysis, I began with a form of open coding (see Figure 4.4) to categorize the wide variety of forms of data (Glaser, 2016; Saldana, 2016). Open coding was used to begin coding the observations and interviews, since it incorporated a variety of methods that were compatible to the different types of data I had collected (Saldana, 2016). For the open coding of the data, two types of elemental coding were implemented to extract data: (a) descriptive and (b) In Vivo.



Week 1 Oct 1-3 Observations

5:16

Team A - Daniel looks inside his favorite example game to find the code that he wants to use in his project. Daniel works to test the code in his own project. He spends time trying to figure out how to get his sprite character to start in a specific spot

Debugging Testing

Tinkering, Algorithmic Thinking, Problem Solving

5:20

Team A - Israel and David sit together to play the same game at the same time and discuss the features they want to include in their own project.

Ideate discuss the features

Cooperativity, Critical Thinking - Using others ideas to refine and develop their own project.

Oct 2

Oct 4 Interview Group A

Uh Oh.

Okay. I'll come back to you. The coatings on scratch. Makerspace. Makerspace. [inaudible]. Um, maker-space when date when we did the little robot, I think it was actually interesting because the way the robot followed the colors. Okay. Yep. Makey Makey. Makey Makey. Okay. How did using the steps of design thinking help you this week? How did design thinking help you work this week?

Coding coding in Scratch Computational Thinking Algorithmic Design Interesting how the robot followed colors

Um, because with coding in scratch we had to do like we could change our clothes and my care too. So it just, it all kind of colorful things to show us our creativity. Well

Coding Creativity Creativity

you got to speak loud for me to coding. So the design thinking steps helped you know better how to code. Could you say more about that? Can you think of an example?

Yeah, like the path at the light you have to like [inaudible] in order of that, the Sprite can know what to do.

Okay. So let me ask another question about making experiences this week. How did you define your problem?

What was the problem? But it's that, that the dog would, when I was making my a scratch project, the dog wouldn't

Figure 4.4: Interview and observation Delve transcripts in the first round of coding.

Descriptive allowed for short words and phrases to be used to summarize topics as codes (Saldaña, 2016). An example of this type of code was the *adding things* code. This code served as a place to note observations of one method students used to fix problems when designing during the challenges. Eventually, this code was revised to *trial and error* and during later rounds of coding was grouped with the *tinkering* code. This type of coding was used to help me begin to develop an inventory of possible ways to merge the codes and was mainly used with observation data.

In Vivo coding is a method of literal coding that refers to actual language found in the data record (Charmaz, 2014; Manning & Kunkel, 2014; Saldaña, 2016). An example of this type of coding would be the use of the code *one piece at a time*. This code appeared across comments made by several participants during focus group interviews. This code allowed me to preserve the language of the students and was later incorporated into the *problem solving* category of *decomposition*. These phrases were extracted from both the interview data and the sample of student conversations noted in my observation. They were later organized into hierarchical lists and grouped into clusters as categories were developed during a third cycle of coding.

Prior to beginning a second cycle of coding, I began to recode my data based on new discoveries and insights gained from the first cycle coding process. The codes I had collected so far appeared difficult to organize, so I began to reanalyze my data for possible connections using eclectic coding as a transitional technique (Saldana, 2016). This process allowed codes to serve as triggers for reflection through analytic memo writing on the deep and complex meanings that had developed in the wide variety of descriptive and In Vivo codes I had developed. These codes were printed, cut apart, and arranged alphabetically on a table (see Figure 4.5).

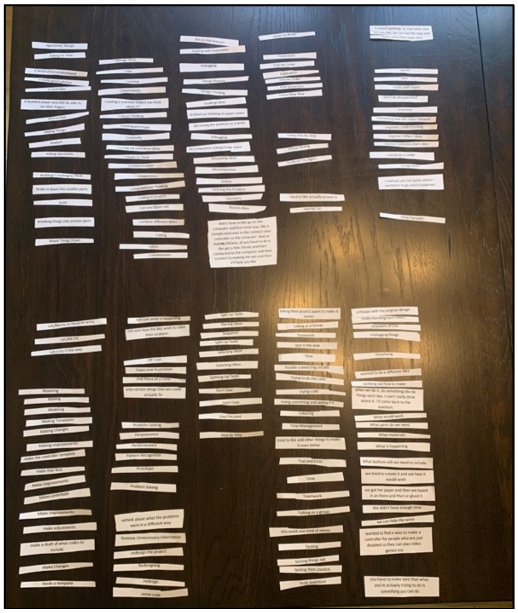


Figure 4.5: First Cycle Codes in Alphabetical Order

I began to generate some initial code mapping (Corbin & Strauss, 2008; Saldaña, 2016). Code mapping allows the researcher to analyze data using a self-generated map to better frame view the data. By developing a visual way to view the codes in one place, I was able to see how the data was grounded within theory. At this point, the use of open coding techniques provided the best means for starting the process of grouping codes.

From this reflection process, a second cycle of coding was begun in order to bring a better understanding of the data by reorganizing, renaming and merging codes based on similarities (Creswell, 2013; Saldana, 2016). Using open coding to find similarities and differences in the data showed me when patterns began to emerge (see Figure 4.6). This technique allowed me to see the direction the study was taking (Gee, 2011; Saldana, 2016), and I started a second cycle of coding by placing participants' responses from interviews and my observations into a new series of codes that combined the original set of codes into more manageable groups (see Figure 4.7).

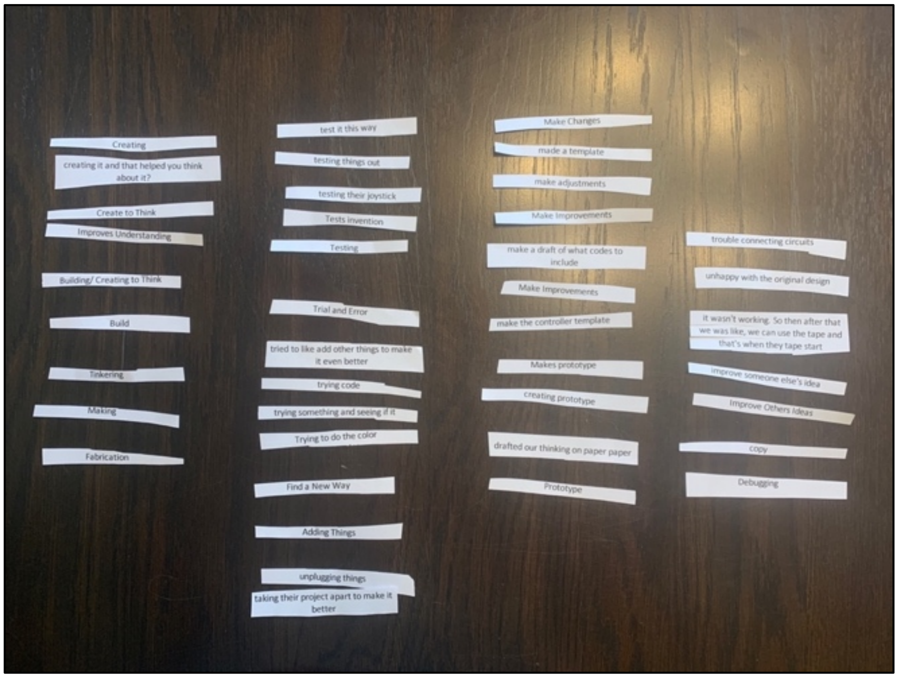


Figure 4.6: Grouping Second Cycle Codes Related to Making

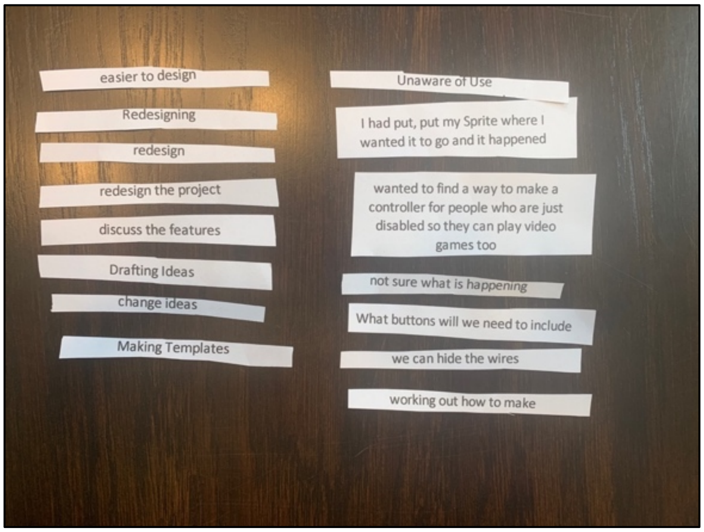


Figure 4.7: Combining Codes Related to Design Thinking

These new codes would assist in creating categories to help me organize my data. Each time codes were combined; I recorded an analytic memo in Delve to track my thinking, assertions, and analysis about the codes' meaning (Bazeley, 2013; Mertler, 2017; Saldaña, 2016). An example of how open coding was used to combine first cycle codes would be the use of *tinkering* in place of the first cycle codes of *making improvements, testing, taking things apart, adding things,* and *trying different things*.

Once the interviews and observations had been analyzed for initial codes, the portfolio artifacts were then analyzed using these same set of codes. Examining the portfolio artifacts during the second cycle of coding helped me to add to the analysis of the study. This helped to guide my process of beginning to develop themes and categories (Saldaña, 2016).

Following the development of a refined set of initial codes, I began a third cycle of coding. During this cycle, my goal was to reorganize and arrange the data in a meaningful way so that facts could be linked logically and outlined into categories and themes (Charmaz, 2014; Saldana, 2016). I merged the thinking behind both the first and second round codes to begin to form the categories and themes for my data. In this round, I used pattern coding. This type of coding groups summaries into smaller categories and creates explanations and inferences to identify emerging themes (Corbin & Strauss, 2008; Saldaña, 2016). I began by assembling the revised codes into one place. With the codes arranged into groups I looked at how the information fit together as concepts. I grouped the codes together based on how they best fit into conceptual groups (see Figure 4.8). Groupings included design thinking, critical thinking, modeling, analyzing, building, debugging, making, tinkering, abstraction, decomposition, algorithmic thinking, pattern recognition, creativity, discovery, invention, persevering, collaboration, cooperation, communication, and teamwork issues.

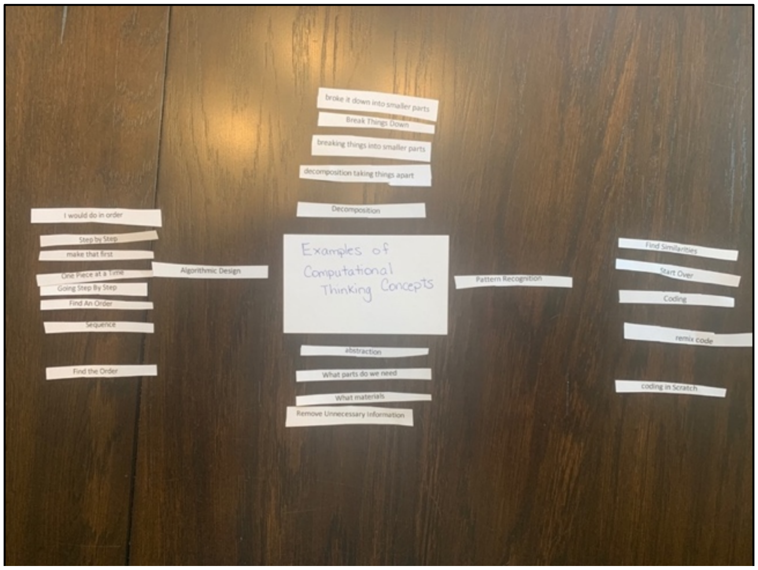
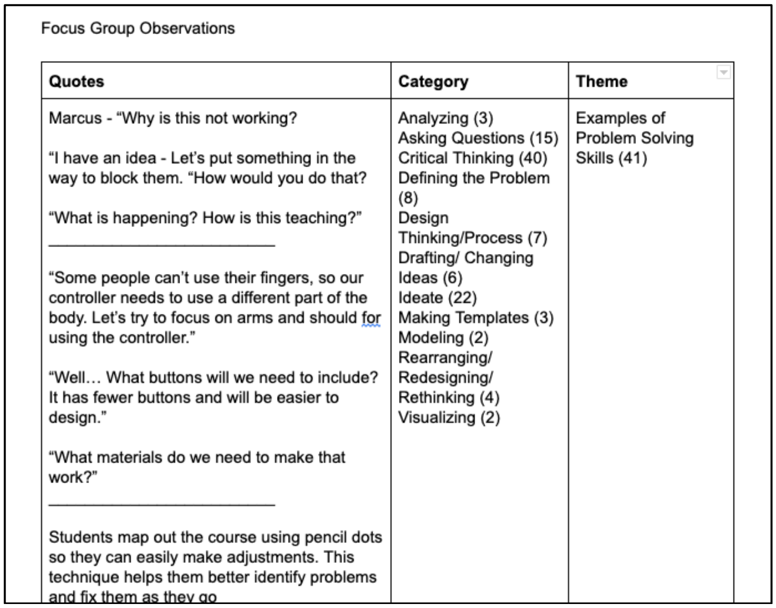


Figure 4.8: Grouping Codes Related to Computational Thinking

Having completed several rounds of the coding process, I began to organize my codes into themes. I created a Google Document Table that identified the important participant quotes and observer comments alongside related categories (see Figure 4.9). This could be likened to Axial Coding, in that I was able to connect some categories and subcategories together and determine their relationships (Saldaña, 2016). I had several subcategories that were listed under more than one category during this process. I also noted the number of codes that were related to each category.

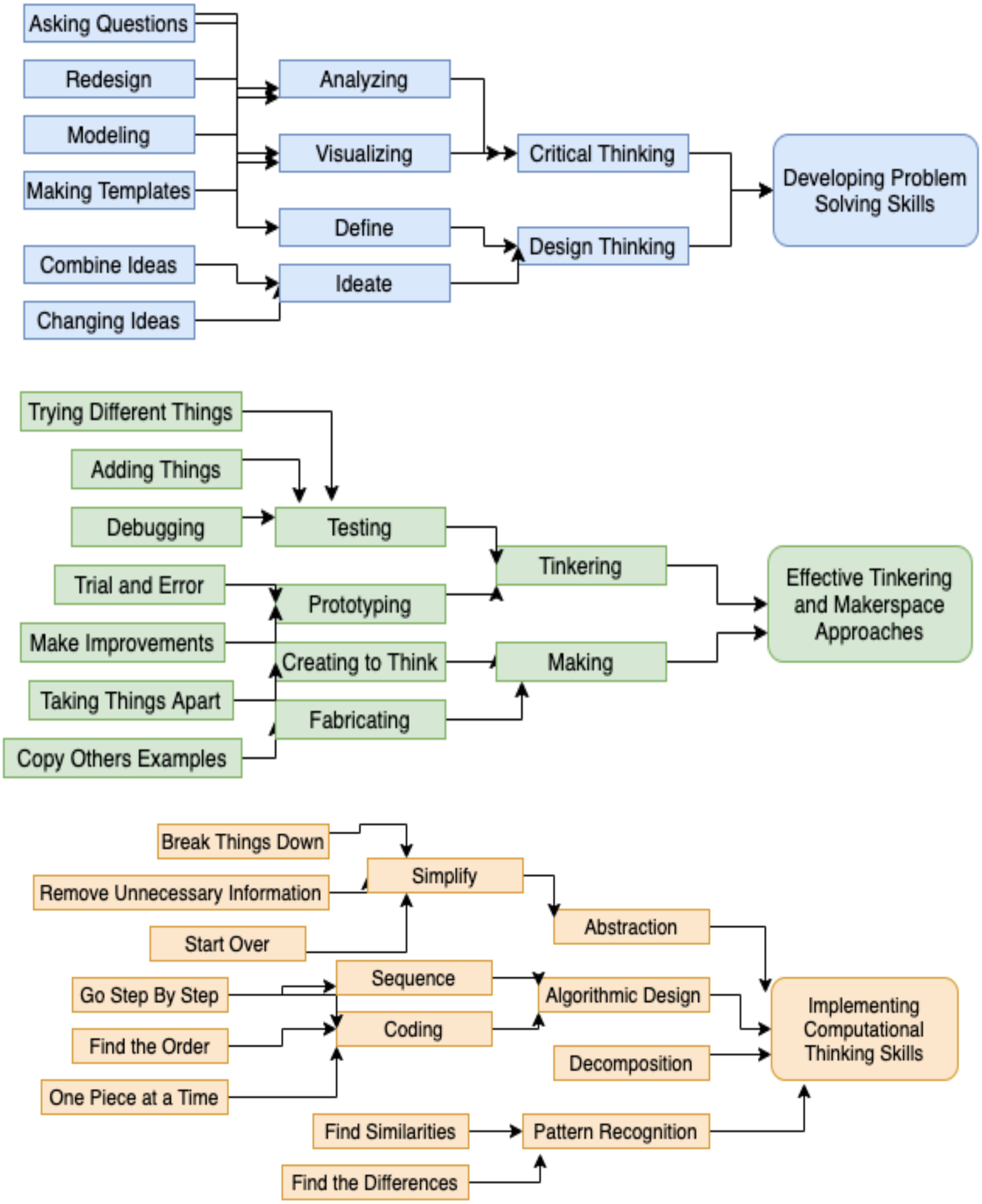


Focus Group Observations

Quotes	Category	Theme
Marcus - "Why is this not working? "I have an idea - Let's put something in the way to block them. "How would you do that? "What is happening? How is this teaching?" ________________________ "Some people can't use their fingers, so our controller needs to use a different part of the body. Let's try to focus on arms and should for using the controller." "Well… What buttons will we need to include? It has fewer buttons and will be easier to design." "What materials do we need to make that work?" ________________________ Students map out the course using pencil dots so they can easily make adjustments. This technique helps them better identify problems and fix them as they go	Analyzing (3) Asking Questions (15) Critical Thinking (40) Defining the Problem (8) Design Thinking/Process (7) Drafting/ Changing Ideas (6) Ideate (22) Making Templates (3) Modeling (2) Rearranging/ Redesigning/ Rethinking (4) Visualizing (2)	Examples of Problem Solving Skills (41)

Figure 4.9: The beginning list of themes from categories

I edited this list of categories several times. Each version began to show more specific themes with categories that supported them. In completing this editing process, I was provided with a better understanding of the themes and categories that were emerging. For example, themes called "Improving student motivation" and "Developing persistence with solving problem" were revised into one theme "Improving motivation and perseverance," because the categories of the two contained interrelated subcategories and codes such as: *staying focused*, *having fun*, and *trying new things*. Additionally, the themes of "Communication," "Teamwork," and "Collaboration" were also combined into the theme of "Issues with communication, teamwork, and collaboration" because the interrelated nature of the quotes and observations comprising subcategories that each contained similar codes such as: *asking for help, understanding each other, dealing with* *frustration,* and *talking as a group*. I continued by creating a flow chart for each of the themes. Figure 4.10 shows the flow from code to category for each theme.



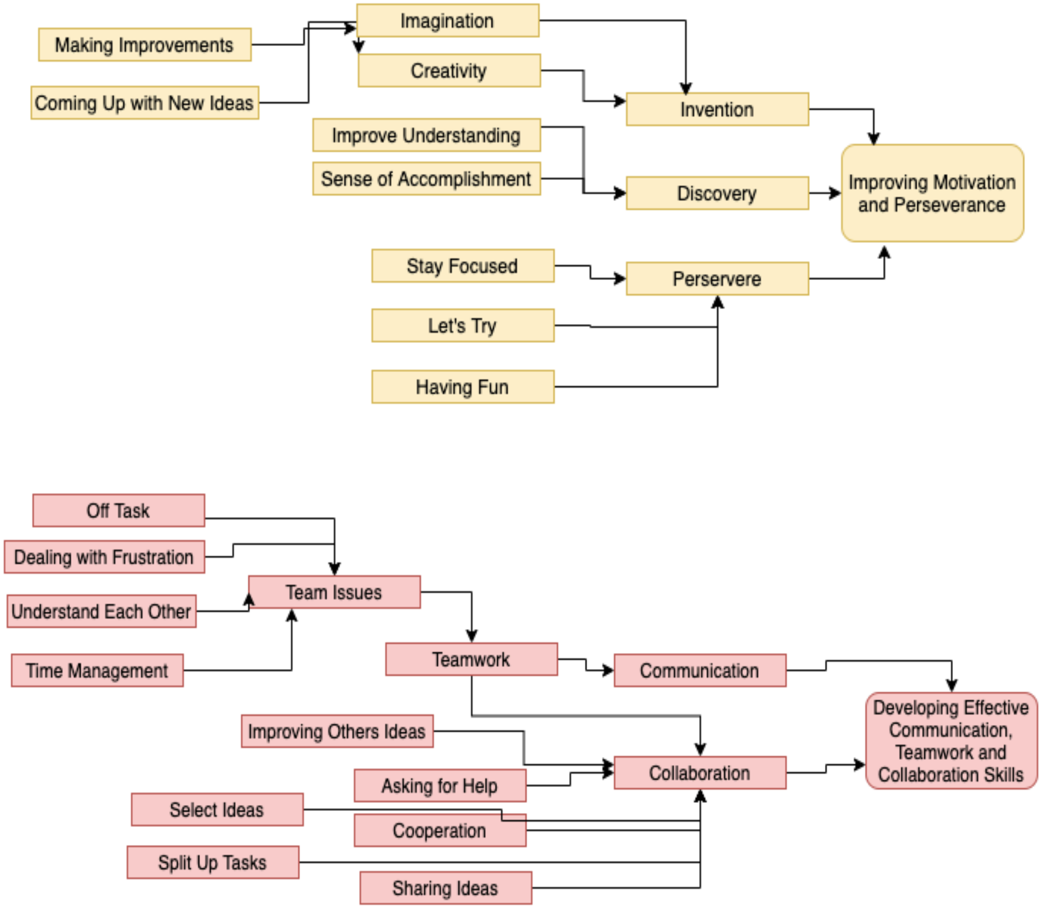


Figure 4.10: Code to Category to Theme Flowchart

Member checking occurred through a meeting with the students who participated in the makerspace innovation. I met with students two months after the end of the afterschool meetings and presented students with the categories and themes I had identified. I shared my interpretations of their actions and words to ensure they were accurate. They commented on the problem-solving skill and the design process they had learned. They shared how the makerspace motivated them to work as a team and showed them that they were creative and capable students.

Themes and Interpretations

Through my observations, participant interviews and portfolio artifact reviews, five themes evolved from the data: 1) developing problem solving skills, 2) effective tinkering and makerspace approaches as a method of thinking, 3) implementing computational thinking skills, (4) improving motivation and perseverance, and (5) developing effective communication, teamwork and collaboration skills (see Table 4.3). Each of these are discussed in detail below. Participants are referred to using pseudonyms for confidentiality. Any quotations are verbatim from participants' verbal interview responses or written reflections.

Developing Problem Solving Skills

Problem solving is an essential component of 21st century skills and connecting these skills to a student's world is an important part in developing abstract knowledge for students (Brown et al., 1989). Since students today live in an increasingly complex society, there is a growing need to develop problem solving skills in schools. Makerspace learning provides the opportunity for students to acquire and produce these skills (Kanbul & Uzuboylu, 2017).

In this study, problem solving is promoted through a connection with design thinking and critical thinking characteristics. Design thinking is defined by this study as a process that helps students implement solutions to problems through creativity, teamwork, and trial and error (Jarret, 2016). Critical thinking is defined as using a set of problem solving skills for why a concept is correct (June et al., 2016). An important aspect of problem solving is to be able to create ideas and find viable solutions for problems. The learning aspects of a makerspace encourage cognitive, spatial, motor, and social skills related to these areas (Bers et al., 2018). The data collected in this study suggest that participants were able to incorporate design thinking and critical thinking processes into their projects. The two categories identified in this theme, (a) changes in

Table 4.3 *Themes, Assertions, and Categories from Qualitative Data*

Theme	Assertion	Categories
1. Developing problem solving skills	Participants were able to incorporate design thinking and critical thinking processes into their projects	• Changes in critical thinking (asking questions, modeling, analyzing, and visualizing) • Changes in design thinking (defining the problem, developing, changing plans through ideating)
2. Effective tinkering and makerspace approaches as a method of thinking	This intervention equipped participants to implement tinkering and making approaches towards solving a problem.	• Effective tinkering characteristics (adding things, copying examples, taking things apart, testing/ trial and error) • Impactful making approaches (building, designing, innovating)
3. Implementing computational thinking skills	Participants demonstrated thinking and actions aligned with computational thinking skills development.	• Participants equipped to encounter opportunities to use abstraction, algorithmic design, decomposition and pattern recognition. • Participants not able to recognize terminology use (breaking things down, going step by step, finding similar and different, finding the order
4. Improving motivation and perseverance	Participants cited multiple improvements contributing to a greater sense of motivation and perseverance than past experiences.	• Positive changes in perseverance (staying focused, having fun, trying new and different things) • Positive changes in motivation through creativity, imagination, discovery and invention
5. Developing effective communication, teamwork and collaboration skills	Participants identified negative examples of communication, teamwork, and collaboration and through the intervention developed characteristics for improving these areas.	• Overcoming team issues (off task, dealing with frustration, understanding each other, and time management) • Effective characteristics (asking for help, improving others ideas, splitting up tasks)

critical thinking, and (b) changes in design thinking are described below.

Changes in critical thinking. One way students developed problem solving skills was by learning to use critical thinking. In this study critical thinking means being able to ask questions, model, analyze, and visualize solutions to a weekly design challenge. Critical thinking is related to problem solving because it involves tasks that require evaluating information to develop knowledge around how to make an effective decision (Nold, 2017). Students will have to use critical thinking to determine if their makerspace project appropriately solves each week's challenge. Students received no formal training in using critical thinking. For example, students did not receive any additional instruction about how to develop or use questioning, modeling, visualizing, or analyzing skills. The school where this study took place did not have any curriculum or instruction specifically in place for these skills. Observational records and interview comments suggest that critical thinking played an important role in how students improved problem solving approaches through the makerspace.

Observational records, artifacts, and interview comments suggest that critical thinking played an important role in how students improved problem solving approaches through the makerspace. Critical thinking skills developed intuitively from groups of students making projects each week. As students tackled the weekly challenges, they encountered situations that supported their own active, persistent and careful considerations (Dewey, 1910). This resulted in the development of critical thinking skills that improved with each new week. An example of this process is evidenced by my observational notes where students developed their own questioning, modeling, visualizing, and analysis skills through the making experiences. For example, during the first week of challenges, Marcus became frustrated and asked "Why is this not working? What is happening? How is this teaching?" Although frustrated, his work with the group continued, and later improved as he and his partner began to develop more effective questioning skills. By the end of the session, the student was asking specific questions about the problem such as, "How do we want this to look?" and Daniel, another student in his group asked, "What parts do we need?" This part of the process led to the creation of a list of materials and later a drawing of what their project could look like.

Critical thinking skills improved each week and became more advanced as the innovation continued. Students learned to use questioning as a strategy for developing models to visualize possible solutions to each week's challenge. For example, my observation records show that by the third week of the innovation students were learning to use models to create maps that visually represent the final product. This skill allowed groups to make adjustments in their projects as they worked. My notes show this was demonstrated with two of the four groups that were using pencil dots to map out a course instead of drawing lines or using a pen. This allowed the groups to make a draft of the final project that they could edit. By having a draft version, the groups could make changes easily.

Interviews of the participants show this same pattern. While students did not refer to critical thinking skill development directly, their comments from the beginning to the end of the innovation demonstrated how their critical thinking skills became more advanced. Early in the study, when speaking about how he solved problems, Marcus commented, "I just kept testing different things until it moved." Later, by week five, his response was more detailed. When speaking about how his group created a video game controller for a person with a physical disability, he said:

> We first talked about what our problem was, which was people who are disabled can't really play this, that much games cause the controllers are only used for people to make use of their hands. And so then we wanted to find a way to make a controller for people who are just disabled so they can play video games too. And so, then we drafted our thinking on paper and then after we discussed and looked at left track, we tried to make it so like we tried to create it and see how it would work.

Marcus' comments are not unique to the experience either. During the course of the study, students regularly used models to develop early drafts to be able to visualize how their project would solve each week's challenge. Students commented on how modeling allowed them to improve how they solved problems. This is best demonstrated when students were using the Ozobot robots to develop a map. Students were able to use the maps to think visually through the problem. By creating a picture they were able to were able to improve the analysis of their design. Students began incorporating this type of critical thinking into their interviews: Taman said, "I was picturing that [the Ozobots] are like little kids walking around the school" and Israel said, "We modeled our design first by creating a map."

Another student reflected on the ways his group became better at solving problems. After developing a machine to deliver worksheets to the class so that teachers can save time in the classroom, Cameron said,

> So, we had to write down all of our ideas that we thought would work and some of the ideas were… make the desk better, or… make the desk bag. And we were like, we couldn't technically do that. And so we had to change ideas. You have to make sure that what you're actually trying to do is something you can do. Right. So that kind of was important to learn. Was there only certain things that we could actually fix?

For Cameron, he discovered a way to use critical thinking to analyze for possible solutions. His remarks demonstrate how the makerspace challenges encouraged his critical thinking to not just develop new ideas, but to also consider the viability of his ideas.

Changes in design thinking. A second way students developed problem solving skills was through the use of design thinking. In this study, design thinking means being able to use the design process steps to solve problems. For this study, the design process included the following steps: ideate, prototype, build, analyze and share. Design thinking is related to problem solving because it demonstrates how to build concrete solutions to complex problems (Douglas, 2016). Since using the free and open nature of a makerspace can be overwhelming, students used design thinking as a process that provided direction for their group work. The components provided students with established procedures of what to do. Over the course of each week's challenge, a different step of the design process was assigned to a different day of the week. Every daily session would begin with a brief class meeting where I would review the design goals for the day. Using the design process became the format for how groups organized their work each week. Observational records, artifacts, and interview comments suggest that design thinking played an important role in how students improved problem solving approaches through the makerspace.

While students initially reacted negatively to using the steps of the design process, over the course of the study they started to integrate the steps more and more. For example, my observational records of the first week show that three of the four groups worked without first taking time to define the problem for the week. As a result, groups did not give much attention to how their projects would actually solve the problem. Students were to design video games using a web-based coding platform called Scratch. The students were asked to develop games to help students study a subject at school. The projects that were shared at the end of the week did not address the learning aspect of the challenge. This was noted by my review of artifacts collected at the end of the week. Of the four protocol reviews that were conducted, two of the games had no connection to a school subject. This later came up during our interview at the end of the week, and the students commented that at the start of the week they didn't see how the design process would help them. Ashlynn recapped the feelings of the group when she said, "At first, we didn't see any reason to use the steps. We just wanted to make something, but as you are doing it the more and more you begin to see that there is a process." Ashlynn recognized that using the design process steps is an important part of the problem solving process.

In following weeks, groups began to better integrate the design process steps into their projects and work. This was most apparent in how groups gave more attention to beginning with the steps of defining and ideating. My observations noted that during these weeks groups were spending more time at the start of each week by asking questions. Groups also started to look at additional possible solutions rather than looking at just the first idea. My observations point out that the groups that began asking questions improved their analysis of the challenge. Having a better understanding of the problem by spending time to define the problem helped students develop better ideas for the weekly challenges. This development was evident when groups began to ask about specific design requirements. Students incorporated this into their discussion while working in the makerspace:

Audrianna: What buttons will we need to include on our controller?

Cameron: Our game will only need to go up and down. I think two buttons will work.

Audrianna: So this is for someone who can't use their finger, right?

Kaiden: Yes, so how large will we need to make the buttons?

Cameron: [Pointing to his elbows] I think they should be about this big. Remember, the controller has to be designed for a different part of the body.

Kaiden: What materials will we need?

Audrianna: I think we can cut this cardboard to make it work.

When students were asking questions about the design considerations for a specific challenge, they developed critical thinking skills. Their understanding of how the design process supported their problem solving grew each week.

Once students developed an understanding for how the design process supported problem solving, students began to develop more than one idea for each week's challenge and began paying closer attention to how using the design process steps. Students noticed that by using the design process steps their approach to solving problem was improving.

For example, Carl said, "At first, we would have trouble coming up with ideas, and our group would just make something. Now, we spend time at the beginning of each week to come up with lots of new ideas." This introduced increased attention to how ideas were evaluated and implemented each week. This changed how students approached building their projects. Over the course of the study, my observational notes point out that groups began to utilize prototyping in more complex ways. One way was this was evident was by how students incorporated the concept of creating project drafts. Students began to refer to the different versions of their designs and discussed ways to make improvements. For example, when working with the LittleBits to design a machine that helped teachers, Israel said, "Wait… we could make the fan part better. We should add something so it can follow a teacher." After this, his group stopped to work out several different ideas for how their robot could drive around a classroom. By the end of the week, their final project had gone through several revisions and looked very different from the original idea.

Having the design process steps showed students how to tackle problem solving through critical analysis. This skill supported the students through all types of problem solving and was later incorporated into their work with computational thinking as well. Eventually, students were able to connect the problem solving ideas into their computational thinking concepts. Their work in the makerspace supported their growth into understand how computational thinking is another type of problem solving.

Using Effective Tinkering and Makerspace Approaches as a Method of Thinking

Makerspaces provide students with the opportunity to learn through experimentation and play (Litts, 2015). This study defines a makerspace as a space for class activities centered on the designing, building, modifying, and repurposing of material objects for play or useful ends aimed at developing some sort of product (Martin, 2015). Additionally, these spaces focus on bringing together the fields of computation and engineering through the skill of tinkering (Blikstein, Kabayadondo; Martin & Fields, 2017). An important part of this study was the students' ability to make effective use of tinkering as well as other makerspace approaches as a learning environment. In particular, this study looked at how students were able to build models, revise ideas, apply skills, and share new knowledge in the act of solving real-world problems. Of key interest was how students valued the process of making as an opportunity to use skills and knowledge as a tool. The data collected provides evidence that this intervention equipped participants to implement tinkering and making approaches that encouraged building, testing and prototyping towards solving a problem. Through the data collected in this study, two categories emerge: (1) effective tinkering characteristics, and (2) impactful making approaches.

Effective tinkering characteristics. One way students developed in the makerspace learning environment was through the use of tinkering as a problem solving tool. Tinkering is defined as improvisational problem solving that draws upon the design process through open-ended design and construction of objects using both high- and low-tech tools (Bevan, Petrich & Wilson, 2014; Bers et al., 2014). According to Derosa (2016), tinkering allows students to develop an understanding of innovation by allowing multiple pathways which encourage diverse ways of thinking. Tinkering is an important part of problem solving because it helps students develop deeper understandings of concepts through design activities (Harel & Papert, 1991). The data presented by this study indicates that the effective use of tinkering can give students a greater sense of control over the learning process. In this project, students used tinkering by building and creating concrete artifacts related to weekly design challenges. This meant utilizing a variety of skills. For the purpose of this study, the skills of tinkering are identified as: (a) adding things to a project, (b) copying examples from other projects, (c) taking things apart to see how they work, and (d) testing out new possible solutions, which was also described as "trial and error."

Adding things to a project. Adding to a project was a popular tinkering skill that supported problem solving. During both interviews and observations, students would refer to adding to a project. I also noted this when describing their physical interactions that solved challenges while making artifacts. My observations made repeated notes of how students tinkered by adding things to a project. Observations during the first two weeks of the project show that this was one of the first tinkering skills used by students. My notes state examples such as, "Kaiden keeps adding more stuff to the project, " "Students in group B are adding an extra controller for their fingers to use," and "Students in group C suggested to add something to the project, since it wasn't working." When students were faced with a problem, one of their first solutions was to try adding on to the project. For example, when Khloe was asked how she was able to get her Scratch game to work during the first week of the study, she said:

> When I was doing the game, most of the things weren't working. So, I had to go back and find more colors to make it okay. When I was working on the Scratch project, it was hard to actually answer it. I had to keep adding more stuff. I just kept adding thing until it started to look right.

When students were using this tinkering skill, they learned they were not always able to use it successfully. This encouraged them to explore other types of tinkering. This developed over the course of the study. Students used tinkering to move beyond a basic design. This lead to a more creative product and added to their ability to think about how they are solving problems. In this way students began repeating the same process each week. They began with an idea and then found ways to start making improvements.

Copying examples from other projects. Some students in the study began looking at examples of how others had designed solutions to the different challenges. They found this helped them with creating a successful design. Groups started each week by defining how they would solve the problem. While working on this step, students were able to research topics by researching ideas on the internet. By doing this, some groups discovered they could develop their own ideas from something that was made by someone else. My observations show that Marcus was the first to try this skill. While developing a video game using Scratch, he spent time looking at examples of games that were posted by other users. My notes stated, "Marcus is copying code from a game he found on Scratch. He is looking at the code and finding sections to copy to his own version of the game." At first other groups asked me, the teacher, if this was allowed. I explained to students that as long as Marcus did not copy the whole program, he could use the game to help him create his own version. By the end of the week, Israel mentioned this as a big part of how he was able to get his program to work, He stated, "I was stuck. I had no idea how to get my game to work. I looked at other games like Marcus, and I found something to add to my game."

Later during the course of the study, groups continued to use copying as a tinkering skill. While designing a project using LittleBits, one group researched ideas for how to build their project using the company's website. They looked at project examples posted by other students. During an interview at the end of the week, Taman stated:

> We kind of like improved someone else's idea. We made it smaller. You are able to do that, because it was already created by someone else. We looked at a different project that helped us figure out how to create a light dimmer for the whole room. We used that idea to wire our whole house. We could get all the rooms to light up using that idea.

While working in the makerspace, finding different methods of tinkering led to new ways of solving problems. Students used tinkering skills to help them think through ideas as they were building.

Taking things apart to see how they work. Another way that groups incorporated tinkering in the problem solving process was by taking things apart. As participants began to see that adding things to a project did not always solve their problem, they began look at other possible ways of getting projects to work. Examples of this type of tinkering are evident in my observations during the fourth week. While working with LittleBits to create a machine to help teachers, one group was stuck trying to get their robot moving. My notes stated, "Students are unplugging things on the robot to find out how the robot should be wired. They are looking to see which wires control the movement." To better understand how the different parts interacted as a whole, groups used tinkering to think about how the pieces come together. Another example of how students used taking things apart during problem solving was evident from Dashay's interview response about getting the LittleBits to light up in a project:

> It wasn't working. Then it did work. Then it didn't work. It wasn't working fully. It was like blinking. We started adding extra stuff, but then we had to take that out. Then we looked at stuff separately and started taking things off. It started to work better. That's when we learned that it was just one little thing that wasn't connected.

Taking things apart led students to a more effective form of tinkering. As their tinkering skills developed, students learned to organize their problem solving in better ways.

Testing out new possible solutions. The final way that students used tinkering to solve problems in the makerspace was by using an approach they called "testing." They often described the role of testing as trial and error. In this study, the terms testing and trial and error are used to describe the same acts of tinkering. This form of tinkering developed from earlier skills and represents a more advanced approach to problem solving. Groups were not observed using this skill until the middle of the study, and students did not refer to these types of tinkering by name until the final weeks of the innovation. My notes show that students began referring to testing while learning to create templates. The first use of templates appeared during the third week, while students created maps for an Ozobot robot to follow. Students found creating the maps to be difficult, and they often encountered problems getting the robot to follow the path and act out their ideas. My notes stated:

> Students are testing out different types of code. They have created a template so they can create multiple prototypes at the same time. By using small slips of

> paper, they can create different sections of the map at the same time. They can also go back and make small changes without having to start over. They are testing each small piece one at a time. When each piece works, they then assemble the completed map.

The use of a template quickly caught on with other groups. By the end of the day, every group had begun to use the technique. By using small slips of paper, students could cover up mistakes. Since they could edit and make changes without having to start the entire project over, this encourage them to test out different ideas. Students commented that this allowed them to improve their designs. Portfolio artifacts reviews from this week also show evidence groups not only began working faster, but their projects started showing increased tinkering, creativity, and invention.

During the study, the use of testing began to combine and replace all other forms tinkering. Students began to describe solving problems while working as "testing" or "trial and error" in the final two weeks of the study. Examples of this are evident from student interviews. During the last week, Adrianna remarked, "We used a lot of trial and error this week. We learned to try something to see if it worked or not." In the fifth week, Kaiden said, "I just kept testing different things until it moved." My observations over the same two weeks point out other examples such as: "Groups are testing the materials to see which works better in the controller," and "Students in group B and C are testing different ways to get the sensor to work." By using testing as a tinkering skill, students were able to find what was working and why things were not working in their projects. This allowed students to identify ways to make changes in a project. Students improved their ability to find and fix errors as they developed better understanding of how different parts of the project interact.

Impactful making approaches. A second way students developed in the makerspace learning environment was through the use of making as a problem solving tool. Making refers to the holistic participatory process that occurs during activities that include the integration of different knowledge skills and contexts (Brahms, 2014; Chu et al., 2015). For this study, making is defined as the active process of building, designing, and innovating with tools and materials to produce shareable artifacts (Martinez & Stager, 2013). At the core of making, students should participate in activities that encourage learners to explore, question, tinker, test and iterate (Davis & Mason, 2016). While tackling problem solving through the exploration of different tinkering skills, students integrated the concepts of making into their learning process. Students often had to integrate the skills of tinkering to match their making experiences. For the purpose of this study, the making experiences that were associated with tinkering are identified as either (a) building, or (b) designing.

Building. Initially, students used tinkering in ways that encouraged building. This was a central task included in each week's challenge. Students were challenged to develop an artifact using the tools and materials provided. The act of building encouraged students to use their hands. Using their hands to solve problems became the essential characteristic of the makerspace learning experience. Students noticed that creating a physical artifact by using their hands had a positive effect on how they solved problems. They enjoyed how the key to each week was coming up with a product. By the end of the second week of the study, students were already commenting on how using their hands to create an invention with the Makey Makey was helpful. For example, the following is an illustration of how students recognized that creating artifacts with their hands helped them solve problems:

Irsael: Putting our hands on the cords of the Makey Makey helped us out.

Kaiden: Yeah, the Makey Makey let us figure things out. Being able to build things and attach the cords helped us figure things out.

Audrianna: It helped me. So, it's like it helped me cause then like when you were talking to us on how to create it, it was like when you were making it then I thought on what you say.

This discussion demonstrates that even at the start of the study students were beginning to recognize how building and creating artifacts can play a key role in solving problems. The creation of the controller improved their thinking about how to solve the problem. My observational notes from the study also indicate that students gained in their ability to solve problems by using their hands to build and create. Once they had their tools and materials in front of them, students would often make improvements during the building process. My notes stated, "Group B sorted their materials, and created buttons. As they were building the buttons, they created holes to hide they wires." This was different from their original plan and solved a problem they were having with how to connect the buttons. When I asked the group about how they solved the problem, Carl said, "We didn't come up with that idea at first. We didn't see it until we had the cardboard and wires in our hands. Once we started placing the wires, it just came to us." They used these experiences to expand their making skills into further areas.

Designing. A second way that students utilized the making experiences of the innovation was through the development of design skills. Designing occurred during the study when students worked on the development of artifacts. Design skills improved as students gained experience and began to utilize templates and prototypes in their creations. Students became more involved with designing towards the end of the study as they became more comfortable with building and tinkering. For example, during the fifth week of the study, my observations noted that groups were focused on making templates. My notes show that students would use the templates prior to building a final project, and that the templates helped them improve how their artifact was made. Additionally, prototyping became a key part of how students designed their projects each week. My observations show that groups started developed different versions of their projects. By creating multiple versions, groups began to make design improvements.

Implementing Computational Thinking Skills

Computational thinking is a necessary problem solving skill for survival in a digital world. Students today need to contend with how to use computers to solve problems. Computational thinking is defined by this study as the thought processes involved in formulating problems and their solutions so that the solutions are presented in a form that can be effectively carried out by an information-processing agent (Cuny, Snider & Wing, 2010). Wing (2011) argues computational thinking is now a universal skill for everyone and not just computer scientists. This means computational skill experiences should be included in the elementary school pedagogy. In this study, computational thinking skills were promoted through the problem solving challenges of the makerspace innovation. An important characteristic of computational thinking is improved critical thinking (Nold, 2017). This involves learning to make effective decisions through analysis, synthesis and evaluation (Douglas, 2016). This study is interested to look at how elementary students implement computational thinking to solve problems in an efficient way. This theme represents how participants in the study incorporated computational thinking in their problem solving. Based on the data collected by this study, participants demonstrated thinking and actions aligned with computational thinking skill development. Through the analysis of observational records and interview transcripts two categories emerged: (a) equipping students with opportunities to address computational thinking, and (b) related student terminology.

Opportunities to address computational thinking. One characteristic of implementing computational thinking involved equipping students with opportunities to experience computational thinking. Students need the opportunity to develop skills and tools to participate in a society where problems are increasingly complex (Norris, 2014). While the participants in the study were not always able to identify computational thinking by name during interviews, their actions suggest they did successfully develop computational thinking characteristics. These characteristics emerged as four subcategories: (a) abstraction, (b) algorithmic design, (c) decomposition, and (d) pattern recognition.

Abstraction. Abstraction involves filtering out the information we don't need in order to concentrate on the necessary details (Grover & Pea, 2013). Students can utilize abstraction while considering how to make a problem easier to think about. This can be expressed by creating a model of the problem. When students remove unnecessary details or make a problem less complex, they are involved in the skill of abstraction (Buitrago

Florez et al., 2017). An example of how students encountered abstraction during the study comes from my observational notes of a group of students considering the materials they will need for their Makey Makey project. While building their project, the students became confused about how to assemble the different pieces they have gathered. Asjia asked, "What materials do we actually need to make this work?" Her group stops to consider which pieces in the pile they will need. They decided to simplify their project because it is too complicated. They changed their plan and began with a simpler design. This was also noted in a separate observation where a group of students was running into a problem getting a program to run their code instructions. They began to simplify their code by removing blocks. This process helped them discover where they had made a mistake. Students repeatedly demonstrated the skill of abstraction by learning to remove unnecessary information. Groups often encountered this issue after adding too much to a project. They begin to reflect more about what pieces they added to a project. My notes point out that groups often learned to sort materials and make piles of what they did and didn't need when a project was not working the way they wanted it to. While talking with a group during the fourth week of the study about their work, I asked about the different piles they had made. Taman stated, "We just had too many things. That was the problem." The process of removing pieces from a project helped students think critically about how they were solving the problem each week.

Algorithmic design. Algorithmic design involves coming up with a set of steps needed to get a solution (Grover & Pea, 2013). Students can engage in algorithmic design when developing a sequence or series of steps to solve a problem. When students express a solution through the process of a series of different steps, they are involved in algorithmic design (Buitrago Florez et al., 2017). An example of how students encountered algorithmic design during the study comes from my observation during the first week of the study. While working on creating their own video games using the online coding platform Scratch, students immediately ran into issues trying to figure out how to get started. My notes indicate that several groups noticed the importance of putting events in the right order by using the following statements, "Where should we start," "We should figure this out first," and "Our game needs to start with a menu. Then we can add different levels to that." In a separate example during this week, a different group encountered a situation involving an opportunity to use algorithmic thinking. While creating a discussion between two characters in their game, two students made a connection with the importance of putting their steps in the right order. While animating their game, the text was not appearing at the correct time. The students solved the issue by inserting new code to pause the text at the right time. When sharing how the problem was solved, Khloe stated, "After I typed in the words for them to talk, I had to add in how many seconds after that person talked to get them in order." In a later week, students experienced the importance of algorithmic design again while using LittleBits to create inventions. While using the LittleBits, students discovered the pieces of the kit will only work when they are assembled in a particular order. For example, my notes from a group of students working on creating an alarm clock show they experienced trouble when their project would not light up. In order to get the lights to come on and off, they had to create a sequence in the right order by putting the input pieces in front of the output pieces. Because they were learning to put steps in a certain order, students experienced solving problems with computational thinking.

Decomposition. Decomposition involves thinking about problems in terms of their parts (Grover & Pea, 2013). Students can engage in decomposition when splitting a problem into smaller sections. When students express a solution by creating sub problems that are more manageable, they are involved in decomposition (Buitrago Florez et al., 2017). An example of how students engaged in decomposition is evident from how students approached using Ozobots to create a school map. During this challenge, students ran into trouble creating a large map all at one time. In this circumstance, my observations noted that two of the four groups started by breaking the map into different sections. My notes stated:

> Group C is having difficulty creating a map for the Ozobot to follow. The robot is following the wrong lines. Their solution is to break the map into different sections. They have divided up the map into four areas. Each student in the group is working on one of the areas. Once they each finish their section, they plan to attach the pieces together.

When faced with a problem that was too difficult to solve, groups adapted their work to break the problem down into smaller parts. This computational thinking skill was supported by their ability to tinker and persevere. Tinkering allowed students to see how making small changes affected the overall effectiveness of their solution. Students demonstrated the use of decomposition in other ways. One way this skill was evident in students' actions occurred as they began to make design improvements by taking apart projects. During the final two weeks of the study, my observations pointed out that students increased their use of prototyping. While prototyping, students would create a version of their project only to take it apart and look for ways to make it work better. For example, during the sixth week of the innovation, one of the groups decided they wanted to make the lights on their project work better. My notes stated, "Group D is removing the pieces of their project. They want to make the light more sturdy. To do this, they remove the pieces in sections." While doing this, the group found a way to improve the lights without having to change the whole project. They created a stronger base for the lights, and then assembled the project back together. Having the opportunity to remove pieces from a project to solve problems is necessary to developing critical thinking. By being able to think of solutions in terms of their parts, students experienced ways to use computational thinking in their work in the makerspace.

Pattern recognition. Pattern recognition involves finding the similarities and differences among problems that enables more efficient solutions (Grover & Pea, 2013). Students engage in pattern recognition when they connect ideas from one problem to support solving another problem (Buitrago Florez et al., 2017). An example of how students used pattern recognition is evident from how students used prototypes to develop their weekly project. By creating prototypes, groups improved how they analyzed their designs. Each new version of their project showed how they would develop projects by looking for similarities and differences as they changed their designs. Besides the use of prototypes, pattern recognition became apparent as students developed ideas by looking at the examples of others. An example of this is evident in how groups approached developing their ideas for weekly challenges. During the initial weeks of the study, students generated ideas for projects using only the members in their group. My observations during the later weeks of the study noted that groups spent additional time researching projects using the Internet. This was apparent when students developed an invention using LittleBits that would help teachers. For example, my notes stated:

> Students are using the LittleBits website to search for ideas. They are using the site's catalog of projects to look for ideas similar to what they want to create. Using the site helps them discover ways to improve their own design ideas.

This example illustrates how students were able to solve problems more efficiently by using pattern recognition. By using outside sources students discovered more about how tools worked and generated more ideas for their designs.

Related student terminology. A second characteristic of implementing computational thinking involved the terminology students used to relate to computational thinking. In this study, students demonstrated the use of computational thinking in their actions and practices of design-based learning activities but were not always able to depict how they used it in their descriptions. As Cameron stated during one interview, "Sometimes you're doing computational thinking and you don't even realize you are doing it." This feeling was reiterated by Audriana who said:

> You can use it even if you don't know you are doing it. Solving the problem is harder without computational thinking. It helps you understand what you are doing better. Without it, you don't understand the problem as well.

Research suggests that computational thinking does not come naturally (Sanford & Naidu, 2016). Developing as a computational thinker takes place in different contexts and different time scales, therefore, assessing the development of computational thinking with young learners should include active conversations (Kafai & Resnick, 2012). The authentic voices of the participants in this study provided a picture for how young learners approach incorporating computational thinking within their problem solving. The interview responses of participants demonstrated that their descriptions of computational thinking used their own inventions of terms. Students describe computational thinking in the following three ways: (a) breaking things down, (b) going step by step or finding the order, and (c) finding similar.

Breaking things down. During their weekly interviews, one way participants described their problem solving was by using the terminology of "breaking things down." This description was included in the majority of weekly interviews and appeared throughout all the interview data for each week. According to the interview transcripts, students used a form of this term 17 different times across the weekly interviews. Students used this term when describing the computational thinking concepts of abstraction and decomposition. Examples of student descriptions of breaking things down include: "You break them down so you can get an easier way through it," "It helps to break lots of things down. It will make better sense to you," and "I broke it down into smaller parts to figure it out." During his interview after the second week of the study, Israel provided an explanation of how his group used this term to create a game controller using the Makey Makey board. He stated:

> To make the controller this week we had to break things down. We had to fix our wires. To find out how to switch things around, I had to organize it. So that's when we took the wires off. It helped us figure out how to fix it.

In this instance, Israel may not be able to directly express how computational thinking was used in problem solving, but his description demonstrates how the practices of tinkering engaged him with the concept.

Going step by step. During their weekly interviews, a second way participants described their problem solving was by using the terminology of "going step by step," or "finding the order." This description was also included in the majority of weekly interviews and appeared throughout all the interview data for each week as well. According to the interview transcripts, students used a form of this term 15 different times across the weekly interviews. Students used this term when describing the computational thinking concept of algorithmic design. An example of how students used this term appears in a discussion from the interview during the third week of the study. When asked how the solved problem, students responded:

> Taman: When we were doing it, we had to make sure we were doing everything all right. It was all mixed up. We had to put it in order.
>
> Carl: We were going to do this and then have it do that, because we didn't want it all mixed up. We had to make sure everything was in the right order. That's when we knew it was not wrong.
>
> Adrianna: It helped because once you had it step by step, you knew do it in a specific order. Then you could see how to solve the problem. Oh, I can use this piece here if I do this.

Students understood that in order to develop their projects they needed to come up with a method that organized their work. Groups learned that creating an order helped them improve their teamwork and designs. This became a key element for how students started their projects each week. Participants described this in a variety of different ways during the interviews. Kaiden said, "Our group always started by finding out what part needed to come first." Jeveah said, "We didn't know how to get started. The first thing we had to figure out was making the sprite go away." Marcus said, "It was always really important to get things in the right order. " The purpose of establishing a step by step order became a key to solving the challenges each week.

Finding similar. During their weekly interviews, a final way participants described their problem solving was by using the terminology of "finding similar." This description was also included in many of the weekly interviews and appeared throughout most the interview data for each week as well. According to the interview transcripts, students used a form of this term 12 different times across the weekly interviews. Students used this term when describing the computational thinking concept of pattern recognition. An example how students incorporated this skill into their problem solving was evident during the fifth week of the study. A group was observed looking at LittleBit project ideas on the Internet. Their group found a similar design to the circuit they were making and changed it to work with their project. During an interview that week, the students in the group mentioned this was a key step in figuring out how to build their project. Students in the group spoke directly about how this affected their project:

Taman: We had trouble getting our project built this week. We wanted a fan on our robot, but we didn't know how to do it.

Dashay: We had to come up with something that would work, but we didn't have any ideas of what to do. We looked at the website and found a project similar to ours.

Taman: That project showed how to build a heater using the bits. We decided to take that idea and change it into a fan.

Overall, students refined their approach to problem solving week by week. The use of computational thinking increased by their understanding of concepts. The understanding of these concepts is demonstrated by the data collected in this study. Students show the development of these skills in their practices as well as their own perspectives.

Improving Motivation and Perseverance

The use of hands-on activities, such as the experiences found in a makerspace, have been found to increase student engagement (Brown et al., 1989; Carroll et al., 2010). Studies have suggested that by improving student engagement, student performance can be significantly improved (Chu et al., 2015; Cetin-Dindar, 2016). Despite regularly running into failures and mistakes, students in this study reported feeling more engaged and motivated to learn. Student motivation is defined as a process where the learners' attention becomes focused on meeting their scholastic objectives and their energies are directed towards realizing their academic potential (Joslyn et al., 2016). Additionally, the learning characteristics of a makerspace have also been found to encourage persistence and passion (Ryoo et al., 2015). The variety of tools and distinct challenges of a makerspace require energy and resourcefulness. These traits sustain students through difficulties and deepen their commitment to the learning process (Lahana, 2016). Students in the study routinely demonstrated a positive attitude towards overcoming coming frustrations and developed strong traits of perseverance. Perseverance is defined as the ability to see failure as a positive learning experience and empowers the student to try and try again until the learning goal is attained (Blikstein, 2013). This study is interested to look at how makerspace learning experiences affect elementary students' perceptions of motivation and perseverance. Participants cited multiple improvements contributing to a greater sense of motivation and perseverance than past experiences by improving understanding, developing a sense of accomplishment, and a desire to learn more through discovery. Based on the data collected by this study, participants demonstrated thinking and actions aligned with positive growth in the areas of motivation and perseverance. Through the analysis of observational records and interview transcripts two categories emerged: (a) positive changes in perseverance, and (b) positive changes in motivation.

Positive changes in perseverance. One category of this theme involved positive changes towards feelings of perseverance. Part of the process of working in a makerspace is learning to deal with and overcome repeated failures. Because students are working in an environment that encourages failing and trying again, students are more likely to work through frustration while achieving their goal (Blikstein, 2013). In this study, observations and interviews collected indicate that students increased their perspectives towards perseverance. In regard to this positive change, the data suggested that three characteristics of perseverance in a makerspace emerged: (a) staying focused, (b) having fun, and (c) trying new and different things.

Staying focused. Participants shared that focusing on a problem helped them achieve their goal each week. An example of staying focused from this study is students continuing to develop a map using Ozobots despite repeated failures. During the third week of the study, students ran into many types of failure designing a path for their robots to follow. Working with the Ozobots presented several issues. Students had difficulty drawing a line clearly so their robots would follow a path. They also had a hard time using the color codes. Getting the colors in the right order and drawn to the right size required careful work. Observation notes from this week state, "Group A is starting over because their robot keeps going the wrong way," "Group C is not able to get their Ozobot to follow the turbo code," and "Groups are asking for extra sheets of paper so they can start over." Despite the many issues with designing a map using the Ozobots, every group stayed focused on the challenge. Eventually, every group developed a technique to deal with the issues. Student interviews at the end of the week show evidence of how they persisted through these failures. For example, Adrianna expressed the following:

> There were lots of problems using the Ozobot this week. We had to find a way to work around them. It made you think harder. I stayed focused because I had to think of a way to get the robot to move the right way. We had to come up with a new idea about how to get the Ozobot to go around. It took several tries, but when we started using small slips of paper to fix our mistakes, it started working better.

Working on a task that kept them focused on a goal supported the students as they worked through failures. In addition to the previous example, students reported on staying focused in other ways as well. One way this was expressed was in describing their frustrations. One statement that was noted was, "I started to get frustrated, so then I tried making little improvements." The students learned to grapple with situations when their ideas didn't work out. To reach their goal they had to develop new methods and ideas.

Having fun. A second characteristic that supported students in developing a greater sense of perseverance in a makerspace was being able to have fun. This characteristic came up during student interviews across several different weeks. Participants shared they could handle frustration and failure as long as they felt they were having fun. The makerspaces tasks were designed to include real-world examples using new tools and experiences. One example of how students used having fun to overcome frustrations occurred as they spent time exploring the tools each week. Even though students had a specific goal to accomplish during each challenge, groups began a habit of spending some time at the start of each week exploring the new tools and materials presented at the start of the challenge. My observation notes demonstrated this during a conversation with a group using the LittleBits during the fourth week. The group expressed their feelings about having fun in the following:

Cameron:	We decided to just play with the LittleBits for a minute.
Israel:	We don't want to start the project yet. We like to see what neat things we can make.
Layke:	I noticed how to make a box light up. [Cameron] is making a thing that claps.
Israel:	Yeah, I like to see what tricks we can get it to do.

By exploring the materials prior to starting the weekly challenge, groups develop a greater sense of how the tools worked. By having the opportunity to have fun prior to engaged in problem solving, students were more likely to develop a variety of ideas. Having lots of ideas supported their ability to persevere through frustration and failure.

Trying new and different things. A third characteristic that supported students in developing a greater sense of perseverance in a makerspace was being able to try new and different things. This characteristic came up during student interviews across several different weeks. Participants shared they did not mind mistakes, because they felt it was a part of trying out new and different ideas each week. An example of how students persevered by trying new and different things comes from the weekly interview after the second week of the study. While discussing the use of the Makey Makey to invent a game controller, students reported on how they dealt with problems when the controllers would not work. Taman said, "Our first try didn't work out. We had to find another way to do it. We had to like find another way around to do it. Because we learned to try different things, it wasn't frustrating." She reflected on how her group kept working at their task even though the project was not working. Taman's group overcame their problems by focusing on new ways to organize their work. Khloe said, "I don't be disappointed just because there's like one little mistake." The group's response to frustration was also noted in my observations of their work that week. At the beginning of the week, my observations stated, "Group A is having trouble getting their controller to connect with the Makey Makey. They are looking to figure out why it's not working." Later during the week, I noted, "Group A is now going back and trying some new ideas for their controller. It is now working." The students were successful despite having initial set backs. They appear to find failure as a natural part of solving problems. They are not bothered by having to develop new ideas in order to fix mistakes.

Positive changes in motivation. The second category of this theme involved positive changes towards feelings of motivation. Research suggests that student learning is affected by student's motivation (Bandura, 1997). When students develop the capability to be self-efficacious towards their work, they will become more engaged in their effort towards learning new material. For meaningful learning, students should be motivationally engaged in the process as well as cognitively and behaviorally (Linnebrink & Pintrich, 2003). In this study, observations and interviews collected indicate that students increased their perspectives towards motivation. In regard to this positive change, the data suggested that two characteristics of motivation in a makerspace emerged: (a) creativity and use of imagination, and (b) a sense of discovery and invention.

Creativity and imagination. An initial characteristic that supported students in developing positive changes in motivation in a makerspace was the use of creativity and imagination. The process of solving problems in a makerspace requires exploration beyond engaging in a rote series of steps (Sheridan et al., 2014). Creativity has been identified as a key learning skill needed for students to be successful in the 21st century (Partnership for 21st Century Learning, 2016). Creativity is encouraged when students are led to new discoveries through the process of innovation (Austin, 2017). The use of creativity and imagination was increasingly referenced by students during the study. While creativity was not mentioned by the participants during the first two weeks of interview, their discussions after the third week showed they began to see value in creativity as an important part of the makerspace experience. One example is demonstrated by the way students mentioned the desire to be unique and different. Carl reflected on how creativity motivated his work, while talking about how his group developed a map using the Ozobots in the third week of the study. He said, "Being able to do tricks helped you be creative with your map." He liked that his project was unique and different, since his robot performed movements other groups did not use. While Carl was the first to mention the importance of creativity, this touched off comments from others in the study. Many students agreed with Carl's view on creativity. During this same interview, Kaiden discussed the importance of expressing her personality. She said, "The colorful things helped me be creative. I liked being able to make my project unique using colors no one else used." Cameron added to this as well by when he stated, "The colorful things showed us we could be creative. I liked finding a way to make my map unique." Students demonstrated this focus throughout the rest of the study. My observations noted that students made it a point not to create something like the invention of another group. They purposely cultivated projects so that their solutions were not the same. Creativity became a purposeful aspect of their work.

A sense of discovery and invention. A second characteristic that supported students in developing positive changes of motivation in a makerspace was a sense of discovery and invention. Discovery prompts learners to try out new ideas and encourages the creation of new skills (Sheridan et al., 2014). This process is linked to the central experiences of a makerspace through the process of figuring things out in playing with the available tools and materials. At the same time, by focusing on the development of a product, innovation and inventiveness are fostered by the tools and materials of the space (Ito et al., 2010). The role of discovery and invention is evident from my observational notes during the final week of the study. During this week, students identified their own problems and selected any combination of tools and materials from previous weeks to build a product. Rather than providing students with a predetermined problem and selected tools and materials, this challenge opened up a new set of possibilities for the groups. The open-ended self-directed work during this week engaged students in deeper levels of discovery and invention. For instance, two of the four groups decided to combine tools from previous challenges in new ways. My notes describe the groups discovering how to combine the use of the LittleBits circuits with the Makey Makey controllers. By the end of the week, one group was also combining the use of a program made in Scratch. Over the course of the week, participants in these two groups organized parts from different kits and discovered new ways to get them to work together. As Audrianna described her group's work, "We wanted to come up with something new and fun. We said let's try it this way, and it just worked." Layke stated, "We wanted to make our robot work better. Adding the Makey Makey to the Littlebits helped us do that." Their group started with a simple design using the LittleBits. The group used motors and switches to control lights but made a more complex design by adding a Makey Makey. They figured out how to make their robot talk using the touch sensitive features in combination with a program in Scratch. Their design process demonstrates how invention and discovery play a key role in the building motivation.

Developing Effective Communication, Teamwork, and Collaboration Skills

A key aspect of the learning environment in a makerspace is the support it provides for the development of collaboration skills (Bevan et al., 2014; Blikstein, 2013). Additionally, research suggests making experiences can play a vital role in providing students the opportunity to experience in developing complex designs that encourage computational concepts beyond programming (Kafai, 2015). This study defines collaborative learning as the joint intellectual effort by students, or students and teachers together where students are working in groups of two or more, mutually searching for understanding, solutions, or meanings, or creating a product (Sheridan et al., 2014). An important part of this study was the students' ability to integrate collaboration into their problem solving. In particular, this study looked at how students were able to demonstrate effective communication skills and teamwork habits. Participants began by identifying negative examples of effective communication, teamwork, and collaboration and later developed effective habits to overcome these issues. Through the data collected in this study, two categories emerge: (1) overcoming team issues, and (2) effective characteristics of collaboration.

Overcoming team issues. One way students encountered issues with collaboration, teamwork and communication was by learning to overcome issues within their teams. Research suggests that when students are involved with multifaceted design spaces, such as a makerspace, students encounter issues with teamwork as they combine knowledge and skills (Kangas, 2011). As students work together to create and share design ideas, making joint decisions became a key roadblock. For students to move forward with the development of collaboration skills, they must learn the importance of how their group can all contribute, maintain focus, and share tasks (Kangas, 2011). In this study, observations and interviews collected indicate that students were faced with overcoming several issues with working as a team. In regard to this, the data suggested that four characteristics of overcoming team issues emerged: (a) off task behavior, (b) dealing with frustration, (c) understanding each other, and (d) time management.

Off task behavior. An initial characteristic that students addressed in overcoming team issues was dealing with off task behavior. Understanding how to address situations where a group members off task behavior affected others became an immediate problem during the first week of the study. Because they felt students in their group were off task, some participants were unable to work as a team. Groups all approached this problem differently. Sometimes groups avoided the problem and each group member worked in isolation. My observations notes show that it did not take long before groups asked me for help in dealing with a group member that was not on task. Students became upset when someone was not helping with the project. An example of students encountering off task behavior is shown from the student interview at the end of the first week:

Taman:	Too many people were playing in our group. So I decided not to work with them. I did my project on my own, since they were all playing.
Cameron:	It was hard working with so many different people. We had five people in our group. Not everybody got along. We couldn't talk about solving the problem as a group because people were playing. We ended up splitting up and working on things separately.

This example illustrates that when faced with someone in their group that was off task, students preferred to work by themselves.

Dealing with frustration. A second characteristic that students addressed in overcoming team issues was dealing with frustration. As students worked to develop solutions, they began to encounter problems with getting tools and materials to work. Interviews and observation during the second and third week of the study demonstrate that learning to deal with frustration became a critical aspect of developing collaboration skills. My observation notes during the second week of the study show that two groups encountered issues with frustration. They stated, "Group A has stopped working today. They are not sure how to get the Makey Makey to connect. They have stopped talking to each other," and "Group C is having trouble getting the wires to connect. Two group members are sitting and not talking with the group." This was also illustrated during the interview for the third week of the study. While reflecting on the hardest part of the challenge, Marcus shared:

> I really got frustrated this week. Things did not work the way we wanted them to. It was really hard because no one listened. Our teammates all had different ideas. We could not figure out which one to use. We ended up yelling at each other. Figuring out how to get everyone to work together was hard.

Students struggled to work as a team when problems developed. When groups became frustrated, this illustrated the importance of good communication. These examples show how student struggled to communicate when facing issues that lead to frustration.

Understanding each other. A third characteristic that students addressed in overcoming team issues was understanding each other. As students discussed ideas and possible solutions, they experienced difficulty explaining and listening to different ideas from different group members. This characteristic was often observed in combination with other team issue problems. When group members had trouble understanding each other this could lead to frustration as well as off task behaviors. An example of how understanding each other affected groups is evident from my observational notes during the first week of the study. My notes stated, "One group has become frustrated and stopped working. One group member has an idea that no one else understands." This difficulty indicates the importance of effective communication. This is also evident from notes from the third week of the study which quoted a discussion I had with a student who wanted to quit working with his group. While trying to share an idea for his group's project, Carl became upset and walked away from his group. In order to help his group, I spoke with Carl and asked him about his problem. Carl stated:

> My teammates all have different ideas. I keep trying to show them my idea, but no one seems to understand me. Then they get angry or mad at me, if I tell them I don't want to try their idea. There are a lot of ideas and the group doesn't know how to figure out which one to go with.

The struggles these students were experiencing with communication show the importance interpersonal skills play in group problem solving situations. During this period of the study, one participant shared the effect this was having on her personally. Khloe stated, "I was stressed out because my teammate is a perfectionist. She wants everything perfect. I felt bad every time I did not understand what she wanted me to do." As Khloe made this comment during the group interview, many other participants expressed feeling the same way. In what served as a key moment in learning how to better understand each other, Javeah reflected by sharing:

> You have to be more specific when you are dealing with lots of other people. This is because they don't know what you mean sometimes and that you have to slow down. Like even if you get it, you have to like wait for other people to get it. You can't just rush. You have to break problems down, so it's not as hard. Then if you break them down, you can get like the easier way out of it instead of rushing through it and getting like the wrong answer.

As the study moved forward, groups appeared to implement this idea in their discussions each week. My notes indicated fewer problems with communication, and interview comments from later weeks in the study noted how groups did a better job talking with each other.

Time management. A final characteristic that students addressed in overcoming team issues was time management. The weekly challenges meant students were expected to develop a product within a specific time limit. This factor meant groups needed to deal with problem solving under specific time constraints. Collaborating under these conditions was difficult for the groups in the study. In this study, students regularly expressed concern for how their groups would deal with the issue of time. Handling time management came up often during the first three weeks of the study. For example, students mentioned concerns about time during interviews for these weeks. Ashlyn stated, "We didn't have enough time to do it in one day." During a separate interview, Carl reflected, "We spent the rest of our time designing our bonds and what it's going to go in and how look so we wouldn't have to do everything in one time or space it out over just two day." In another instance of time management issues, Taman stated, "We had trouble trying to do it all in one day. We ended up finding a way to do one thing on each day." As students began to find ways to spread out the tasks of their project, time management became less of an issue. Time management was not mentioned as an issue with collaboration during the final weeks of the study.

Effective characteristics of collaboration. The second way students encountered issues with collaboration, teamwork and communication was by developing effective collaboration skills. Research suggests collaborative interactions are characterized by shared goals, and a high degree of negotiation, interactivity, and interdependence (Dillenbourg, 1999). Interactions producing elaborated explanations are particularly valuable for improving student learning (Bevan et al., 2014; Blikstein, 2013). The interactions that took place in this study encouraged development of skills such as coordination, communication, conflict resolution, decision-making, problem solving, and negotiation. The ability to collaborate is an important outcome of education. The Partnership for 21st Century Skills (2008) has identified collaboration as one of several learning and innovation skills necessary for post-secondary education and workforce success. As students work together in this study, they developed their own strategies for overcoming team issues. These strategies formed the basis of developing effective communication, teamwork and collaboration skills. In this study, observations and interviews collected indicate that students were successful in achieving these goals. In regard to this, the data suggested that three characteristics of effective collaboration developed: (a) asking for help, (b) improving other ideas, and (c) splitting up tasks.

Asking for help. An initial characteristic of effective collaboration that students demonstrated was asking for help. Where participants were observed working in isolation over the first few weeks of the study, groups began to change this habit towards the final weeks. Observational notes show that one key change in teamwork developed when participants began asking others in their group for help with their projects. During the third week of the study, my notes stated, "Taman asked Carl to help her cut a cardboard piece for her project." This marked a major change in how her team worked on projects. Prior to this event the group developed projects separately. Later in an interview, Carl reflected on how this changed the way his team collaborated. He shared:

> Our group began to make lots of progress this week. I think we learned to work together better. When Taman asked me for help, I was able to help her out. I saw how if I helped her that she could get more done. She was not able to cut the

> cardboard as well as I could. When I cut things for her, she was able to build her project.

Other groups soon followed Taman's example. Asking a group member for help was observed by two more groups during the fourth week of the study and by the final week it had become a regular collaboration skill used by every group.

Improving other ideas. A second characteristic of effective collaboration that students demonstrated was improving other ideas. Once the members of a group learned to collaborate by asking each other for help, the participants began to improve their communication. While helping group members, participants began to share ideas. As students started to share ideas, they improved how they communicated with their group. One way this occurred was by sharing projects ideas. As students shared their ideas, they began offering suggestions for how to make improvements. As participants began offering ideas for making improvements to individual projects, groups started to combine ideas into a single shared project. For example, one group spoke about how they learned to collaborate during an interview after the third week:

> Cameron: At first it was hard for us to work in a group. We had to learn to cooperate.
>
> Carl: We solved it because we worked together this week. I didn't know how to do it all, but when I started working with the other people in my group, I started to get it.
>
> Cameron: When I saw what Carl was doing, I realized his idea was like mine. We decided to build our project together.

Other groups demonstrated this same sort of behavior. My observational notes in later weeks identified other examples of discussions leading to shared project ideas. My notes stated, "Taman and Dashay are discussing ideas for creating a game that mixes their two ideas for a math game that takes place in outer space," " Israel and Marcus are sitting together to play Israel's game. Marcus shares a way for Israel to improve his game. They start to develop a project together that includes these features," and "Group C is sitting together and writing a list of the pros and cons of each project idea they have. They use the list to decide on which idea has the most direct path." As students incorporated ways to improve the different ideas they each had, groups started solving problems together. Rather than working in parallel to create a project, groups demonstrated that they could work together on the same task.

Splitting up tasks. A final characteristic of effective collaboration that students demonstrated was splitting up tasks. Once the members of a group learned to work on a shared project idea, they developed strategies to work more efficiently. The most common approach that groups demonstrated was by splitting up tasks. Examples of how groups incorporated splitting up tasks was evident from their interviews. Ashlyn stated, " We had two ideas, so we had to split up who worked on each part." Taman stated, "We decided to do one part of the project and had the boys do the other part." Adrianna also described how her group improved communicating, "We had to cooperate. We saw what they parts were and talked about what parts we were willing to do for the project." Marcus explained about how his group worked better by dividing up tasks, "Well, we solved it because we worked together, but it was hard to work in one group. We decided it would be best to split up different parts." The stories from these students validate the importance of splitting up tasks to improved collaboration. The participants improved their teamwork, communication and collaboration, because they implement strategies that allowed them to work together on a shared project.

Chapter Summary

For this study, quantitative and qualitative data were collected. Quantitative data included the Computation Thinking Skills questionnaire. Qualitative data included semi-structured participant observations, semi-structured focus group interviews, and participant artifacts. Five themes emerged from the data: 1) developing problem solving skills, 2) effective tinkering and makerspace approaches as a method of thinking, 3) implementing computational thinking skills, (4) improving motivation and perseverance, and (5) developing effective communication, teamwork and collaboration skills. The analysis of the data and creation of themes helped me understand the outcomes of the study.

CHAPTER 5

DISCUSSION, IMPLICATIONS, AND LIMITATIONS

This chapter positions the findings within the existing literature on the impact makerspace learning experiences have on the development of computational thinking. The purpose of this study was to evaluate the implementation of making experiences to support computational thinking through the implementation of makerspaces for fifth grade students in an elementary school in South Carolina . Six primary themes emerged from the data analysis (see Table 4.3). Data from both quantitative (i.e., CTS questionnaire) and qualitative methods (i.e., participant observations, participant interview, and participant artifacts) were collected and subsequently analyzed. This chapter will present (a) a discussion, (b) implications, and (c) limitations.

Discussion

It is important to situate this study's findings within the larger literature, particularly the literature associated with makerspace learning experiences and the development of computational thinking. To answer the research questions, the data were combined and viewed through an understanding that technological education must include the development of computational fluency since students today need innovation skills for work environments that don't yet exist (Grover & Pea, 2013). Literature on makerspace learning and design thinking also contributed to understanding conditions that facilitate developing makerspaces and making as possible school learning environments. This discussion is organized by the three research questions.

Research Question 1: To what extent will the implementation of a makerspace improve computational thinking skills for fifth grade students at an elementary school in South Carolina?

Computational thinking skills allow students to use technology to solve problems by developing and testing possible solutions (ISTE, 2016). While computational thinking was once only considered a skill for engineers and programmers, research suggests these concepts have become a necessary skill for all students (Aho, 2012; Barr et al., 2011; Barr & Stephenson, 2011; Brennan & Resnick, 2012; Cuny et al., 2010). In this study, computational thinking was integrated into makerspace learning experiences as a means of problem solving. To design an effective makerspace learning environment, I referenced existing research that identified a number of different necessary components. These included the following: identifying problems, building models, applying skills, revising ideas, and sharing new knowledge (Sheffer, 2018; Hira et al., 2014; Kafai, 2018; Moorefield-Lang, 2014; Sheridan et al., 2014). These makerspace learning components were connected to Chen, Shen, Barth-Cohen, Jiang, Huang, and Eltoukhy's (2017) computational thinking framework for elementary students that identified the following six dimensions: (1) formulating problems in a way that machines can help to solve, (2) processing data in a logical way, (3) representing data abstractly, (4) algorithmizing the automated solutions, (5) solving problems in an efficient way, and (6) transferring knowledge and skills in solving other problems. Answering research question one, participants improved computational thinking due to (a) effective tinkering and making approaches, (b) practices that fostered computational thinking opportunities, resulting in (c) terminology aligned with computational thinking development.

Effective tinkering and making approaches. Although the research on making as an educational practice is relatively new, it has begun to document the ways in which maker activities support the development of productive learning (Bevan & Petrich, 2014; Blikstein, 2013). If implemented effectively, making has been found to have a powerful potential for young students in STEM fields (Vossoughi & Bevan, 2014). Research into the maker mindset suggests that when the socially-determined practices of a makerspace are situated within a given activity setting, students are more likely to integrate different knowledge skills (Brahms, 2014; Chu et al., 2015; Litts, 2015).Within the act of making, an important aspect centers on the improvisational problem solving that takes place while students tinker or play. Tinkering engages students in an iterative design process that encourages students to increase performance by focusing on the process that allows students to get to the end product (Martinez & Stager, 2013). Research suggests tinkering develops deeper understandings of computational thinking concepts through design activities (Harel & Papert, 1991; Kafai, 1995; Resnick, 1998; Papert, 1993; Resnick & Rosenbaum, 2013; Soloway et al., 1994). The tinkering mindset supports students in developing an understanding of how to approach solving real world problems (Lundberg & Rasmussen, 2018). Effective tinkering and making approaches developed better understandings of (a) the design thinking process, and (b) an enhanced focus on the end product, and (c) integrating computational thinking into problem solving.

The design thinking process. Qualitative data collected by this study shows that students were able to demonstrate effective tinkering characteristics alongside the use of the design thinking process. The act of tinkering allowed students to demonstrate new and different knowledge skills through the steps of design thinking. Over the course of the study, student observations and interviews showed that students used tinkering as a way to develop improvements in their projects. In this way, design thinking supported their building, designing and innovating. For example, students showed increased attention to defining the problem over the course of the study. My observations show that students spent little time considering the design aspects of the challenge during the first week of the study. This resulted in many Scratch projects that did not include a learning aspect to the game that was developed. This changed over the course of the study. Later, in the third week of the study, I observed students spending more time considering how their project would connect to the challenge. For example, my notes show that several groups demonstrated how asking questions improved their designs. Audrianna's group spoke about this during their group work:

Audrianna: What buttons will we need to include on our controller?

Cameron: Our game will only need to go up and down. I think two buttons will work.

Audrianna: So this is for someone who can't use their finger, right?

Kaiden: Yes, so how large will we need to make the buttons?

Cameron: [Pointing to his elbows] I think they should be about this big. Remember, the controller has to be designed for a different part of the body.

Kaiden: What materials will we need?

Audrianna: I think we can cut this cardboard to make it work.

Later in the study, students utilized these questioning skills towards designing and innovating. For example, observations from the third and fourth week of the study show that students were using templates and prototypes to consider making design changes and improvement to their artifacts. Observations of students in the fifth week of the study noted, "Students are spending more time this week creating new versions of their projects. They are finding problems with their projects and going back to solve the issues they find." Design thinking helped students to work as problem solvers. Their understanding of how the design process supported their problem solving grew each week. This was demonstrated as groups changed their approach to coming up with an end product.

An enhanced focus on the end product. Focusing on enhancing the end product helped students as they tinkered. Students used tinkering and making as a way of building, designing, and innovating a shareable artifact each week. Being able to use their hands to create an end product each week was a key characteristic in how students perceived themselves to use tinkering. Interviews of the students show that they first made connections to tinkering and making as a hands-on method of problem solving. During the first and second week of the study, students shared that a key characteristic of their problem solving was being able to build things with their hands. For example, during their interview at the end of the second week, students commented that an important component of their work was being able to build things using the Makey Makey. Their discussions at the end of the week show that students were able to recognize that creating an artifact helped them to think about solving the problem. For example, students mentioned this as the biggest factor of their problem solving in the first week of the study. Carl spoke for the group when he said, "I was able to solve problem because I used my hands to make something." Martinez and Stager (2013) and Lundberg and Rasmussen (2018) found similar results that when students focused on making an end product, they became more aware of how they solved real world problems.

Integrating computational thinking into problem solving. Additionally, students showed a change in how they implemented and used tinkering in increasingly complex ways over the course of the study. This occurred as they integrated computational thinking into their problem solving. As Bevan and Petrich (2014) found, tinkering activities support students in becoming more capable problem solvers because they encounter diverse ways of thinking. These participants were encouraged to development of computational thinking skills. This demonstrated as students learned to test out possible solutions. Testing for possible solutions helped students develop deeper understandings of concepts through design activities (Harel & Papert, 1991). For example, when students first started in the study, they were observed engaging in tinkering activities included adding things to a project and copying examples from others. These skills were later developed into more complex forms of tinkering that the students described as "testing things out," and "trial and error." Student became more diverse problem solvers as they developed a variety of tinkering skills. For example, while creating maps using Ozobots during the third week, students used tinkering to develop and test out a number of different possible solutions. This was demonstrated by how students approached the problem by developing prototypes so they could explore multiple solutions. For example, Israel referred to creating a template so his group could "make small changes without having to start over." This corroborates the assumption that tinkering supports students in becoming better problem solvers (Harel & Papert, 1991) Because these participants perceived themselves to be developing tinkering skills, they improved their problem solving throughout the study.

Practices that fostered computational thinking opportunities. The development of improved problem solving through effective making approaches and tinkering was linked to practices that fostered computational thinking. One connection critical to the development of computational thinking was providing young students early opportunities to engage in computational concepts and practices (Brennan & Resnick, 2012). Yadav, Hong, and Stephenson (2016) posit that since computational thinking focuses on problem solving; it can be fostered by practices using designing processes. In this study, students practiced these computational thinking constructs which were embedded into the design processes of the makerspace. Observations and interviews show that students' actions towards computational thinking practices increased over the course of the study. This suggests these ideas can be successfully addressed in a makerspace learning environment. In order to focus on computational thinking development, students need experience participating in solving problems that demonstrate the following actions: (a) abstraction, (b) algorithmic design, (c) decomposition, and (d) pattern recognition (Shen et al., 2017).

Abstraction. Abstraction was one computational thinking practice fostered by problem solving. Abstraction involves filtering out the information we don't need in order to concentrate on the necessary details (Grover & Pea, 2013). For example, students were observed using abstraction while making problems less complex and removing unnecessary details. Each week, students had to consider what pieces were necessary in the creation of their weekly artifact. One way this was demonstrated was during the development of a game controller using a Makey Makey. During the second week of the study, student groups were observed demonstrating abstraction while considering the different pieces that would be needed to make the project work. Taman asked, "What materials do we actually need to make this work?" Her grouped considered the pile of materials in front of them and decided the problem was too complex. Their solution to solve a simpler problem by using fewer parts demonstrated the role abstraction played in problem solving in a makerspace. Additionally, abstraction was evident when students realized adding things to a project did not always solve their problem. Adriana explained this by stating, "Adding extra stuff wasn't always helping. We learned to take things off. We found that separating the pieces helped." My observations noticed this development when students worked to identify errors in the designs. My notes stated, "Group C is learning to remove unnecessary information to solve their problem. They are taking things off the project and learned they had too many connections. This was causing the problem." Designing solutions to problems encouraged students to practice abstraction (Barr & Stephenson, 2011).

Algorithmic design. Computational thinking practices were also evident in how students engaged in algorithmic design. This took place during programming activities but was also evident as students employed a step by step processes in making physical artifacts. For example, students were observed using programming activities to developing sequences when they created a program using Scratch. My notes described that while working to create their own educational video games, students practiced putting steps into the right order as they learned to develop a program. They had to devise a plan that followed a series of events and needed to consider ways to get their code into the correct order. Dashay mentioned the helpfulness of putting code into the right order and stated, "Scratch helped us see how to put things in the right order. Our program wasn't working until we figured out what to put first." Coding in Scratch helped students engage in actions that emphasized the importance of algorithmic thinking, but this was also expressed in activities beyond programming. Algorithmic design during the creation of an artifact was demonstrated during the fourth week while students developed inventions using the LittleBits circuits. As students developed their machines, they were observed discussing sequences using input and output. For example, one group of students that chose to create a working alarm clock experienced trouble getting their lights to come on and off. They discovered the order of the pieces to their invention needed to be in a certain order. Students also commented about this during an interview. Ashlynn said, "We had the pulse bit in the wrong order. We had it used as an input. We changed the order and learned it was actually the output of the circuit. That made our clock work." The makerspace manifested the development of computational thinking through an atmosphere of figuring things out by trial and error while engaged in tools to solve problems (Barr & Stephenson, 2011).

Decomposition. Decomposition was another computational thinking practice fostered by problem solving. For example, students were observed using decomposition while taking things apart. An example of this type of practice was noted in my observations during the fourth week. Students were creating a machine to help teachers and a group was unable to get their robot to move. My notes stated, "Students are unplugging things on the robot to find out how the robot should be wired. They are looking to see which wires control the movement." The group solved the problem by taking the robot apart. This helped them to understand the different parts which led them to the solution. Another example of how students used decomposition was evident from Cameron's interview response:

> It wasn't working. Then it did work. Then it didn't work. It wasn't working fully. It was like blinking. We started adding extra stuff, but then we had to take that out. Then we looked at stuff separately and started taking things off. It started to work better. That's when we learned that it was just one little thing that wasn't connected.

This comment shows the opportunity to explore a problem by taking it apart and looking at its separate pieces helped students use decomposition to solve problems. This supports the finding that when students express a solution by creating sub problems that are more manageable, they are involved in decomposition (Buitrago Florez et al. 2017).

Pattern recognition. A final practice that fostered computational thinking was pattern recognition. For example, students were observed using pattern recognition during the development of templates and prototypes. By creating prototypes, groups improved how they analyzed their designs. My observations noted that students learn to use prototypes to improve each version of their projects. Prototypes allowed them to look for similarities and differences as they changed their designs. This was also shared in student interviews. Carl stated prototyping help his group "see how to make changes that improved their design." Besides the use of prototypes, pattern recognition became apparent as students developed ideas by looking at the examples of others. Another example of pattern recognition was observed when students used templates to work more efficiently. This was first observed when students created maps for the Ozobots. Students discovered that making a new map after every mistake took lots of time to fix. My observations noted that groups learn to work more efficiently by creating templates. The templates allowed students to create and edit their maps without having to start over. Khloe commented during an interview that discovering to use templates help her because they "didn't have to build the whole thing at once." By using a template, they could repeat using sections multiple times. When students were able to solve problems, they used pattern recognition to develop more efficient methods. As Grover and Pea (2013) posited by using pattern recognition my students worked more efficiently at generating ideas for their designs.

Terminology aligned with computational thinking development. While students were able to positively demonstrate the use of computational thinking through practices that were fostered by the makerspace, this was not readily apparent based on their own depictions and reflections during the study. Students participating in the study were not always able to directly recall instances of using computational thinking to solve problems, however, they did describe its use using their own invented language. Brennan and Resnick (2012) found that computational thinking development "takes place in different contexts, on different timescales, with different motivations, and with different structures" (p.22). Research suggests that these differences then should lead to using different approaches towards assessing computational thinking in young students (Brennan & Resnick, 2012). While the students in this study did not describe computational thinking through the terms introduced by this study, their invented language does suggest they were able to incorporate computational concepts and practices into their thinking.

Qualitative data collected during this study showed that students developed their own contexts and structures towards computational thinking. In this study, interviews showed that students opted to develop their own language to describe their problem solving that was different from the academic computational thinking terminology introduced by the study. For example, when asked to describe using computational thinking, students were unable to recall examples of abstraction or decomposition, but student interviews did include students talking about "breaking things down." This behavior was repeatedly recorded in the interview data collected by this study. For instance, when students were asked for examples of using algorithmic design, they replaced the term with the phrases "going step by step," "using the right order," or "find the specific order" in its place. Additionally, this was observed with pattern recognition. Interview transcripts show students using the language "finding similar" to describe instances where groups used pattern recognition. When asked to share direct experiences with computational thinking, students were rarely able to connect their problem solving skills to computational thinking, however, they did include descriptions of using computational thinking in their own invented language. This invented approach aligned with the practices that were fostered by the makerspace but did not directly related to computational thinking descriptions used during the study. As Brennan and Resnick (2012) posit computation thinking is not a binary state of there or not there. Assessments should explore these multiple ways of knowing through the use of rich conversations about development processes that go hand-in-hand with artifacts that have been developed. This corroborates the assumption that computational thinking assessments for young students should adopt a formative approach that involves checking in at multiple points across a computational learning experience (Barr & Stephenson, 2011; Brennan & Resnick, 2012).

Research Question 2: How do these students' perceptions of using computational thinking as a problem solving method change based on makerspace experiences?

Research identifies that students will need the ability to think critically, problem solve, adapt and innovate through the use of 21st century skills (Acedo & Hughes, 2014; Aslan & Reigeluth, 2016). Therefore, it is important to investigate new pathways to learning that addresses these skills. This study takes the approach that learning takes place as students modify their understanding by experimentation and explanations stemming from different learning resources (Kafai & Resnick, 1996). As a result, the role of the teacher changes to one of a facilitator (Wilson, 1996). In this way, a constructivist learning environment encourages students to test out and improve upon their ideas on their own. Changing the instruction process in this way requires students to take on new roles and become autonomous learners. As the work in a makerspace focuses on meeting the fundamental and universal needs of its people, this develops a relatedness which is necessary for developing a connection to new knowledge (Cetin-Dindar, 2016; von Glasersfeld, 1989; Jonassen, 1991; Litts, 2015). A key interest of this study is how the participants changed perceptions of the relatedness between knowledge and learner as a result of their problem solving in a makerspace.

Kurti, Kurti, and Flemming (2013) found that as students engage in hands-on learning they better construct their own knowledge alongside of others. By building things, they become actively engaged on both learning and teaching. Kurti, Kurti and Flemming (2013) are expressing that student awareness of learning plays a key role in the constructivist approach. For this study, student perceptions of awareness of learning were collected through quantitative and qualitative measures. The findings from these two measures show different perspectives on how students perceived computational thinking as a problem solving method. Both show that student perceptions of using computational thinking grew through the makerspace learning experience, however, the role these factors play is different between the two types of data. Because of this difference, the quantitative and qualitative data are discussed separately.

Computational thinking perceptions are reported. The quantitative data comes from the pre- and postquestionnaire students completed. The assessment evaluated student perceptions of computational thinking. Their perceptions were collected across five different areas of computational thinking skills. These included: (a) creativity, (b) algorithmic thinking, (c) cooperativity, (d) critical thinking, and (e) problem solving. Students showed a significant increase between prequestionnaire (*M* = 106.000, *SD* = 17.927) and post questionnaire results (*M = 114.64, SD* = 17.452, p < .005). Students reported significantly higher perceptions of computational thinking on the postquestionnaire than the prequestionnaire. The assumption is learners developed a positive relationship with computational thinking as a result of their makerspace learning experiences.

While the questionnaire results indicate that overall perceptions had a positive relationship with computational thinking, this was not the case for all subgroups of computational thinking. Based on the data, only the subgroup of creativity showed significant growth from prequestionnaire (*M* = 29.500, *SD* = 5.431) to postquestionnaire (*M* = 33.357, *SD* = 5.665). No other subgroups demonstrated such a high increase in perceptions. The subgroups of critical thinking, algorithmic thinking, and cooperativity showed little increase between the pre- and postquestionnaire results. In fact, the subgroup of problem solving actually showed a slight decrease from prequestionnaire (*M* = 17.714, *SD* = 6.170) to postquestionnaire (*M* = 17.214, *SD* = 5.889). The assumption from this data is learners did not develop a positive relationship with all areas of computational thinking. Specifically, the skill of problem solving showed a decrease as a result of their makerspace learning experiences. This came as a surprise to me, because I had not anticipated these views from students.

Students in this study participated in practices that embodied a constructivist theory of knowledge acquisition. Previous research in the field of making indicates that act of inquiry through experimentation supports students in increased perceptions of problem solving skills (Martinez & Stager, 2013; Rosenfeld & Erson, 2014). The quantitative findings of this study do not appear to entirely corroborate these assumptions.

Issues of creativity, motivation, and communication. Interviews and observations conducted during this study show a different perspective towards student perceptions of computational thinking than the data presented by the CTS questionnaire results. Whereas the data from the CTS questionnaire presented mixed results towards an increase in computational thinking perceptions, the qualitative data suggests students changed significantly towards their perceptions of computational thinking. Over the course of the study, this was evident in their creativity, motivation and communication.

Brown, Collins, and Duguid (1989) believe that giving students the opportunity to approach problem solving that is situated in everyday activity allows learners to gain access to knowledge and improves their understanding of meaning and purpose. An examination of student behaviors, actions and discussions over the course of this study revealed that students perceived themselves as having become better problem solvers by using computational thinking. Students demonstrated this in their actions related to (a) creativity, (b) motivation, and (c) communication.

Creativity. Giving students the opportunity to express creativity gives them a resource that benefits their approach to solving problems (Norris, 2014). Creativity has been identified as a key learning skill needed for students to be successful in the 21st century (Partnership for 12st Century Learning, 2016). Creativity was identified as an important makerspace skill by the students in this study. This experience showed that as students found ways to express their creativity, they felt better about their approach to solving problems with computational thinking. Interview data collect by the study shows that students increasingly identified creativity as an important part of problem solving. The desire to be unique and different each week encouraged students to develop a purpose for students as they worked on their project. For example, Carl reflected on how creativity improved his problem solving. While talking about how his group developed a map using the Ozobots in the third week of the study, he said, "Being able to do tricks helped you be creative with your map." He liked that his project was unique and different, since his robot performed movements other groups did not use. Students repeatedly brought up creativity as a factor that kept them focused while solving problems. Austin (2017) has identified creativity as an important part of the problem solving process in a makerspace. This study found similar results as students increased their references to creativity as a method of problem solving in their weekly interviews. For example, Carl mentioned the role of creativity when he how it encouraged him to be unique and different. He said, "Being able to do tricks helped you be creative with your map." Kaiden also added to this feeling when she discussed the importance of expressing her personality. She said, "The colorful things helped me be creative. I liked being able to make my project unique using colors no one else used." Students purposely cultivated projects so that their solutions were not the same. In this way, students perceived creativity as a purposeful aspect of their problem solving.

Motivation. Positive changes towards feelings of motivation made for improved perceptions of the use of computational thinking. Bandura (1997) suggest that all learning is affected by a student's motivation. Feeling like a capable problem solver is related to the amount of engagement a student feels when learning new material (Linnebrink & Pintrich, 2003). Students gained a sense of discovery and invention; they were motivated to try out new ideas and gain new skills. This improved their perception of themselves as problems solvers. One way this occurred was through the open-ended self-directed work encouraged by the makerspace. During weekly challenges students engaged in deeper levels of discovery and invention. For instance, my observations noted that groups would decide to combine tools from previous challenges in new ways. My notes describe the groups discovering how to combine the use of the LittleBits circuits with the Makey Makey controllers. Participants in two groups organized parts from different kits and discovered new ways to get them to work together. As Audrianna stated, "We wanted to come up with something new and fun. We said let's try it this way, and it just worked."

Layke stated, "We wanted to make our robot work better. Adding the Makey Makey to the Littlebits helped us do that." They figured out how to make their robot talk using the touch sensitive features in combination with a program in Scratch.

An important component of the makerspace learning environment is improved participation. By participating in a community of practice, makerspaces assist the development of self-efficacy, motivation, and interest which establishes the idea of knowing through doing (Litts, 2015). By discovering new ways to combine the use of different tools, students felt motivated in problem solving. The role discovery plays in motivating learners has been found to prompt learners to try out new ideas while solving problems (Sheridan et al., 2014). As students became more motivate to work, they perceived their work each week as more fun. Having fun became a key part of the problem solving process. This was noted by Audrianna who described her work, "We wanted to come up with something new and fun. We said let's try it this way, and it just worked." Additionally, participants shared they could handle frustration and failure as long as they felt they were having fun. One example of this occurred as they spent time exploring the tools to start the week. Groups began a habit of spending some time at the start of each week exploring the new tools and materials presented at the start of the challenge. A group expressed their feelings about having fun in the following:

Cameron: We decided to just play with the LittleBits for a minute.

Israel: We don't want to start the project yet. We like to see what neat things we can make.

Layke: I noticed how to make a box light up. [Cameron] is making a thing that claps.

Israel: Yeah, I like to see what tricks we can get it to do.

By having the opportunity to have fun prior to engaged in problem solving, students were more likely to develop a variety of ideas. The role discovery plays in motivating learners has been found to prompt learners to try out new ideas while solving problems (Sheridan et al., 2014). Several studies found makerspace learning encourages active participation that leads to exploration through the open communities and shared interests supported by makerspaces (Brahms, 2014; Chu et al., 2015; Davis & Mason, 2016; Martin & Dixon, 2013). Figuring things out by playing with the available tools and materials has been identified as an important part of computational thinking development (Ito et al. 2010). As was described by previous research, the findings of this study are similar to these studies because my students demonstrated improved motivation through their perceptions of a sense of discovery and inventiveness.

Communication. Extended and repeated opportunity for communication between group members improved student perceptions of themselves as problem solvers. Learning to develop communication and collaboration skills is a key aspect of effective problem solving (Bevan et al., 2014; Blikstein, 2013). Learning to develop better communication and collaboration skills played a vital role in how students perceived computational thinking. Kangas, Seitamaa-Hakkarainen and Hakkarainen (2011) found students can only move forward with the development of collaboration skills when they learn the importance of how their group can all contribute, maintain focus, and share tasks. Students showed an understanding for this connection as they encountered issues communicating during the first three weeks of the study. Interviews and observations from this study show students repeatedly mentioned having trouble working as a team. Students commented about poor communication in a variety of ways: (a) off task behavior, (b) dealing with frustration, (c) understanding each other, and (d) time management. An example of how students encountered poor communication is shown from the student interview at the end of the first week:

> Taman: Too many people were playing in our group. So, I decided not to work with them. I did my project on my own, since they were all playing.
>
> Cameron: It was hard working with so many different people. We had five people in our group. Not everybody got along. We couldn't talk about solving the problem as a group because people were playing. We ended up splitting up and working on things separately.

This example illustrates that when faced with someone in their group that was off task, students preferred to work by themselves.

Developing effective collaboration skills has been identified as a way that makerspace learning leads to innovative work (Sheridan et al., 2014). Several other studies support the idea that knowledge results from the combination of grasping and transforming the experience (Jagielski, 2016; Richard & Giri, 2017; Simpson, 2016, Yanez et al., 2015). Students in this study demonstrated improved communication and collaboration skills over the course of the study. Observations and interviews collected indicate that students were successful in achieving these goals in the following ways: (a) asking for help, (b) improving other ideas, and (c) splitting up tasks. Observational notes show that this change in communication developed when participants began asking others in their group for help with their projects. During an interview, Carl reflected on how his group changed the way they communicated. He shared:

> Our group began to make lots of progress this week. I think we learned to work together better. When Taman asked me for help, I was able to help her out. I saw how if I helped her that she could get more done. She was not able to cut the cardboard as well as I could. When I cut things for her, she was able to build her project.

Students also demonstrated collaboration by improving each other's ideas. One way this occurred was by sharing projects ideas. As participants began offering ideas for making improvements to individual projects, groups started to combine ideas into a single shared project. One group spoke about how sharing ideas helped them learn and work together:

Cameron:	At first it was hard for us to work in a group. We had to learn to cooperate.
Carl:	We solved it because we worked together this week. I didn't know how to do it all, but when I started working with the other people in my group, I started to get it.
Cameron:	When I saw what Carl was doing, I realized his idea was like mine. We decided to build our project together.

Communication was also improved when groups learned to split up tasks. As they learned to do this, working on projects became more efficient. This was mentioned several different times in interviews the last two weeks of the study. For example, Taman stated, "We decided to do one part of the project and had the boys do the other part."

Adrianna also described how her group improved communicating, "We had to cooperate. We saw what they parts were and talked about what parts we were willing to do for the project." Marcus explained about how his group worked better by dividing up tasks, "Well, we solved it because we worked together, but it was hard to work in one group. We decided it would be best to split up different parts." Research suggests collaborative interactions are characterized by shared goals, and a high degree of negotiation, interactivity, and interdependence (Dillenbourg, 1999). Interactions producing elaborated explanations are particularly valuable for improving student learning (Bevan et al., 2014; Blikstein, 2013). Qualitative data collected by this study corroborates these findings.

Research Question 3: How do their problem solving skills change through the use of computational thinking in makerspaces?

Norris (2014) found that for students to develop new abstract knowledge, learning must be connected to everyday activity so that it connects with their real-world experiences. This aligns with Brown's (1989) research which states problem solving skills must be connected to a student's actual world. In this study, as students engaged in real world experiences their knowledge of problem solving was promoted through (a) design thinking and (b) critical thinking activities.

Design thinking. Design thinking focuses on the need to create ideas and find viable and novel solutions for problems. Research has found that design thinking can leverage the learning aspects of a makerspace by encouraging problem solving skill development. (Akins & Burghart, 2006; Bers et al., 2018; Douglass, 2016 Kangas et al., 2013; Rauth et al., 2010; Scheer et al., 2012). Integrating the design thinking process into the makerspace environment gives structure to the principles of 21st century skills.

Douglass (2016) also described that by doing this, students are able to find ways to develop new innovative problem solving methods, while demonstrating how to build concrete solutions to complex problems. In this way, design thinking becomes a critical component of how students change their approach to solving problems.

In this study, the design thinking process was a powerful method of improving problem solving skills. It provided students the ability to imagine without boundaries and constraints (Carrol et al. 2010). This expanded the way they solved problems over the course of the study. For example, the design thinking process provided direction for students while working in groups. The design thinking components provided students with established procedures of what to do. Over the course of each week's challenge, a different step of the design process was assigned to a different day of the week. Every daily session would begin with a brief class meeting to discuss the aspects of that day's design thinking focus. Using the design process became the format for how groups organized their work each week.

Observational records show students initially reacted negatively to using the steps of the design process, but over the course of the study they started to integrate the steps more and more. Notes from the first week show that three of the four groups worked without defining the problem for the week. As a result, groups did not give much attention to how their projects would actually solve the problem, and the projects that were shared at the end of the week did not address the learning aspect of the challenge. Artifacts collected at the end of the week show that while four protocol reviews were conducted, only two of the games had a connection to the weekly challenge. This later came up during our interview at the end of the week. For example, Ashlyn recapped the feelings of the group when she said, "At first, we didn't see any reason to use the steps. We just wanted to make something, but as you are doing it the more and more you begin to see that there is a process." In following weeks, groups began to better integrate the design process steps into their projects and work. This was most apparent in how groups gave more attention to beginning with the steps of defining and ideating. My observations noted that during these weeks groups were spending more time at the start of each week by asking questions. For example, students incorporated this into their discussion while working in the makerspace

Audrianna: What buttons will we need to include on our controller?

Cameron: Our game will only need to go up and down. I think two buttons will work.

Audrianna: So this is for someone who can't use their finger, right?

Kaiden: Yes, so how large will we need to make the buttons?

Cameron: [Pointing to his elbows] I think they should be about this big. Remember, the controller has to be designed for a different part of the body.

Kaiden: What materials will we need?

Audrianna: I think we can cut this cardboard to make it work.

Their understanding of how the design process supported how their problem solving grew each week.

Having the design process steps showed students how to tackle problem solving through critical analysis. This skill supported the students through all types of problem solving and was later incorporated into their work with computational thinking as well.

Eventually, students were able to connect the problem solving ideas into their computational thinking concepts. This was evident in how students spoke about problem solving towards the end of the study. For example, Carl said, "At first, we would have trouble coming up with ideas, and our group would just make something. Now, we spend time at the beginning of each week to come up with lots of new ideas." Their work in the makerspace supported their growth into understand how computational thinking is another type of problem solving. Other case studies acknowledge the premise of how design thinking develops a better understanding of how problem solving can support student learning in the new paradigm (Kangas et al., 2013; Rauth et al., 2010).

Critical thinking. Dewey (1910) defines critical thinking as the active, persistent, and careful consideration of any form of knowledge in the light of the grounds that support it. Recent studies have found that critical thinking skills improve how learners use problem solving skills for why the concept of a principle is correct (June et al., 2014; Kanbul & Uzunboylu, 2017; Nold, 2017). Critical thinking should involve identifying, analyzing, synthesizing, and evaluating information to yield actionable knowledge to make effective decisions (Douglas, 2016). In this study, critical thinking became a characteristic of computational thinking, and was supported by makerspace learning experiences which utilized effective design principles. Studies by Brennan and Resnick (2012) and Sandford and Naidu (2016) both found evidence to suggest focusing on critical thinking skills supports an improvement of problem-solving and reasoning skills even within observations of young children. The findings of this study corroborate this assertion. In this study critical thinking was demonstrated as students were able to ask questions, model, visualize, and analyze solutions to a weekly design challenge. As students tackled the weekly challenges, they encountered situations that supported their own active, persistent and careful considerations (Dewey, 1910). This resulted in the development of critical thinking skills that improved with each new week. An example of this process is evidenced by my observational notes where students developed their own questioning, modeling, visualizing and analysis skills through the making experiences. For example, during the first week of challenges, Marcus became frustrated and asked, "Why is this not working? What is happening? How is this teaching?" Later in the study, this student had learned to use critical thinking as part of his problem solving. This was shown as the student was later observed asking specific questions about the problem such as, "How do we want this to look?" and Daniel, another student in his group asked, "What parts do we need?" Developing models to visualize possible solutions was also demonstrated by students. For example, my observation records show that by the third week of the innovation students were learning to use models to create maps that visually represent the final product.

Student interview data shows how analysis development at the end of the innovation became more advanced. Early in the study, when speaking about how he solved problems, Marcus commented, "I just kept testing different things until it moved." Later in the study his response was more detailed. When speaking about how his group created a video game controller for a person with a physical disability he said:

> We first talked about what our problem was, which was people who are disabled can't really play this, that much games cause the controllers are only used for people to make use of their hands. And so, then we wanted to find a way to make a controller for people who are just disabled so they can play video games too.

> And so, then we drafted our thinking on paper and then after we discussed and looked at left track, we tried to make it so like we tried to create it and see how it would work.

Students made many choices throughout the process that showed they discovered a way to use critical thinking to analyze for possible solutions. Critical thinking is related to problem solving because it involves tasks that require evaluating information to develop knowledge around how to make an effective decision (Nold, 2017). Bers, Strawhacker, and Vizner (2018) found that kindergarten makerspaces highlight the potential for critical thinking in the makerspace learning environment. Their work found critical thinking can promote positive behaviors related to problem solving (Bers et al., 2018). Students in my study had a similar reaction because they incorporate design thinking and critical thinking processes into their projects by asking questions, modeling, analyzing, and visualizing the solutions to the problems they were solving.

Implications

This research has implications for me, classroom practitioners, and scholarly practitioners and researchers. Three types of implications are considered: (a) personal implications, (b) implications for integrating computational thinking in a makerspace, and (c) implications for future research.

Personal Implications

As a result of this study, I have learned many personal lessons that will help me in planning for my own classroom practice and guiding teachers in the future. These include (a) changed perceptions of teaching and learning, (b) implementation of makerspace learning, and (c) becoming a scholarly practitioner.

Changed perceptions of teaching and learning. Piaget (1954) describes learning as a process that takes place as children build knowledge from experience. Constructivism stresses that knowledge is constructed through social activity (Kafai & Resnick, 1996). Constructivism encourages students to test out and improve ideas on their own through a carefully selected and prepared learning environment (Wilson, 1996). Constructivism is valuable towards helping students develop critical thinking skills (June et al., 2014). While this learning theory dates back to research that began more than 50 years ago, teachers still have much to explore in this area. I agree with Piaget's statement of learning and have come to find that present day technology instruction has much to gain from understanding how a constructivist teaching approach can benefit instructional practices in the 21st century classroom. Technology integration often only focuses on students becoming technology literate (Yadav et al., 2016).

With completing this study, I have changed as an educator and instructional coach. Through the research and implementation of this innovation, I have learned more about how the constructivist learning theory can benefit technology-based instruction. As a teacher, I have had to change how I view the learning process and the learning environment. With a constructivist approach, the instructor takes on the role of facilitator (Wilson, 1996). Constructivism needs to be integrated into technology-based instruction. I now see the how experimentation and explanations stemming from different learning resources (Kafai & Resnick, 1996) are important to students as they discover ways to develop knowledge through problem solving with the use of computational tools. During the course of developing this study, my perceptions of teaching and learning now include considerations for (a) meaningful experiences, and (b) learning artifacts.

Meaningful experiences. One insight I gained from this study was to include meaningful experiences in classroom practices. By directly interacting with carefully designed environments, learning can take place in a student centered classroom - students are capable of gaining knowledge on their own through meaningful experiences (Litts, 2015). By directly interacting with carefully designed environments, learning can take place in a student centered classroom (Litts, 2015). Prior to this study, I felt classroom instruction supported students in gaining necessary skills to become autonomous problem solvers and thinkers. In reality, I have now found that traditional classroom instructional practice does little to support students in developing their fundamental and universal needs. Children need to experience learning in a way that develops social and emotional well-being alongside academic knowledge. As I planned for this learning experience, I had to contemplate how students build knowledge and consider what elements were required for this new knowledge to be gained. However, I because of this study, I also learned to include the need for opportunities for communication, teamwork and collaboration. I met these needs through a focus on incorporating new technological tools by the use of meaningful projects. I learned to develop a setting that impacted technological learning through the use of problem solving tools. I found I needed to create a setting where the notion of building knowledge occurred as students consciously engaged in constructing a public entity or usable artifact (Bers et al., 2014; Galloway, 2015; Kafai & Resnick, 1996; Kafai & Vasudevan, 2015; Litts, 2015; Papert, 1980; Martinez & Stager, 2013). This approach to a constructivist environment emphasizes the creation of an actual artifact and has been describe as constructionism (Harel & Papert, 1991). This developed over the course of the study and my change in thinking took some time and practice, but I found great value in an education experience that was tied to the social contexts of learning (Calderon, 2009).

Learning artifacts. Learning artifacts offer a way to engage students in the learning process. In the past, I planned instruction based on a predetermined set of procedures. These procedures were developed as a recipe of how students would gain knowledge and learn based on a setting where the teacher was the central aspect of the learning environment. My basic understanding was that learning could only take place in the presence of the teacher. I did not plan learning activities through the philosophy of hands-on learning by building things so students could become actively engaged on both learning and teaching (Kurti et al., 2014). When a constructionist approach was added, I found I was able to alter my focus. Instead of concentrating on developing a written set of procedures, I began to frame learning around having the students develop and learning artifact. This process helped me to discover how student learning through concrete objects can generate the most knowledge with the least amount of instruction (Papert, 1991). From these new insights, I gained a new perspective on the importance of the learning artifact (Papert, 1991). By doing this, my entire mindset of how the instructional setting should be designed changed. I found that I could reframe how students approach the learning process by integrating a maker mindset into the classroom experience. Through this study, I was able to see students benefit from a holistic participatory process that encouraged all types of activities regardless of what technology is used (Brahms, 2014). Overall, adopting a constructivist approach has changed the way I look at teaching and learning.

Implementation of makerspace learning. During this research, computational thinking was improved through the implementation of a makerspace learning environment. Makerspace learning increases student engagement which allows for increased meaningful learning (Brahms, 2014). One key is the development of community learning practices. As students engaged in activities and tasks in a makerspace, they learned from each other and become more engaged through the collaborative nature of the setting. Students that took part in the study all commented on the importance of teamwork. At the outset of the experience, students had difficulty navigating the social aspects of learning, but given time developed their own ways of dealing with group issues. Students showed improvement in communicating with each other. By the end of the study, they showed remarkable skill handling how to participate and negotiate work as a team. For me, an important component of the makerspace learning environment was learning how participation, engagement, and community learning were connected to how students gain new knowledge. As a teacher, it was hard stepping back and allowing students to work through difficult experiences. I had to fight the urge to step in and try to resolve their conflict. Observing students improve their teamwork, collaboration, and communication skills as a result of the makerspace activities gave me new insight into the importance of promoting a student-centered learning environment.

Another key to the implementation of makerspace learning was the role tinkering played in the way knowledge was gained. Tinkering is described as a branch of making that emphasizes creative improvisational problem solving that the draws upon the design process (Bevan et al., 2014). As the students progressed through the experience, I reflected on the role tinkering played in the study. Tinkering allowed students to persist and explore challenges in unexpected ways. They explored challenges in diverse ways and develop multiple paths towards success. Often, their designs were different my own expectations. Students routinely used the act of tinkering in creative and unexpected ways. Tinkering developed deeper understandings of computational thinking concepts through design activities (Harel & Papert, 1991; Kafai, 1995; Resnick, 1998; Papert, 1993; Resnick & Rosenbaum, 2013; Soloway et al., 1994). This realization helped me to understand the importance of giving students experiences with failure. Because of the role tinkering played in the study, students did not become frustrated by failure during the challenges. Instead, they showed an interesting perspective towards failure. Their response was typically positive. They viewed failure as an opportunity to try a new idea.

Their actions helped me to know how I needed to embrace the role of facilitator. So much can be learned by participating in the makerspace process. Because I observed students overcoming obstacles through repeated failures (Azevedo, 2013; Derosa, 2016) and develop social skills important to success beyond the classroom (Brahms, 2014; Chu et al., 2015; Litts, 2015), I gained insight into how makerspace learning benefits student knowledge acquisition.

Becoming a scholarly practitioner. Conducting a review of literature related to technology integration, makerspace learning, and computational thinking helped me to gain knowledge of what has been done in the past for technology implementation and how measurement of critical thinking and motivation has taken place. As I conducted this study, I became aware of research in my fields of interest and was able to use the prior knowledge base of others to inform my own innovation and analysis of the data I collected. I found it important to frame my makerspace learning experience with the existing literature of the fields of computational thinking and makerspace learning environment. As a result, I was able to better understand and connect the results of my study. Doing this allowed me to become a scholarly practitioner. The review of literature allowed me to use an existing computational thinking questionnaire (i.e., CTS) and adapt it to my needs for greater reliability. I was drawn to the constructivist and constructionist approaches for how students learn as I analyzed previous research during the literature review. This directed me towards the idea of integrating a makerspace learning environment to address technological content knowledge. Past makerspace learning frameworks (Brahms, 2014; Kurti et al., 2014; Martin & Dixon, 2013; Sheridan et al., 2014) were a guide to the development of my own design innovation. Additionally, I incorporated frameworks of computational thinking (Chen et al., 2017; Estapa et al., 2015; Kafai & Burke, 2014; Kanbul & Uzunboylu, 2017; Korkmaz et al., 2015; Korucu et al., 2017) into my data collection.

In summary, designing a makerspace learning environment for computational thinking has changed the way I think about classroom instruction. I have learned to plan and design my own innovation based on a critical analysis of current education philosophies. By engaging in the process, I have developed a better sense of how to design learning experiences that address student learning concepts. Reading the field of study in my interest areas allowed me to see what others have done. From this reflective process, I was able to use this knowledge base to design experiences that benefited my students. I plan to continue to incorporate these learning experiences and classroom design concepts into my teaching. Additionally, in my role as an instructional coach, I am also able to use this gained insight into teaching and learning to assist others interested in these areas. Continuing my investigation of current and future research in the area of computational thinking will play a key role in my current role at an elementary computer science magnet program. As I share my findings and results, I will be able to help other teachers in my school move towards using the lessons I learned from developing a makerspace into their own practice. My experiences developing this innovation will benefit me as I develop computational thinking integration into classroom practices at my school. Knowing how to evaluate and implement concepts of computational thinking into all areas of instruction will allow me to work and share this experience with other practitioners in my setting. This will benefit the larger population of students at my school.

Implications for Integrating Computational Thinking into Makerspace Learning

Computational thinking should be integrated into the 21st century learning experience in many different ways. To prepare students to succeed and thrive in our increasingly technological society they must tackle complex problems (NRC, 2011). K-12 educators need to begin exploring ways to embed computational thinking into their curricula and practice (Yadav et al., 2016). With the challenges of today's curricular demands this is a challenging request. One approach to integrating computational thinking ideas is to encourage its constructs and capabilities within the context of a makerspace. Doing this allows instruction to take place within existing content areas. In this study, two important aspects of integrating computational thinking into makerspace included (a) tools for developing problem solving and critical thinking skills and (b) tools for developing perseverance and collaboration skills.

Tools for developing problem solving and critical thinking skills. Tools for developing problem solving and critical thinking skills helps students become more empowered in their own learning. By focusing on the need to solve problems students are encouraged to develop cognitive, spatial, motor, social, and aesthetic skills (Akins & Burghart, 2006). In this study, students leveraged the actions of making and tinkering to develop their own strategies for problem solving and critical thinking. For example, critical thinking skills developed intuitively from groups of students making projects each week. An example of this process is evidenced by my observational notes where students developed their own questioning, modeling, visualizing, and analysis skills through the making experiences. This occurred as students began to develop more effective questioning skills in order to better define the work they were doing. They also showed critical thinking as they developed models to visualize possible solutions. This resulted in the development of critical thinking skills that improved with each new week. Later towards the end of the study, students spoke about discovering a way to use critical thinking to analyze for possible solutions. Students would go through a process of prototyping where different versions of their project would be developed and tested. They used trial and error to explore ways to make improvements on their ideas. The makerspace challenges encouraged his critical thinking to not just develop new ideas, but to also consider the viability of his ideas. As students tackled the weekly challenges, they encountered situations that supported their own active, persistent and careful considerations (Dewey, 1910).

Another tool for developing problem solving and critical thinking skills was the use of design thinking. For this study, design thinking was presented as a series of steps to be used in the act of making. This process allowed students the opportunity to build concrete solutions to complex problems (Douglas, 2016). Design thinking played an important role in how students improved problem solving approaches through the makerspace. While students showed an initial reluctance to follow the steps in designing their artifacts, their actions at the end of the study showed a dramatic improvement towards their perspective of the design thinking process. Design thinking gave students a structure that supported the way they developed and produced ideas each week. As students became more familiar with the steps, their solutions improved. Students noticed that by using the design process steps their approach to solving problem was improving. Students commented that instead of just making something each week they were now spending more time coming up with ideas. This introduced increased attention to how ideas were evaluated and implemented each week. This entirely changed how students approached building their projects. Using the design process gave students a system that organized their work and improved their critical thinking and problem solving within the makerspace activities. One of the greatest impacts that was noticed was how students spent more time thinking about why the concept of a principle they were developing was correct (June et al., 2014; Kanbul & Uzunboylu, 2017; Nold, 2017).

Tools for developing perseverance and collaboration skills. Attention is not often given to the role social learning plays in the acquisition of new knowledge. My experiences are such that I rarely see opportunities for students to incorporate social learning into the classroom learning experience. Giving students exposure to social learning skills, such as perseverance and collaboration, are vital tasks required by careers. Focusing on skills like perseverance and collaboration improves student employability

(Simpson, 2016). The integration of computational thinking skills into makerspace learning provided students the opportunity to witness the importance of social learning. By providing students a setting to practice these skills, their engagement in learning activities increased. Student engagement needs to be a primary concern of the learning environment (Brown et al., 1989; Carroll et al., 2010). The correlation between students' engagement and performance has been found to be rather significant (Chu et al., 2015; Cetin-Dindar, 2016; Clark, 2016; Kostaris et al., 2017). For example, participants in this study often cited feeling more engaged and motivated to learn. This was largely due to their positive attitude towards overcoming coming frustrations and developed strong traits of perseverance. Since the process of working in a makerspace is learning to deal with and overcome repeated failures, students were encouraged by failing and trying again. Students became more likely to work through frustration while achieving their goal (Blikstein, 2013). Students explained the failures helped them remain focused because it made them think harder about what they were doing. This was also evident in their actions. Students developed perseverance by trying new and different things. Participants shared they did not mind mistakes, because they felt it was a part of trying out new and different ideas each week. Student comments such as "finding another way to do it," and "we learned another way to do it" show how participants did not let set backs interrupt their learning. In demonstrating this, student learning was affected by each student's motivation (Bandura, 1997). When students developed the capability to be self-efficacious towards their work, they became more engaged in their effort towards learning new material (Linnebrink & Pintrich, 2003).

Collaboration also played a vital role as an important aspect of social learning. Collaboration skills were important to encouraging computational concepts (Kafai, 2015). Initially, students perceived collaboration as a roadblock. This presented students with several issues. They had to struggle with off task behaviors and often became frustrated trying to communicate in the makerspace setting. The communication and collaboration struggles students were experiencing showed the importance interpersonal skills play in group problem solving situations (Brown et al., 1989). Students in this study learned to overcome these roadblocks because their learning was situated in meaningful and purposeful actions (Brown et al., 1989). The learner centered approach of the makerspace forced students to face collaboration issues, and over time, all students demonstrated use of improved collaboration, teamwork and communication. Teamwork developed when participants began asking others in their group for help with their projects. Once a group learned to collaborate by asking each other for help, the participants began to improve their communication. Participants began offering ideas for making improvements to individual projects, groups started to combine ideas into a single shared project. The concept of a shared project changed how groups perceived their work. They saw the benefit of working towards a shared goal. Because of their shared goals, students found ways to negotiate, interact, and depend on each other (Dillenbourg, 1999).

Implications for Future Research

As this was my first action research study, I have learned a lot about designing research, collecting data, and analyzing results. The finding of this study offers implications for future research by teachers and researchers. Although not intended as an original part of the design, this study primarily used low performing students. As a result, the data collected suggests makerspace learning may have an impact on low performing students. Additionally, teachers who are looking to implement makerspace learning or computational thinking in their classroom or school may be interested in future research related to these topics.

If I were to replicate this study, I would make several changes and adjustments. Cycle two of this action research in my classroom would develop a computational thinking assessment specific to elementary age students in my setting. After evaluating the questionnaire items, I have concerns about its use with young students. The CTS questionnaire used in this study was originally developed for use with college age students (Korkmaz et al., 2015). While it has been found to be valid to measure the computational skills levels of secondary school students (Korucu et al. 2017), its use in this study may not have been an accurate measure of computational thinking. There is reason to believe that students participating in this study had difficulty understanding the questionnaire. Because the questionnaire was originally written in another language, and since the qualitative data collected by this study presents contrasting data, I would conduct a second cycle of this study using an updated computational thinking scale. A revision of the computation thinking scale would include vocabulary specific to the needs of young learners.

Future iterations of this study could also include comparative data to my first implementation. Three changes and improvements could significantly impact future findings. One change would be to conduct the study during the regular school day. Because of constraints and guidelines developed by my school district, I was not able to conduct this study during normal school instructional hours. This study was conducted in an afterschool setting. A second cycle of this study conducted during traditional instruction hours could provide more information about how makerspace learning and computational thinking can be integrated into traditional curricula content. Second, replicating this study across different grade levels at my school could give a broader view of the effects of computational thinking over a larger population of students. By collecting data across a larger body of participants, I could better evaluate the effects makerspace learning environments have on computational thinking. Third, conducting a longitudinal study by following students through several years of makerspace learning could help determine the long-term effectiveness of the improvements identified by this study. While students participating in this study showed an increase in computational thinking during the innovation not much is known about how they will develop these skills in future years. The implementation of this study was rather short in term. By doing this, further studies could use the data collected across each year of the study. This could be used to determine if student performance increased compared to previous years. I would be interested to know more about how students incorporate computational thinking over a longer period of study.

A change in study design would also be of interest. This study collected data from participants that all attended the same school. A second cycle of this study could include increasing the participants, but also the number of school sites. By increasing participants and locations who take part in the study this would increase the validity and reliability of the findings and their significance. In doing this, I could generalize the findings to a larger group and have more confidence in how the findings could be used in different school instructional contexts. Additionally, I would suggest exploring a different quantitative methodology. This study collected data across the same set of subjects using a pre- and postcomparison. I am interested in developing a second cycle of this study using a true experimental design with a control group. I would be interested in how the random assignment of participants to different groups would affect the outcomes of the study by the elimination of systematic differences (Creswell, 2014).

Limitations

As with any research study, there are limitations associated with this study. An action research study is a way to bring about results that are informative and immediate to a direct application (Mertler, 2017). Through this study, I was able to identify problems associated with implementing computational thinking in makerspace learning. There were, however, issues that could be improved with future research.

One key limitation of all action research is the concern of researcher bias. As Bloomberg and Volpe (2007) state, "since analysis ultimately rests with the thinking and choices of the researcher, qualitative studies in general are limited by researcher subjectivity" (p. 87). Therefore, one of the key limitations of this study is the issue of subjectivity and potential bias regarding the researcher's own participation in the study. A related limitation was that interviewees may have had difficulty adjusting to the researcher taking on the role of interviewer. Because a few of the participants knew the researcher, their responses may have been influenced or affected. According to Creswell and Miller (2000) participants may try to cooperate with the researcher by offering responses they perceived might be helpful.

Findings of this study are limited to the contexts of my afterschool group. The small sample size is a limitation because it may not be representative of the entire school. Participants in the afterschool group were selected based on their performance in previous years of state testing. The selection of participants included purposive sampling measures to exclude students that had performed at or above grade in state testing the prior year. It is possible that working with a more generalized group of students would have yielded different results. As a result, the sample group that participated in my study were largely representative of students who had low performance on state testing. Therefore, it may not be possible to assume the study findings are applicable to the whole grade level or other students at nearby schools. This study consisted of 16 students, all of whom participated in the innovation. There was no control group for comparing data. This study, while providing insight on computational thinking and makerspace learning, cannot be generalized beyond this context. Typical of action research, small sample sizes prevent generalizability of the findings beyond the context for the study. As with any small purposively selected sample, the number of participants limits the use of research study (Creswell, 2014). Readers are advised to use discretion when making assumptions beyond the context of this study.

Another limitation to this study is the interruptions faced in my school setting. The design of this study took place during an afterschool program. Students participating in the makerspace were not able to meet every week. Due to scheduling conflicts, students were only able to meet every other week. This interruption may have influenced the development of computational thinking skills. This presented an issue as students felt the process was not continuous at times.

Another limitation is the instrument used to collect data. The CTS has been validated and its internal reliability was found to be acceptable, however, the results from the quantitative data collection are concerning. Respondents who took part showed a high degree of variance. Students of this age may not have the vocabulary to express the exact words to represent the concepts and processes that they have used. The significance of the assumptions based on the findings of the study are questionable and indicate that students may not have understood the concepts asked by the questionnaire.

Recognizing these limitations, the researcher took the following measures. First, I acknowledge my research agenda and stated my assumptions up front. To reduce the limitation of potential bias during data analysis, I removed all participant names and coded all interview transcripts blindly so as not to associate any material or data with any particular individual. To address the problem of participant reactivity, I made a conscious attempt to create an environment that was conducive to honest and open dialogue.

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APPENDIX A

LIST OF CRITICAL THINKING SCALE QUESTIONS

Creativity

1. I like the people who are sure of most of their decisions.
2. I like the people who are realistic and neutral.
3. I believe that I can solve most of the problems I face if I have sufficient amount of time and if I show effort.
4. I have a belief that I can solve the problems possible to occur when I encounter with a new situation.
5. I trust that I can apply the plan while making it to solve a problem of mine.
6. Dreaming causes my most important projects to come to light.
7. I trust my intuitions and feelings of “trueness” and “wrongness” when I approach the solution of a problem.
8. When I encounter with a problem, I stop before proceeding to another subject and think over that problem.

Algorithmic thinking

9. I can immediately establish the equity that will give the solution of a problem.
10. I think that I have a special interest in the mathematical processes.
11. I think that I learn better the instructions made with the help of mathematical symbols and concepts.

12. I believe that I can easily catch the relation between the figures.
13. I can mathematically express the solution ways of the problems I face in the daily life.
14. I can digitize a mathematical problem expressed verbally.

Cooperativity

15. I like experiencing cooperative learning together with my group friends.
16. In cooperative learning, I think that I attain/will attain more successful results because I am working in a group.
17. I like solving problems related to group project together with my friends in cooperative learning.
18. More ideas occur in cooperative learning.

Critical thinking

19. I am good at preparing regular plans regarding the solution of the complex problems.
20. It is fun to try to solve the complex problems.
21. I am willing to learn challenging things
22. I am proud of being able to think with a great precision.
23. I make use of a systematic method while comparing the options at my hand and while reaching a decision.

Problem solving

24. I have problems in the demonstration of the solution of a problem in my mind.

25. I have problems in the issue of where and how I should use the variables such as X and Y in the solution of a problem.
26. I cannot apply the solution ways I plan respectively and gradually.
27. I cannot produce so many options while thinking of the possible solution ways regarding a problem.
28. I cannot develop my own ideas in the environment of cooperative learning.
29. It tires me to try to learn something together with my group friends in cooperative learning.

APPENDIX B

SEMI-STRUCTURED OBSERVATION PROTOCOL

<table>
<tr><td>Date:</td><td>Observations
(What I see)</td><td>Interpretations
(Observer Comments)</td></tr>
<tr><td colspan="3">Note any characteristics of makerspace learning as design thinking, tinkering, invention, and/ or fabrication.
Note any characteristics of computational thinking as creativity, algorithmic thinking, cooperativity, critical thinking, and/or problem solving.</td></tr>
<tr><td>Time
:</td><td></td><td></td></tr>
</table>

APPENDIX C

SEMI-STRUCTURED INTERVIEW PROTOCOL

Interviewer: Thanks for joining me today. This will be a focus group interview about your experiences during the makerspace challenge that took place this week. This will take about 45 minutes. I have 3 questions I would like to ask you today. I may also ask some follow up questions as well if needed. This will be a chance for your group to reflect and think back on your work this week. You have done a lot of hard work, and I wanted to make sure we have a chance to discuss the things you did. As you may recall, you are taking part in a study that I am conducting on makerspace learning experience and computational thinking. You and your parents have previously given consent to your participation in this study, but I wanted to remind you that you are welcome to stop at any time if you do not feel comfortable. I will take notes about what we discuss and I will be recording this session, however, I want to assure you that your names will not be used in the study. Please feel free to share your thoughts and opinions honestly. Are there any questions before we begin?

OK…

1. What making experiences did you find most useful?
    a. Did using the steps of design thinking help you? How did you define the problem? What ideas did your group consider? What steps did you take in building the solution? What testing you conduct?

   b. Do you recall tinkering with any ideas or objects? Did you try things out? Were there any failures? What materials did you find helpful? Did you make any improvements along the way?
   c. Can you describe a time when you had to be inventive or use fabrication? Did you make something new or did you improve someone else's idea? What digital technology tools did you use or find helpful and why?
2. Do you recall using any computational thinking?
   a. In what ways was your solution creative, new or different?
   b. In what ways did your solution use algorithmic thinking? Did you use any steps to solve the problem? How was your solution effective or efficient? Did any resources help you make improvements?
   c. Did your solution require any cooperation in the group? Did you find ways so that everyone could help? What roles did you each person take on?
   d. Does you solution show any critical thinking? How did you analyze the situation? Did you prioritize anything? How did you evaluate your progress?
   e. How did you solve the problem? Did any skills help you with this? What steps did you take?
3. Have your makerspace experiences change how you think about problem solving?
4. Does computational thinking change how you solve problems?

APPENDIX D

PORTFOLIO REVIEW PROTOCOL

Student: Date:

Evidence to support makerspace learning characteristics

Key Concept	**Description of Evidence**	**Analysis of Evidence/ Comments**
Design Thinking		1 2 3 4 5
Tinkering		1 2 3 4 5
Invention		1 2 3 4 5
Fabrication		1 2 3 4 5

Evidence to support computational thinking skill development

Key Concept	**Description of Evidence**	**Analysis of Evidence/ Comments**
Creativity		1 2 3 4 5
Algorithmic Thinking		1 2 3 4 5
Cooperativity		1 2 3 4 5
Critical Thinking		1 2 3 4 5
Problem Solving		1 2 3 4 5

Notes:

APPENDIX E

INSTITUTIONAL REVIEW BOARD DECLARATION

UNIVERSITY OF
SOUTH CAROLINA

OFFICE OF RESEARCH COMPLIANCE

INSTITUTIONAL REVIEW BOARD FOR HUMAN RESEARCH
DECLARATION of NOT RESEARCH

Tim Swick
205 Ringwood Lane
Elgin, SC 29045 USA

Re: **Pro00089013**

Dear Mr. Tim Swick:

This is to certify that research study entitled ***IMPROVING COMPUTATIONAL THINKING: ACTION RESEARCH IMPLEMENTING A SCHOOL MAKERSPACE WITH ELEMENTARY STUDENTS*** was reviewed on **5/8/2019** by the Office of Research Compliance, which is an administrative office that supports the University of South Carolina Institutional Review Board (USC IRB). The Office of Research Compliance, on behalf of the Institutional Review Board, has determined that the referenced research study is not subject to the Protection of Human Subject Regulations in accordance with the Code of Federal Regulations 45 CFR 46 et. seq.

No further oversight by the USC IRB is required. However, the investigator should inform the Office of Research Compliance prior to making any substantive changes in the research methods, as this may alter the status of the project and require another review.

If you have questions, contact Lisa M. Johnson at lisaj@mailbox.sc.edu or (803) 777-6670.
Sincerely,

Lisa M. Johnson
ORC Assistant Director and IRB Manager