USING A MULTIFACETED ROBOTICS-BASED INTERVENTION TO INCREASE STUDENT INTEREST IN STEM AND COMPUTATIONAL THINKING SKILLS

by

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The following individuals read and discussed the dissertation submitted by student Mary Alice Hudson, and they evaluated the student's presentation and response to questions during the final oral examination. They found that the student passed the final oral examination.

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DEDICATION

This work is dedicated to my husband and children who put up with, supported, and listened to me as I worked my way through the dissertation process and to my running buddies who let me rattle on about educational robotics mile after mile. I am very grateful to these individuals for their patience, encouragement, and support through the years!

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ABSTRACT

This dissertation examines the impact of a robotics-based intervention on elementary-aged students' interest in STEM subjects and careers and development of computational thinking skills. Previous research suggests educational robotics programs integrate a wide array of skills projected to be essential for success in the workforce of the future. The current research was motivated by two research questions: (1) What is the impact of a robotics-based intervention on elementary-aged students' interest in STEM subjects and careers? (2) What is the impact of a robotics-based intervention on elementary-aged students' computational thinking skills? To answer these questions, action research was used to examine a multifaceted, constructionist, robotics-based intervention that included weekly WeDo Lego Robotics building and coding sessions facilitated by trained, STEM-speaking adults, the use of the Use-Modify-Create learning progression (Lee, et al., 2011) to scaffold student development of computational thinking skills, a classroom STEM learning center, and student participation in a robotics showcase.

Participants were thirty-seven second and third grade students from two classrooms at a rural, Title I elementary school in the Southeastern United States. The intervention was found to have a positive impact on students' interest in STEM subjects and careers and development of computational thinking skills. Critical intervention elements included: STEM-speaking adults, constructionist building and coding opportunities, opportunities to work with and learn from peers, classroom learning center

activities including access to robotics and STEM reading materials and opportunities for student reflection, use of the Use-Modify-Create learning progression, and student participation in a robotics showcase.

Based on the findings of this research, elementary schools should strive to incorporate educational robotics into the regular school day. This research provides practitioners with a multifaceted robotics-based intervention that can be integrated into elementary classrooms in as little as two hours per week for sixteen weeks and result in student acquisition of positive attitudes toward STEM subjects and careers and computational thinking skills. These are attitudes and skills which are valuable to students' future school and career success.

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LIST OF ABBREVIATIONS

AR	Action Research
CTt	Computational Thinking Test
GE	General Electric
ISTE	International Society for Technology in Education
S-STEM	Student Attitudes toward STEM
STEM	Science, Technology, Engineering, and Mathematics
WLR	WeDo Lego Robotics

CHAPTER ONE: INTRODUCTION

K-12 public education strives to prepare youth for an uncertain and ever-changing future. This is a complex task, as rapid advancements in technology ensure tomorrow's job market and labor force will look vastly different from today's. Nevertheless, it is incumbent upon the K-12 public education system to prepare students to meet the demands of their future careers. Therefore, K-12 public education must adapt and evolve to ensure today's students have the skills and knowledge to be successful members of tomorrow's workforce.

It has been predicted tomorrow's jobs will require innovation, creativity, and the ability to solve problems. According to Carnevale, Smith, and Melton (2011), science, technology, engineering, and mathematics (STEM) careers are the careers of the future because they fuel economic competitiveness and have direct ties to innovation, economic growth, and productivity. To prepare students for these careers, schools must change in ways that allow students to experience, learn, utilize, and internalize STEM skills, abilities, work values, and career interests. The International Society for Technology In Education (ISTE) Standards for Students (2017) focus on ensuring students develop the building blocks necessary to be successful in a future workforce driven by STEM. These standards are designed to ensure students become empowered learners, digital citizens, knowledge constructors, innovative designers, computational thinkers, creative communicators, and global collaborators. According to ISTE, these standards represent the knowledge and skills students require to become lifelong learners who thrive in an ever-changing technology landscape. These standards support the intent of this research, which is to examine an intervention designed to promote early elementary-aged student acquisition of attitudes and skills necessary to succeed in the workforce of the future.

This research examines the use of a multifaceted robotics-based intervention to increase elementary-aged student interest in STEM subjects and careers and to develop student computational thinking skills. The use of educational robotics in elementary school classrooms has the potential to allow students to prepare for and glimpse their possible future. This is a future in which students will be members of the workforce who utilized STEM and computational thinking to build, create, program, problem solve, brainstorm, work collaboratively, and think deeply.

Background of the Study

This study was built upon previous research (Hudson, 2016), which was implemented in a rural, Title I, public elementary school in the Southeastern United States and found the inclusion of robotics in an elementary school day had a positive impact on student learning. In this prior research, action research (AR) was conducted to examine the impact of student participation in an elementary WeDo Lego Robotics (WLR) program on six student outcomes. Outcome selection was based on teacher feedback, opportunities presented by the WLR program, and criteria deemed necessary for student engagement in learning and overall success in school. Outcomes examined were: 1) student attendance, 2) demonstration of positive behavior traits, 3) student attitude toward school, 4) technology vocabulary, 5) robotics knowledge, and 6) robotics/STEM career interest. Research found participation in an elementary school day WLR program for one to two hours per week for twelve weeks positively impacted student demonstration of positive behavior traits, student attitude toward school, student technology vocabulary, and student robotics knowledge. These findings demonstrated the tangible value of the inclusion of robotics in education and supported the inclusion of WLR in an elementary school program targeting at-risk students. However, participants did not grow in terms of interest in robotics or STEM careers. As student interest in STEM subjects and careers has tremendous potential to impact students' future success (Nugent, Barker, Grandgenett, & Adamchuk, 2010; Scaradozzi, Sorbi, Pedale, Valzano, & Vergine, 2015), the current study was developed to examine an intervention designed to achieve this goal. The current study builds upon the successful inclusion of robotics in an elementary school program and is designed to examine a multifaceted robotics-based intervention that promotes the development of student interest in STEM subjects and careers and the development of students' computational thinking skills. Computational thinking skills are an appropriate addition to this research as they integrate STEM subject matter and are the basis for working with and understanding computational products.

The inclusion of robotics during an elementary school day is an ideal way to expose students to integrated STEM concepts and develop and encourage pursuit of STEM interests and ultimately careers (Eguchi, 2014; Keengwe, Onchwari, & Wachira, 2008; Park & Han, 2016). Likewise, the development of computational thinking skills can be achieved through exposure to educational robotics (Atmatzidou & Demetriadis, 2015; Bers, Flannery, Kazakoff, & Sullivan, 2014; Chen, Barth-Cohen, Jiang, Huang, & Eltoukhy, 2017; Eguchi, 2014; Eguchi, 2016; Grover & Pea, 2013; Leonard et al., 2016; Sullivan & Heffernan, 2016; Voogt, Fisser, Good, Mishra, & Yadav, 2015). Computational thinking is the use of logical thought processes to formulate, analyze, and solve problems in a way that can be understood by a computer. This skill set is and will continue to be in high demand in the workforce and will benefit students as they pursue future educational opportunities and career prospects (Eguchi, 2014; Grover & Pea, 2013; Lee, Martin, & Apone, 2014; Lee et al., 2011; Leonard et al., 2016; Voogt et al., 2015; Wing, 2006). While there are many factors that lead to student success, developing student interest in STEM subjects and careers and computational thinking skills were selected for this research because they have the potential to positively impact student current and future success. This research sought to examine the impact of participation in a multifaceted robotics-based intervention that incorporated student participation in WLR building and coding sessions facilitated by trained, STEM-speaking teachers and volunteers, a classroom STEM learning center, the use of the Use-Modify-Create learning progression to scaffold student development of computational thinking skills, and a student robotics showcase, on the development of these skills and interests.

Purpose of the Study

The purpose of this study was to examine the impact of a robotics-based intervention on elementary-aged students' interest in STEM subjects and careers and development of computational thinking skills. This was undertaken through regular school day use of robotics as an extra activity in an elementary school setting. A review of the literature suggests robotics is an ideal constructionist tool to expose children to integrated STEM concepts (Altin & Pedaste, 2013; Barak & Zadok, 2009; Barker & Ansorge, 2007; Beer, Chiel, & Drushel, 1999; Benitti, 2012; Eguchi, 2014; Kandlhofer & Steinbauer, 2015; Nugent et al., 2010; Petre & Price, 2004) and computational thinking skills (Bers et al., 2014; Kabatova & Pekarova, 2010; Lee et al., 2011; Papert, 1993;

Sullivan & Heffernan, 2016; Voogt et al., 2015).

Research has shown the future workforce will be driven by STEM careers which require employees who are innovative, creative, able to solve problems, and who have an understanding of scientific and mathematical principles, as well as computer hardware and software (Carnevale et al., 2011; Tsupros, Kohler, and Hallinen, 2009). As STEM and computational thinking skills are projected to be in high demand in the future workforce, it is necessary to prepare students for this future reality. Robotics provides an all-in-one tool to teach students the skills, knowledge, and attitudes required for future success (Eguchi, 2014). Research has shown regular school day use of robotics as an extra activity promotes student development of computational thinking skills, application of STEM concepts, creativity, persistence, positive social interactions, teamwork skills, and general life skills (Altin & Pedaste, 2013; Barak & Zadok, 2009; Beer et al., 1999; Benitti, 2012; Eguchi, 2014; Kandlhofer & Steinbauer, 2015; Nugent et al., 2010; Petre & Price, 2004; Scaradozzi et al., 2015).

A multifaceted robotics-based intervention was designed, based on constructionist theory, to saturate student exposure to STEM subjects and careers and computational thinking skills through participation in educational robotics as an extra activity during the regular school day. The components of this intervention were selected based on a review of the literature, which revealed research-based methods that could be brought together to create a powerful intervention that could be used to positively impact student attitude toward and interest in STEM subjects and careers and development of computational thinking skills. AR was used to examine the impact of this robotics-based intervention on elementary-aged students' interest in STEM subjects and careers and development of computational thinking skills.

The greatest value of the use of robotics in education lies in the fact that robotics integrates a wide array of skills that are projected to be essential for success in the workforce of the future. Robotics integrates STEM and teaches collaboration, deep thinking, inquiry, and problem solving skills. These are skills deemed necessary in an economy increasingly driven by technology and automation. Therefore, this research sought to examine an intervention designed to promote an early understanding of and interest in STEM and development of computational thinking skills through the use of educational robotics. Acquisition of interest in STEM subjects and careers and development of computational thinking skills has the potential to positively impact student current and future success.

Intervention

A multifaceted robotics-based intervention was used to support, scaffold, and focus student learning in an effort to develop student computational thinking skills and interest in STEM subjects and careers. During a sixteen-week period, students participated in intervention-related activities for two hours per week (see Table 1). Component 1: Students participated in WLR building and coding sessions facilitated by trained, STEM-speaking teachers and volunteers for one hour per week. During the first eleven sessions, student-pairs used and modified the instructions provided by the WLR software to build and code robots. During the final four WLR building and coding sessions, student-pairs created novel robots to be presented in a student robotics showcase. Component 2: Students participated in an independent classroom STEM learning center three days per week for 20 minutes per day. Classroom learning center activities allowed students to participate in self-directed learning opportunities, within prescribed boundaries. The classroom STEM learning center activities were designed to promote self-reflection, development of computational thinking skills, and student understanding of and interest in STEM subjects and careers and included buddy reading, online activities, and written WLR reflections (see Table 2). Component 3: During WLR building and coding sessions and classroom STEM learning center activities, students were required to use, and reflect upon their use of, the Use-Modify-Create learning progression in an effort to increase computational thinking skills. Use-Modify-Create is a learning progression that scaffolds student learning as students progress from users to creators of computational products. It allows students to self-pace and self-direct their learning and exploration of computational thinking concepts. Activities were designed to support and supplement student learning by scaffolding and directing student learning to achieve the desired outcomes. Component 4: During the final four WLR building and coding sessions, student-pairs created novel robots that were presented in a robotics showcase. Each student-pair demonstrated and explained their robot to parents, teachers, and peers attending the showcase.

Table 1 Timeline of Sixteen Week Intervention Components

Intervention Components	Weeks 1-11	Weeks 12-15	Week 16
WeDo Lego Robotics Sessions with Trained, STEM-speaking Adults	Use & Modify Existing WLR Designs	Create Novel Robot for Showcase	
Independent STEM Learning Center Activities	Completed as shown in Table 2		
Use of Use-Modify-Create Learning Progression	Used during WLR & Learning Center Activities		
Robotics Showcase			Presentation of Robots in Robotics Showcase

Table 2 Description of Weekly Intervention Activities

	Tuesday	Wednesday	Thursday
STEM Learning Center Activities	Buddy Reading (20 minutes)	Online Activities (20 minutes)	WLR Reflections (20 minutes)
WeDo Lego Robotics		Building & Coding (1 hour)	

Research Questions

Research Question 1 - What is the impact of a robotics-based intervention on elementary-aged students' interest in STEM subjects and careers?

Subquestions

- Does the intervention have an effect on student attitude toward STEM subjects?
- Does the intervention have an effect on student attitude toward STEM careers?
- How did the intervention impact student attitude toward STEM subjects and careers?

Research Question 2 - What is the impact of a robotics-based intervention on elementary-aged students' computational thinking skills?

Subquestions

- Does the intervention have an effect on student development of computational thinking skills?
- How did the intervention impact student development of computational thinking skills?

Significance

The hands-on, mind-on learning that occurs when students interact with and create robots is supported by constructionist theory, which states that children learn by making (Barak & Zadok, 2009; Bers et al., 2014; Lindh & Holgersson, 2007; Mubin, Stevens, Shahid, Mahmud, & Dong, 2013; Papert, 1980; Papert & Harel, 1991). Seymour Papert, the father of constructionism, grounded constructionist theory in Piaget's constructivism and the idea of children as builders of their own intellectual structures (Papert, 1993). Moving beyond constructivism, constructionism focuses on the role of a child's surrounding culture to provide building materials for learning and contends that a dearth of materials with which to construct knowledge will result in slower and more difficult development of a concept (Papert, 1993). Educational robotics provides children with hands-on opportunities to explore and grow their understanding of a wide range of STEM concepts. Students develop skills such as mathematics process skills, problem solving skills, creativity, persistence, social interactions, and teamwork, through structured and unstructured exploration and creation of robotic designs and code (Altin & Pedaste, 2013; Barak & Zadok, 2009; Beer et al., 1999; Benitti, 2012; Eguchi, 2014;

Kandlhofer & Steinbauer, 2015; Nugent et al., 2010; Petre & Price, 2004). Robotics is a perfect constructionist medium because students can immediately see the results of their decisions. Papert (1993) would describe educational robotics as objects-to-think-with because they provide immediate feedback, which allows students to create and then cyclically test, analyze, and refine their creations. The use of robotics is ideal for encouraging student interest in STEM subjects and careers because robotics incorporates a variety of STEM concepts. Robotics allows students to see practical uses for STEM concepts that might otherwise remain abstract and disconnected from a student's understanding of the world. Likewise, robotics is an ideal means of developing student computational thinking skills. When students create the code required to control a robot, they are tasked with the three As of computational thinking, abstraction, automation, and analysis (Lee et al., 2011). Additionally, the use of the Use-Modify-Create learning progression allows students to experience computational thinking by first using coding as it is provided, then modifying the given-code and immediately seeing the results of their modifications, and ultimately creating new code based on the understanding they have developed through the use and modification of someone else's code. The culminating activity in this intervention was student participation in a robotics showcase. Prior to the showcase, students spent four WLR sessions designing, building, testing, and utilizing computational thinking skills to create a novel robot. These novel robots were presented by student-pairs during the robotics showcase. Students demonstrated and explained their robot's design and code to parents, teachers, and peers who attended the showcase. This creation and presentation is in accord with constructionist theory, which values construction of a physical artifact that is publicly shared (Papert and Harel,1991).

Research has shown student learning can be directed to achieve specific objectives by presenting children with a combination of specially designed robotics and non-robotics activities. This idea is supported by the constructionist belief that children's learning can be influenced by the presence of a robotics culture in their classroom (Papert, 1993). For example, Bers et al. (2014), created a curriculum that utilized robotics and a variety of age-appropriate non-robotics activities, including games and songs, to enable kindergarten-aged students to grasp complex computer programming concepts. In keeping with these findings and constructionist theory, this research incorporated robotics building and coding activities and non-robotics classroom STEM learning center activities to support and scaffold student learning. The addition of trained adult teachers and volunteers, who Papert (1980) would categorize as STEM-speaking adults, to engage students in conversation about STEM subjects and careers and computational thinking skills, helped to saturate students in robotics, further developing the robotics culture in the classroom.

This research was designed to test the theory that a multifaceted robotics-based intervention, which included WLR building and coding sessions facilitated by trained, STEM-speaking volunteers and teachers, non-robotics classroom STEM learning center activities, coupled with the use of the Use-Modify-Create learning progression to scaffold student development of computational thinking skills, culminating in participation in a student robotics showcase, can be utilized to increase elementary school-aged students' computational thinking skills and interest in career opportunities available in STEM fields. Findings show increased student interested in STEM subjects and careers and student development of computational thinking skills. Therefore, this intervention can be replicated within this school and others to promote student development of these attitudes and skills. Empirical testing of the effectiveness of this intervention contributes to theoretical understanding of the ways in which the inclusion of robotics in education can be used to facilitate student growth and promote future student success.

Rationale for Methodology

AR was developed in the 1940s by Kurt Lewin as a way of improving professional practice by studying such practice in context. The goal of Lewin's work was to make an immediate difference in the world (Willis & Edwards, 2014). To accomplish this, AR is conducted in the field and involves using local knowledge and experiences to solve locally identified problems (Willis & Edwards, 2014). AR is an emergent model of research, which allows the researcher to adjust elements of the research as the study unfolds (Macintyre, 2000; Manfra & Bullock, 2013; Wood & Butt, 2014). According to Clark (1980), this characteristic of AR embraces an openness in attitude which allows theories to be changed when they are inconsistent with evidence. Although AR is typically practical rather than theoretical, it is theory informed. It contributes to local knowledge and through the use of thick descriptions, may be generalized by other researchers and practitioners who are seeking to solve similar problems (Willis & Edwards, 2014).

AR is appropriate for this research because it represents a dynamic methodology in which traditional research approaches are applied to real issues faced by educators, enabling educators to address persistent questions within the context of practice. Regardless of the goals, processes, or procedures chosen, AR is intended to bring about change by modifying and improving some aspect of practice, resulting in improved student learning outcomes (Efron & Ravid, 2013; Manfra & Bullock, 2014). Efron and Ravid (2013), succinctly describe AR, saying, “The emphasis is on finding out ‘what works’ and acting upon it” (p. 46).

In this study, AR was used to examine the impact of a robotics-based intervention on elementary-aged students’ interest in STEM subjects and careers and development of computational thinking skills. AR is appropriate for this research, because this research was designed to examine improvements to an existing program with the goal of improving student learning outcomes and to share this knowledge so that the “best education can be obtained for the greatest number of children” (Macintyre, 2000, p. xi).

Assumptions of the Study

Assumptions are elements of research that are agreed to be true (Wargo, 2015). For the purpose of this research, the following assumptions are assumed to be true. Participants were encouraged to do their best work on all pre- and post-tests. It was therefore assumed the results of these tests reflect an accurate representation of the subjects’ understanding of the concepts measured by these assessments. It was assumed that participants answered the interview questions honestly, candidly, and to the best of their abilities. As all classrooms in the research setting are academically and demographically diverse, it was assumed that the sample is representative of the school population. Because all teachers and volunteers were trained to implement the study protocol and interventions, it was assumed they followed the protocol with fidelity and that all participants experienced the same or similar exposure to the intervention implemented in their classroom. As the teachers in the two participating classrooms work and plan together, it was assumed that student experiences were consistent between these classrooms. It was assumed that the number of participants in this study is sufficient to adequately draw conclusions.

Definitions

Attitude/Interest - Attitude is an established way of thinking or feeling about something that is typically reflected in a person's behavior (attitude, n.d.) and interest is a feeling of wanting to know or learn about something (interest, n.d.). Interest may lead to attitude, or attitude may lead to interest, making these two words inextricably intertwined. As such, they are used interchangeably in this research.

Computational Thinking - Computational thinking is the use of abstraction, automation, and analysis to take a complex problem, understand what the problem is, and develop possible solutions that can be implemented using a computer (Bitesize, 2017; Lee et al., 2011). Abstraction is the ability to solve a problem by stripping it down to its essence. Problem decomposition and pattern recognition are important components of abstraction. Automation is the ability to develop a step-by-step solution to a problem which can be potentially implemented by a computer. And, analysis is the ability to troubleshoot and debug the thought processes and programming used to solve a problem, answer a question, and/or perform a task (Lee et al., 2011). Computer programming can be used to teach and assess computational thinking skills, but computational thinking can also be taught and used in a variety of other settings in which individuals need to determine logical means of solving a problem. According to Roman-Gonzalez (2015), "Computational thinking involves the ability to formulate and solve problems by relying on the fundamental concepts of computing…" (p. 2438). While computational thinking is most frequently associated with computer programming, it is valuable in virtually every field, as it teaches and requires the thought processes necessary to evaluate a problem or question and determine the computationally appropriate means of solving the problem or answering the question. According to Wolfram (2016), “Computational thinking is really about thinking. It’s about formulating ideas in a structured way, that, conveniently enough, can in the modern world be communicated to a computer, which can then do interesting things” (“Led by Kids”, para. 19).

Constructionism - Papert’s theory of constructionism is based on Piaget’s theory of constructivism, in which it is theorized that children actively build knowledge through experience and “doing”. Papert expanded on this theory by focusing on ways internal knowledge construction can be supported by physical constructions in the world, (i.e. “making”) (Bers et al., 2014). Constructionist learning environments ideally provide children the freedom to explore while investigating content learning, to exercise metacognitive, problem-solving, and reasoning skills, and have embedded in them “powerful ideas” that are useful and interconnected with a child’s intuitive knowledge (Bers et al., 2014). According to Bers et al. (2014), constructionism states “...children can learn deeply when they build their own meaningful projects in a community of learners and reflect carefully on the process” (2014, p. 146). Papert and Harel (1991) define constructionism in the first chapter of their book, Constructionism:

> Constructionism—the N word as opposed to the V word—shares constructivism’s connotation of learning as ‘‘building knowledge structures’’ irrespective of the circumstances of the learning. It then adds the idea that this happens especially felicitously in a context where the learner is consciously

engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe. (p. 1)

Independent Classroom Learning Center - An independent classroom learning center is a space within a classroom that provides students with an opportunity to engage in activities that allow them to practice, enrich, and enhance their learning. Students may work independently or in small groups at learning centers, which may include art materials, books, manipulatives, computer activities, or other resources. Learning centers may be designed to promote teamwork, hands-on learning, social interaction, problem solving, and/or exploration. When working at a learning center, students are responsible and accountable for their own learning (Scholastic, 2017).

Robot(ics) - Robots are human creations that are designed to help people. Robots can be used to build things, catch criminals, explore the air, land, and sea, and even aid the police and military. They can be designed to vacuum and clean, perform surgery, assemble cars, pack boxes, release and retrieve satellites, carry cameras, tools, and weapons, and explore dangerous places (Alpert, 2012; Swanson, 2016). Ninety percent of the world's robots are used in factories, packaging products and assembling consumer goods. Robots can typically perform repetitive tasks faster and more efficiently than humans (Swanson, 2016). Although there is no single definition of a robot, they typically exhibit some common traits. Robots move, have sensors that interact with their environment, have at least one mechanical limb, and follow programmed instruction (Swanson, 2016). Swanson (2016) adds, "Robotics uses the science of engineering and computer programming to create machines that do things for humans. And robots do lots of things. There are millions and millions of robots doing all kinds of work all over the world (p.10)."

STEM - STEM is an interdisciplinary educational initiative designed to prepare students for college and careers in the fields of science, technology, engineering, and mathematics. In addition to subject-specific learning, STEM education aims to foster inquiry, logical reasoning, deep thinking, and collaboration (TechTarget, 2013).

Student Robotics Showcase - A student robotics showcase is an exhibition of student work. It provides an opportunity for students to display, demonstrate, and explain the design and code of their robotic creations to an audience of their teachers, parents, and peers.

Use-Modify-Create Learning Progression - The Use-Modify-Create learning progression is designed to scaffold and support student learning as students develop computational thinking skills and move from being consumers to producers of computational products (Lee et al., 2011). Students first interact with an existing computational artifact (the "Use" stage). Students develop computational thinking skills by modifying and iteratively refining someone else's project to make it their own (the "Modify" stage). As students gain skill and confidence, they can be encouraged to develop ideas for new computational projects of their own design that address issues of their choosing (the "Create" stage) (K12 Computer Science, n.d.) (see Figure 1).

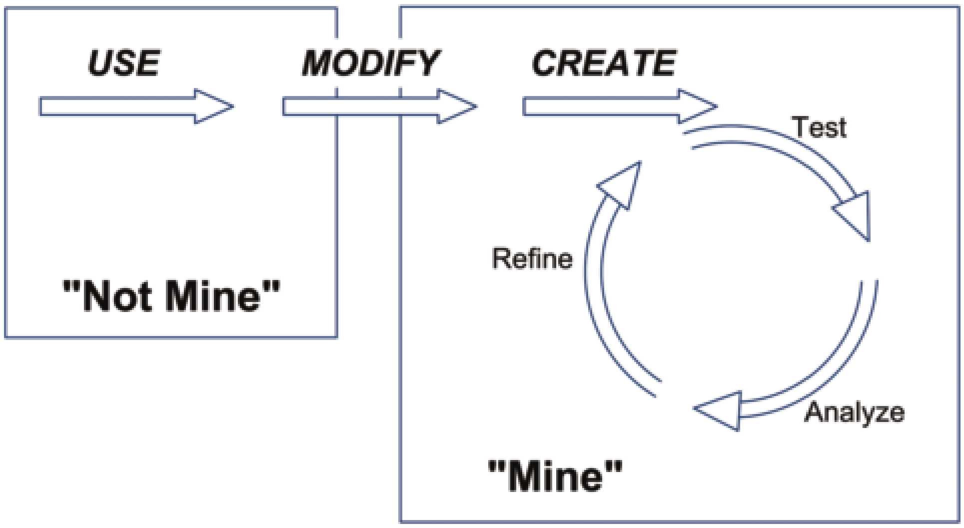

Figure 1. Diagram of Use-Modify-Create Learning Progression (Lee et al., 2011)

WeDo Lego Robotics - WLR is a robotics hardware and software platform specifically designed for second to fourth grade students. It includes step-by-step building and coding instructions for twelve robotic projects. Students are encouraged to explore building and coding possibilities by modifying presented designs (Burfoot, 2013).

Summary

Prior research has shown the inclusion of WLR during an elementary-school day had a positive impact on students' social, emotional, and academic growth (Hudson, 2016). The current research examines a novel intervention designed to increase this positive impact by developing students' interest in STEM subjects and careers and computational thinking skills. Chapter One provides an overview of the research focus, which was to implement a multifaceted robotics-based intervention and examine its ability to increase student interest in STEM subjects and careers and development of computational thinking skills. An understanding of ways to positively impact these factors is valuable because both have been identified as important competencies for student future academic and career success. AR was used to examine the robotics-based intervention. AR was appropriate for this research because it is designed to bring about positive change through the examination and improvement of practices that impact student learning, with the goal of improving student learning outcomes. It was the researcher's goal to use findings from this study to positively impact student growth in the research setting and to add to current knowledge related to the use of educational robotics with young elementary-aged children. It is the researcher's hope to share the findings from, and thick descriptions of, this research so that others seeking to solve similar problems can determine the applicability of the intervention for use in their own setting.

Subsequent chapters include: Chapter Two - A review of the literature related to this research is presented, including robotics, STEM careers, computational thinking, and constructionism, which was the theoretical foundation of this research; Chapter Three - The research methodology and design are explained in detail, including instrumentation, data sources, data collection, and data analysis procedures; Chapter Four - Data analysis and findings are presented in this chapter; Chapter Five - Discussion of findings and implications drawn from data analysis are presented, along with opportunities for future research based on current findings.

CHAPTER TWO: REVIEW OF LITERATURE

This chapter includes a review of the literature related to the elements of this research. Constructionism is described and situated as the theoretical foundation of this research. Literature related to the focus of this research, educational robotics, is also presented, along with research related to the vision of the future workforce predicted to await current elementary-aged students. Research related to educational robotics and the future workforce help to establish the importance of student development of an interest in STEM subjects and careers and development of computational thinking skills. Research is presented that points to ways educational robotics can be used to develop student interest in STEM subjects and careers and computational thinking skills in children. The final section of this chapter reviews research related to the multifaceted intervention, grounding its components in constructionist theory and establishing their inclusion as appropriate to meet the goals of this research.

Constructionism

The conceptualization, design, and creation of the multifaceted robotics-based intervention implemented and examined in this research was strongly influenced by Seymour Papert's theory of constructionism (Papert, 1980). In its simplest terms, Papert described constructionism as learning by making (Keengwe et al., 2014). The theory of constructionism is rooted in Papert's belief that students can learn deeply when their experiences and environment are saturated by a concept, they construct a public, physical artifact, and they reflect on their building and learning experience (Papert & Harel, 1991).

Papert describes viewing the activities in an art classroom, which required students to use their knowledge of art to create a product, as the spark for his belief in the value of physical construction of knowledge (Papert & Harel, 1991). Papert and colleagues at Massachusetts Institute for Technology brought this theory to life with the development of the LOGO programming language and the programmable Turtle, an educational robotics tool that allows children to learn through construction and visualization of their thinking (Mikropoulos & Bellou, 2013; Ucgul & Cagiltay, 2014)

Many current practices regarding the inclusion of robotics in education are grounded in the theory of constructionism (Papert, 1980), which says knowledge is constructed by the learner through active learning and is supported by experience and concrete constructions in the world (Barak & Zadok, 2009; Bers et al., 2014; Lindh & Holgersson, 2007; Mubin et al., 2013; Papert, 1980). There are four main principles of constructionism:

> 1. Learning by designing meaningful projects, creating things and sharing them in community,
>
> 2. Using manipulative objects to help concrete thinking about abstract phenomena,
>
> 3. Identifying powerful ideas, tools to think with from different realms of knowledge, and
>
> 4. Learning by reflection. (Mikropoulos & Bellou, 2013, p. 6)

The value of including robotics in education is well supported by the theory of constructionism, as educational robotics programs are hands-on, encourage deep thinking, creativity, and problem solving, and require the use of computational thinking skills (Bers et al., 2014; Petre & Price, 2004; Sullivan & Heffernan, 2016; Voogt et al., 2015). According to Bers, Flannery, Kazakoff and Sullivan (2014), when children construct meaningful projects and artifacts in a reflective community of learners, they can learn deeply. Papert proposed that technology offers tools to engage students in developing meaningful projects through real-world constructions. He views the role of these real-world construction as a means of supporting the construction of mental models and learning (Mikropoulos & Bellou, 2013).

Educational Robotics

Theory, research, and practice indicate the value of robotics in education is based on the idea that the use of robotics creates hands-on, mind-on student learning (Eguchi, 2014; Nugent et al., 2010; Scaradozzi et al., 2015). Constructionist principles are applied when students build and program robotics models and use real-time feedback to cyclically analyze and improve their design and code (Kabatova & Pekarova, 2010). Research indicates educational robotics benefits students in a wide array of ways, including the development of critical thinking skills, STEM process skills, problem solving skills, creativity, persistence, social interactions, and teamwork skills (Altin & Pedaste, 2013; Barak & Zadok, 2009; Beer et al., 1999; Benitti, 2012; Eguchi, 2014; Kandlhofer & Steinbauer, 2015; Nugent et al., 2010; Petre & Price, 2004). Petre and Price (2004), write,

> In robotics, students' learning is concrete, associated with phenomena they create, observe and interact with, and so the abstractions they derive (or apply later) are grounded and relevant. Problems are

> open-ended, permitting many solutions and many approaches. Hence, robotics affords opportunities for learning problem-solving techniques and processes, integrates a number of domains, exposes realistic constraints and issues, and leaves room for creativity. (p. 148)

However, despite such findings, the inclusion of robotics in schools remains minimal, typically unrelated to the curriculum, and in many ways unchanged for decades (Altin & Pedaste, 2013; Benitti, 2012; Eguchi, 2014). Unfortunately, teachers often view robotics as superfluous to a child's education and are therefore unwilling to devote the time required to include robotics within the structure of the school day (Mubin et al., 2013).

Robotics In Elementary Schools

The literature reveals educational robotics programs typically fall into five categories of activities: (a) competitive events, (b) compulsory, regular school day integration of robotics into the curriculum, (c) regular school day use of robotics as extra activities, (d) robotic camps, and (e) after school, extra-curricular activities.

In competitive events and competition-based learning students compete, typically as teams, to find a solution to a problem. According to Altin and Pedaste (2013), competition has been shown to be the most effective way of getting students to apply math, physics, and other subjects through robotics. Participants described robotics as stimulating and motivating and were willing to persist and learn difficult information to solve the challenging robotics problems they faced (Petre & Price, 2004). Robotics competitions are outstanding and engaging constructionist opportunities for students who are interested in robotics and STEM fields. They provide team-based opportunities to learn and grow in robotics, STEM, computational thinking, and collaboration (Eguchi, 2014; Eguchi, 2015; Petre & Price, 2004). Students who enjoy robotics and are able to participate in such activities will benefit socially and academically.

Compulsory, regular school day integration of robotics into the curriculum includes activities in which teachers integrate robotics into core subject areas, such as math, science, and technology. Park (2015) investigated the impact of a ten-week program in which hands-on robotics was integrated into the core science curriculum in fourth and fifth grade general education classrooms. The experimental group showed significant improvements in motivation toward science and science achievement compared with the control group. Students indicated a positive perception of robotics and reported enjoying using robotics to learn science. Students also felt they grew in terms of communication and collaboration with peers. While this level of school day integration would seem to be the ideal, it is rarely a reality.

Regular school day use of robotics as extra activities is another type of educational robotics integration and is a common field of research found in literature related to robotics. Soares, Leão, Santos, Ribeiro, and Lopes (2011), examined a group of 11- and 12-year old students who took part in a novel robotics project as part of their regular school day. Students participating in the robotics course displayed positive changes in behavior, punctuality, commitment, active participation, and a number of other soft skills. According to Soares et al., “This opens a new paradigm. It was proved that a first successful contact with robots can be achieved at elementary schools” (p. 55). Supporting this finding is the work of Bers et al. (2014), who investigated the impact of a hands-on robotics program in kindergarten classrooms and reported kindergarten-aged children were able to build and program robots when the concepts were presented in a developmentally appropriate, sequential manner. Scaradozzi, Sorbi, Pedale, Valzano, and Vergine (2015), conducted a five year, progressive program that utilized robotics to teach students how to systematically and creatively solve problems and contribute to a global society through the application of STEM concepts. The authors concluded the program allowed children to develop an understanding of robotics and develop general life skills. According to Scaradozzi et al. (2015), “This program helped students to develop the skills that will be necessary to be successful in the 21st century” (p. 3846). Lindh and Holgersson (2007), report a one-year study of fourth and eighth graders in which students in the experimental group took part in 12 experimental classes during which students worked with LEGO construction kits and programmable bricks. Students reported enhanced feelings of community and development of an understanding of how to create code to control the robots. Taken together this research paints a picture of schools integrating robotics into the school day to expose children to STEM concepts, collaborative teams, problem-solving, and more. These efforts appear to be reaping rewards, with findings of student development of computational thinking skills, creativity, persistence, positive social interactions, and teamwork skills (Altin & Pedaste, 2013; Barak & Zadok, 2009; Beer et al., 1999; Benitti, 2012; Eguchi, 2014; Kandlhofer & Steinbauer, 2015; Nugent et al., 2010; Petre & Price, 2004). At present, this method of robotics instruction seems to have the power to reach and positively impact the largest number of students.

Robotics camps are commonly held in the summer and may be conducted by colleges, universities, or other organizations seeking to promote student interest in STEM fields and careers. Students reported the most effective and enjoyable part of camps were the projects (Ucgul & Cagiltay, 2014). Interviews with children revealed the majority felt they learned robotics, programming, science, and mathematics concepts at camp. Children worked in teams that required collaboration, which lead to enhanced social skills. Although opinions were mixed, most students felt competitions were positive and helped them build better robots. According to Nugent, Barker, Grandgenett, and Adamchuk (2012), "This capability for informal educational activities to directly support academic achievement is encouraging and illustrates the complementary potential of formal and informal education" (p. 402). Robotics camps are an important way to further the learning of students who have an interest in robotics. The self-selected group of participants gains valuable robotics, critical thinking, problem solving, STEM, and soft skills through their participation.

The final way in which educational robotics is utilized is through extra-curricular programs, which are typically hosted by schools, colleges, universities, or after school care centers. Barak and Zadok (2009) and Barker and Ansorge (2007), found extracurricular robotics was effective at teaching students STEM concepts. Additionally, when extra-curricular activities were organized in preparation for robotics competitions, students were highly motivated and saw the rewards of their learning in their ability to participate successfully during the competitions. Extra-curricular activities have a great deal of potential to teach STEM concepts. Research shows students were most receptive when projects or competitions were involved (Barak & Zadok, 2009; Barker & Ansorge, 2007).

Robotics, STEM, and Computational Thinking

Fueled by a shift in the American economy from a product-based economy to a knowledge-based economy, the design, construction, use, and maintenance of robots and computer systems are growing career fields, which require extensive STEM knowledge (Carnevale et al., 2011; Eguchi, 2014; ISTE, 2017; Popken, 201; The United States Department of Education, n.d.; The National Math + Science Initiative, n.d.; Tsupros et al., 2009). Because of this shift, workers who lack STEM knowledge and computational thinking skills may be unable to find employment in the current job market. As an example, consider the plight of laid-off factory workers who must return to school to learn how to program the robots that replaced them on the factory floor. When a machine can do the job in a fraction of the time a human can, there is little chance industry will return to human production in the foreseeable future. Therefore, education must meet the demands of the workforce and teach children the knowledge, ideas, integrated STEM and computational thinking skills necessary to be successful members of the future workforce.

STEM

STEM knowledge is in high demand and students must be aware, interested, and ready. According to Tsupros, Kohler, and Hallinen, (2009), the bipartisan STEM Education Caucus writes of STEM education (from the STEM Ed Caucus Steering Committee, US Congress):

> Our knowledge-based economy is driven by constant innovation. The foundation of innovation lies in a dynamic, motivated and well-educated workforce equipped with Science, Technology, Engineering, and Mathematics

> (STEM) skills. However, the nature of our workforce and the needs of our industries have changed over time. Today, an understanding of scientific and mathematical principles, a working knowledge of computer hardware and software, and the problem solving skills developed by courses in STEM are necessary for most jobs. Therefore, STEM education is an enormous and pressing need. STEM Education is responsible for providing our country with three kinds of intellectual capital: 1. Scientists and engineers who will continue the research and development that is central to the economic growth of our country; 2. Technologically proficient workers who are capable of dealing with the demands of a science-based, high technology workforce; 3. Scientifically literate voters & citizens who make intelligent decisions about public policy and understand the world around them. (p. 5)

Theory, research, and practice show robotics can be used to teach STEM skills to children as young as kindergarten (Bers et al., 2014) and help students transform abstract STEM concepts into concrete real-world understanding (Barker & Ansorge, 2007). Students who have experienced success in real-world, constructionist learning opportunities, such as those provided by educational robotics programs, will grow to be adults who understand the demands of the workforce of the future. Educational robotics programs that are built on constructionist theory allow students to experience STEM in action, growing their knowledge and skill through physical construction, deep thinking, and active engagement.

Computational Thinking

Computational thinking, a term coined by Jeannette Wing (2006), has been described as the use of abstraction, automation, and analysis in problem-solving. Lee et al. (2011), describe computational thinking as involving, “defining, understanding, and solving problems, reasoning at multiple levels of abstraction, understanding and applying automation, and analyzing the appropriateness of the abstractions made” (p. 32). These terms are defined by the authors as follows:

> Abstraction is the process of generalizing from specific instances. In problem solving, abstraction may take the form of stripping down a problem to what is believed to be its bare essentials. Abstraction is also commonly defined as the capturing of common characteristics or actions into one set that can be used to represent all other instances.
>
> Automation is a labor saving process in which a computer is instructed to execute a set of repetitive tasks quickly and efficiently compared to the processing power of a human.
>
> Analysis is a reflective practice that refers to the validation of whether the abstractions made were correct. (Lee et al., 2011, p. 33)

In simple terms, computational thinking allows students to take a complex problem, understand what the problem is, and develop possible solutions (Bitesize, 2017). The operational definition of computational thinking, collaboratively created by the International Society for Technology in Education and the Computer Science Teachers Association (2011), states: computational thinking is a problem-solving process that is characterized by the ability to formulate problems in a way that can be solved by a computer, data is organized and analyzed logically, data is represented through models and abstractions, possible solutions are identified, analyzed, and implemented to find the most effective combination of steps and resources, and the problem solving process can be generalized and transferred to a wide variety of problems.

Computational thinking has been described as fundamental to a child's education (Voogt et al., 2015; Wing, 2006), as it is a way of thinking that can be used to solve problems in any field of study or career. Robotics building and coding activities provide an ideal constructionist environment for students to learn and test computational thinking processes (Kabatova & Pekarova, 2010). Robotics requires students to think abstractly, create automations, and analyze their work. Completing these tasks using a robot, allows students to see the results of their thinking in action, providing real-world evidence of the outcomes of student design and coding decisions. Educational robotics programs that are built on constructionist theory allow students to experience computational thinking in action, growing their knowledge and skill through physical construction, deep thinking, and active engagement.

Educational Integration of Robotics, STEM, & Computational Thinking

Robotics education integrates STEM and teaches collaboration, computational thinking, inquiry, and problem solving skills (Altin & Pedaste, 2013; Barak & Zadok, 2009; Beer et al., 1999; Benitti, 2012; Eguchi, 2014; Kandlhofer & Steinbauer, 2015; Nugent et al., 2010; Petre & Price, 2004). These are among the skills deemed necessary in an economy that is becoming increasingly driven by computers, technology, and automation. As schools promote robotics education, they must saturate student STEM and computational thinking exposure, opportunity, and learning.

The inclusion of robotics education during an elementary school day is an ideal way to expose students to robotics, to develop computational thinking skills, to encourage interest in STEM, and ultimately pursuit of STEM-related careers. The United States Department of Education (n.d.) reports, "It's more important than ever for our youth to be equipped with the knowledge and skills to solve tough problems, gather and evaluate evidence, and make sense of information" (para. 1). The National Math + Science Initiative (n.d.) concludes STEM is where the jobs are. And, with the growth of STEM jobs outpacing non-STEM jobs by almost 50% in the next ten years, STEM is the future (National Math + Science Initiative, n.d). Nugent et al. (2010) contend, student interest in STEM careers can be stimulated through programs such as the use of robotics in the classroom, which feature hands-on and inquiry-oriented STEM learning. Additionally, robotics has the potential to engage females and underserved youth in STEM learning, as well as the potential to excite students and attract them to technology-related careers (Nugent et al., 2010). According to Eguchi (2014),

> Robotics in education effectively engages students in the learning of STEM concepts, coding, computational thinking and engineering skills, all necessary knowledge and skills for students to become successful members of the workforce in the future. Educational robotics is an all-in-one technological learning tool that promotes the future success of our students... (pp. 32-33)

Intervention Components

Research indicates robotics is an important way to engage elementary-aged students in math and science, teach coding, robotics, and computational thinking skills, and to interest students in STEM subjects and ultimately careers. (Leonard et al., 2016; Nugent et al., 2010). While voluntary and extracurricular activities are important to increase interested students' knowledge and skill in robotics related activities, the lack of research-based, compulsory integration of robotics into the regular school day misses the opportunity to expose all students to the possibilities and opportunities of robotics and other STEM fields. While the school day is already filled with compulsory curriculum, it is possible to incorporate educational robotics into the regular school day through its use as an extra activity (Altin & Pedaste, 2013; Barak & Zadok, 2009; Beer et al., 1999; Benitti, 2012; Eguchi, 2014; Kandlhofer & Steinbauer, 2015; Nugent et al., 2010; Petre & Price, 2004). This approach allows all students to participate and ensures equal access to the learning opportunities provided by exposure to educational robotics. Although the value of the inclusion of educational robotics during the regular school day is evident in the literature, a review of the literature revealed limited research related to the use of WLR in elementary education classrooms. Therefore, this intervention was developed and examined to provide elementary schools with an efficient and effective way to increase young students' understanding of computational thinking and interest in STEM subjects and careers. It is the author's belief this intervention is a novel undertaking.

In this research, a multifaceted robotics-based intervention, which includes WeDo Lego Robotics (WLR) facilitated by trained, STEM-speaking volunteers and teachers, a classroom STEM learning center, the use of the Use-Modify-Create learning progression to scaffold student development of computational thinking skills, and a student robotics showcase has been designed, implemented, and examined to determine its ability to develop student interest in STEM subjects and careers and the development of computational thinking skills. This model was developed based on the theory of constructionism, an extensive review of the literature related to developing student interest in STEM subjects and careers and computational thinking skills, and opportunities available during the regular school day.

WeDo Lego Robotics

WLR provides age-appropriate scaffolded, independent robotics building and coding opportunities for elementary-aged students. Students are guided through step-by-step building and coding instructions that result in the creation of twelve working robots. Instructions provide additional ideas for robot design and programming modifications. According to research, WLR has been used in educational settings to advance young children's understanding of computer programming (Mayerova, 2012), expose young children to basic engineering concepts, engage creative thinking, teamwork, and problem-solving skills (Scaradozzi et al., 2015), provide a low-ceiling for beginning programmers (Mayerova, 2012; Romero, Lopez, and Hernandez, 2012; Scaradozzi et al., 2015), and improve student engagement in school (Romero et al., 2012).

In a qualitative study, Mayerova (2012) used WLR with third grade students to determine the impact of prior exposure to virtual robotic software on student understanding of computer programming. The author found "...educational robotics using tangible objects is the easiest way for children to understand programming language" p. 39. Scaradozzi et al. (2015) used WLR with first through third grade students and found students developed a skill set deemed to be necessary for success in the 21st century, which included an understanding of robotic construction and programming, as well as an understanding of the value of working collaboratively, developing new skills, and facing new problems. Mayerova (2012), Scaradozzi et al (2015), and Romero et al. (2012) selected WLR for their research based on its ease of use for beginning programmers. Mayerova (2012) describes the WLR programming language as easily compared to a sentence: the beginning lets the robot know to start listening and the remaining blocks, similar to the words in a sentence, tell the robot what to do. This is a simile children were able to understand and apply to their own practice. Scardozzi et al. (2015) and Romero et al. (2012) describe the WLR programming language as appropriate for primary school-age students due to its low learning curve, as it uses visual programming rather than code writing. In a pilot study evaluating robotics clubs in elementary school, Romero et al. (2012) found K-3 teachers who piloted WLR clubs in their schools reported participating students' class attendance, grades, and motivation increased, and behavior improved, indicating participation in WLR increased student engagement in school. Taken together, this research indicates WLR is appropriate for use with early elementary-aged students and can be used to positively impact student learning.

WLR is an established program at the research site in the current study. In prior research conducted at this rural, Title I, public elementary school in the Southeastern United States, WLR was introduced into the school day as a regular school day extra activity (Hudson, 2016). Although students were supported by teachers and trained adult volunteers, students were primarily left to build, code, and construct an understanding of robotics on their own. Data collection and analysis revealed this approach had a positive impact on student positive behavior traits, student attitude toward school, student technology vocabulary, and student robotics knowledge. However, no increase was seen in student interest in robotics or STEM careers. Based on the literature, this is an important outcome for future student success (Eguchi, 2014; Leonard et al., 2016; National Math + Science Initiative, n.d; Nugent et al., 2010; Tsupros et al., 2009; The United States Department of Education; n.d.), and is therefore a focus area of this research.

Classroom Learning Center Activities

A common method of supporting student learning is to provide students with scaffolded activities presented in an independent classroom learning center. Learning center activities can be differentiated to meet individual student needs and to focus student learning by providing background and supporting material to students as deemed necessary to remediate or accelerate learning. Classroom learning centers allow scaffolding of skills, enable transfer of learning, support equity, and are systemic and sustainable (Repenning, Webb, & Ioannidou, 2010). Teachers often use classroom learning center activities as formative assessments to gauge student understanding and to provide activities that aid students in growing or closing gaps in their understanding of the concepts required for achieving learning objectives.

Classroom learning centers, also called stations, which are commonly used to create opportunities for students to participate in self-directed learning, have a long and successful history in education (Drozda & Seaberg, 1978). In 1975, Brick wrote of her discovery and implementation of “a new approach to classroom learning” called, “Stations for Learning”. Brick (1975) utilized this approach to teach Language Arts skills to twenty-seven fifth and sixth graders and reported its use resulted in student knowledge acquisition, success, and happiness. Since that time, classroom learning centers have been used extensively in education to meet the individualized needs of students with varied abilities, interests, and background knowledge, as well as promote independent learning (Bell, 1983), integrate subject matter, build interest, and allow for inquiry (Jarrett, 2010). According to Jarrett (2010), use of learning centers, "...increases motivation, curiosity, content knowledge, and cross-disciplinary understanding…" (p. 59). Classroom learning centers typically focus on core curricular subjects such as math, language arts, science, and social studies (Brick, 1975; Ediger, 2011; Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur & Sendurur, 2012; Jarrett, 2010; Ottenbreit-Leftwich, Glazewski, Newby & Ertmer, 2010; Rounding, Tee, Wu, Guo, & Tse, 2013). However, they have also been used effectively to teach robotics skills during robotics camps (Keengwe et al., 2008; Nugent et al., 2010).

All classroom instruction at the research setting in the current study, both teacher-led and independent, is small-group based. Therefore, the use of independent classroom learning centers is commonplace and viewed as desirable to promote student learning.

Use-Modify-Create Framework

The Use-Modify-Create learning progression was proposed by Lee et al. (2011) as a method for teaching computational thinking skills to K-12 students. It is based on the premise that scaffolding increasingly deep interactions will promote the acquisition and development of computational thinking. Robotics, which allows constructionist learning through hands-on examination of the results of coding decisions, presents an ideal environment to scaffold students' learning experiences and exposure to computational thinking. Grover and Pea (2013) contend educational robotics are ideal for fostering computational thinking skills in students because they exhibit a "low floor, high ceiling," meaning they are easy enough for a beginner to use to create a working program (low floor), but powerful enough to allow advanced programming and retain the interest of advanced students (high ceiling). According to Lee et al. (2011), robotics presents a rich computational environment that allows for the underlying abstractions and mechanisms to be inspected, manipulated, and customized by students. In the use stage, students are consumers who rely on the robotics building and coding activities to guide their thinking and learning. Next, students move from consumers to producers by modifying and testing existing designs and coding. Lee et al. (2011, 2014) posit that as students gain comfort with modifying the model, they will be able to do so with increasing levels of sophistication. Werner, Denner, and Campe (2012) conducted a study in which 311 students, ranging in age from 10-14 years, used the programming language, Alice, and the Use-Modify-Create learning progression for more than 20 hours during a semester. Although the use of the Use-Modify-Create learning progression was not the focus of this research, the authors chose to utilize this approach to instruction because it created an environment which scaffolded student learning. “In the first half of the semester, students worked through a series of self-paced instructional exercises built to provide scaffolding, which we called ‘challenges.’ During the last half of the course, the students freely designed and developed their own games” (p. 8).

During the modification stage students gain a beginning understanding of abstraction, automation, and analysis. “Through a series of modifications and iterative refinements, new skills and understandings are developed as what was once someone else’s becomes one’s own” (Lee et al., 2014, p. 66). As students develop skill and confidence, they can be encouraged to see themselves as producers and to develop their own ideas and create designs and coding of their own. The create stage requires increased utilization of all three key aspects of computational thinking: abstraction, automation, and analysis. Envisioning and designing robots that are able to perform a desired task requires abstraction. Building designs and creating code that allow robots to complete the desired task requires automation. And, iterative decision making, error checking, and program refinement require analysis of the design and code. According to Lee et al. (2014), when students are able to create designs and coding of their own, they are displaying clear evidence of computational thinking. The goal of the Use-Modify-Create learning progression is to scaffold students from users to creators, capable of using computational tools and techniques to construct new robotics designs built upon their prior experiences using and modifying the work of others. “As a foundation moving forward, the Use-Modify-Create framework offers a helpful progression for developing computational thinking over time. Its greatest benefit is in illustrating the benefits arising from engaging youth with progressively more complex tasks and giving them increasing ownership of their learning” (Lee et al., 2011, p. 36).

Inclusion of the Use-Modify-Create learning progression in this intervention provided scaffolding, which according to Lee et al. (2014), and in keeping with the constructionist opportunities provided by robotics, allowed the development of computational thinking to evolve rather than be explicitly taught.

Student Robotics Showcase

Projects, competitions, and showcases are frequent components of educational-robotics programs. Research has shown students are highly motivated by and enjoy opportunities to share their robotics knowledge in a public and/or competitive setting (Altin & Pedaste, 2013; Barak & Zadok, 2009; Kabatova and Pekarova; 2010; Petre &

Price, 2004; Ucgul & Cagiltay, 2014). Altin and Pedaste (2013) qualitatively analyzed a variety of approaches used to teach robotics and found competition-based learning to be one of the most commonly used in schools. Their analysis found it to be the most effective way of getting students to apply core-subject knowledge (math, physics, etc.) through robotics. They concluded students are motivated by competition. In a study of 80 seventh and eighth grade students in which students attended a robotics course two hours per week for fifteen weeks, Barak and Zadock (2009) found that ten pupils from the group who created an original robot to compete in a robotics contest exhibited strong motivation, unlike their classmates who only participated in the robotics course. This finding motivated the authors to redesign their course in the second year. The redesigned course resulted in a considerable change in student motivation. Following several iterations of their robotics course during which they introduced various types of assignments, Kabatova and Pekarova (2010) recommend incorporating competition and exhibition into student robotics programs. Their findings suggest these activities appeal to and motivate different students, potentially broadening the range of students attracted to robotics. Based on findings from empirical studies of a large group of diverse children ages 6 to 18 at two robotics competitions and one long-term case study of two young children, ages 6 and 8, at robotics competitions over a two-year period, Petre and Price (2004) concluded the children were motivated to learn and to persist by the desire to build a better robot, the social context of competition, and the potential prize. In a multiple-case design study of two robotics training camps with a total of 55 children in attendance, Ucgul and Cagiltay (2014) found most children felt competitions were positive and helped them build better robots. The authors concluded tournaments and challenges should be used to increase motivation and make camp more entertaining, but fun should be emphasized, rather than competition.

To maximize the idea of student fun and sharing in a non-competitive environment, the culminating component of this intervention was a student robotics showcase. This showcase allowed students to display and demonstrate their robotics creation, as well as the STEM and computational thinking skills and attitudes they have acquired through participation in this intervention.

Summary

The theoretical foundation of this research is Papert's theory of constructionism which states that children can learn by making. Constructionist theory contends that when children are given the opportunity to learn through experiences situated in an environment saturated by the concept, construct a public, physical artifact, and reflect on their building and learning experiences, they can construct knowledge and learn deeply. Educational robotics programs are often based on the idea that the use of robotics creates hands-on, mind-on student learning. Research has shown educational robotics benefits students in a wide array of ways, including the development of critical thinking skills, STEM process skills, problem solving skills, creativity, persistence, social interactions, and teamwork skills (Altin & Pedaste, 2013; Barak & Zadok, 2009; Beer et al., 1999; Benitti, 2012; Eguchi, 2014; Kandlhofer & Steinbauer, 2015; Nugent et al., 2010; Petre & Price, 2004). Nevertheless, the inclusion of robotics in schools remains minimal and rarely reaches all students during the regular school day. This must change as the growth in the technology segment of the American economy requires schools to prepare students for career fields which require extensive STEM knowledge and computational thinking skills.

Research has demonstrated that robotics can be used to teach STEM skills to children as young as kindergarten (Bers et al., 2014) and help students transform abstract STEM concepts into concrete real-world understanding (Barker & Ansorge, 2007). Robotics building and coding activities have also been shown to provide an ideal constructionist environment for students to learn and test computational thinking processes (Kabatova & Pekarova, 2010). Students who have experienced success in real-world, constructionist learning opportunities, such as those provided by educational robotics programs, will grow to be adults who understand the demands of the workforce of the future. Educational robotics programs that are built on constructionist theory allow students to experience STEM and computational thinking in action, growing their knowledge and skill through physical construction, deep thinking, and active engagement.

The intervention described in this research is designed to expose early elementary-aged students to computational thinking and STEM through the implementation of a multifaceted robotics-based intervention, the elements of which are research-based. This intervention was developed based on the theory of constructionism, a review of the literature related to developing student interest in STEM subjects and careers and computational thinking skills, and opportunities available during the regular school day. The intervention was implemented during the regular school day as an extra activity to ensure equal access to learning opportunities for all students. WLR, which was an established program at the research site and has been successfully used in other educational settings with young children, was the educational robotics platform selected for this intervention. STEM-speaking teachers and volunteers, trained in the methodology and goals of this research, were essential to the implementation of this intervention. Classroom learning centers, which are commonly used at the research site and have been used for many years to support and scaffold core-subject learning, were used to enhance student understanding of STEM and computational thinking. The Use-Modify-Create learning progression was utilized during this intervention to scaffolding student development of computational thinking skills (Lee et al., 2011), by growing students from users to creators of computational products in an effort to advance student understanding and use of computational thinking. Inclusion of the Use-Modify-Create learning progression in this intervention provided scaffolding, which according to Lee et al. (2014) and in keeping with the constructionist opportunities provided by robotics, allowed the development of computational thinking to evolve rather than be explicitly taught. The final element of this intervention was student participation in a robotics showcase during which students shared their robotics knowledge with an audience of their teachers, parents, and peers. Creating and sharing a public artifact is in keeping with the theory of constructionism and has been shown to motivate student participation in robotics.

The literature supports the idea that students benefit from development of interest in STEM subjects and careers (Carnevale, Smith, & Melton, 2011; Eguchi, 2014; ISTE, 2017; Keengwe et al., 2008; National Math + Science Initiative, n.d; Nugent et al., 2010; Park & Han, 2016; Scaradozzi et al., 2015; Tsupros et al., 2009) and development of computational thinking skills (Eguchi, 2014; Grover & Pea, 2013; Lee et al., 2011, 2014;

Leonard et al., 2016; Voogt et al., 2015; Wing, 2006), as these are concepts and skills projected to be integral for success in the workforce of the future (Carnevale et al., 2011; Eguchi, 2014; ISTE, 2017; Tsupros et al., 2009). However, little research exists which examines robotics-based interventions designed to expose early elementary school-age students to these concepts and skills. The use of robotics in the classroom is an ideal way to elevate student understanding of integrated STEM concepts, promote an interest in STEM subjects and careers, and aid students in the development of computational thinking skills. Because STEM careers are predicted to be the jobs of the future, developing this knowledge, awareness, and interest is important for student future success. The inclusion of robotics during an elementary school day is an ideal way to expose students to computational thinking and STEM concepts and develop and encourage pursuit of these interests and ultimately careers. According to Eguchi (2014), "Educational robotics is a transformational tool for learning, computational thinking, coding, and engineering, all increasingly being viewed as critical ingredients of STEM learning in K-12 education" (p. 27). As STEM careers are projected to be in high demand in the future workforce, it is the responsibility of educators to prepare students for this future reality. Educational robotics provides an all-in-one tool to teach students the skills required for future success (Eguchi, 2014).

CHAPTER THREE: METHODOLOGY

Action research (AR) was used to examine the impact of a robotics-based intervention on student interest in science, technology, engineering, and mathematics (STEM) subjects and careers and development of computational thinking skills. The robotics-based intervention examined in this study included: 1) Weekly WeDo Lego Robotics (WLR) building and coding sessions facilitated by trained, STEM-speaking teachers and volunteers, 2) a classroom STEM learning center, 3) the use of the Use-Modify-Create learning progression to scaffold student development of computational thinking skills (Lee et al., 2011), and 4) a student robotics showcase. This intervention was designed to promote an early understanding of and interest in STEM and development of computational thinking skills through the use of educational robotics. These are important learning outcomes that have the potential to positively impact student current and future success.

Statement of Problem

The need for workers with STEM skills and knowledge has grown steadily in recent years and this growth is projected to continue (Carnevale et al., 2011). It is incumbent upon the K-12 public education system to prepare students for the demands of the future workforce. Early development of student interest in STEM subjects and careers and computational thinking skills has the potential to start students on the path to future academic and career success. This research was designed to examine the impact of a robotics-based intervention intended to grow students in these skills, attitudes, and interests.

Research Questions

Research Question 1 - What is the impact of a robotics-based intervention on elementary-aged students' interest in STEM subjects and careers?

Subquestions

- Does the intervention have an effect on student attitude toward STEM subjects?
- Does the intervention have an effect on student attitude toward STEM careers?
- How did the intervention impact student attitude toward STEM subjects and careers?

Research Question 2 - What is the impact of a robotics-based intervention on elementary-aged students' computational thinking skills?

Subquestions

- Does the intervention have an effect on student development of computational thinking skills?
- How did the intervention impact student development of computational thinking skills?

This chapter explains the research methodology and design used in this study. Participants and their context are described, as well as the data collection instruments and strategies used. Data analysis procedures are explained, as well as ethical considerations.

Research Methodology

AR provides a way for teachers to find solutions to problems in education (Willis & Edwards, 2014; Efron & Ravid, 2013). To accomplish this, AR is conducted in the field and involves using local knowledge and experiences to solve local problems. It is an emergent methodology of research that allows modifications to occur based on unfolding events, reflection, and evaluation (Clark, 1980; Macintyre, 2000; Manfra & Bullock, 2013; Wood & Butt, 2014). According to Clark (1980), this characteristic of AR embraces an openness in attitude that allows theories to be changed when they are inconsistent with evidence. This is accomplished through design, implementation, and evaluation of potential solutions, with the ultimate goal of identifying ways to solve the targeted problem. Although AR is typically practical rather than theoretical, it is theory informed. It contributes to local knowledge and through the use of thick descriptions, may be generalized by other researchers and practitioners who are seeking to solve similar problems (Willis & Edwards, 2014). These characteristics make AR ideally suited to this research in which a novel robotics-based intervention was implemented and examined.

Research Design

In this research, AR was conducted in two regular-education classrooms at a rural Title I elementary school in the Southeastern United States. Multiple stakeholders who had a significant investment in the outcome (Clark, 1980), worked collaboratively with the researcher to design, implement, and examine a robotics-based intervention with multiple components, 1) weekly WLR building and coding sessions facilitated by trained, STEM-speaking teachers and volunteers, 2) the use of the Use-Modify-Create learning progression to scaffold student development of computational thinking skills, 3) a classroom STEM learning center, to aid students in the development of interest in STEM subjects and careers and computational thinking skills, and 4) student participation in a robotics showcase.

Two classroom teachers, who were interested and invested in using robotics to positively impact students and their learning, collaborated in this study. These teachers developed their weekly lesson plans together, which created consistency in their teaching style and in the material presented to their students. To maintain consistency between classrooms during this study, all teachers and volunteers received the same training. Additionally, all classroom STEM learning center materials were created collaboratively, resulting in identical STEM learning centers in each classroom. The researcher monitored implementation of WLR and classroom STEM learning centers to ensure consistency.

The intervention was a coordinated, multifaceted robotics-based effort to scaffold and focus student learning. During a sixteen-week period, students in these classrooms participated in intervention-related activities for two hours per week. Students participated in fifteen one hour WLR building and coding sessions. These weekly WLR sessions were facilitated by trained, STEM-speaking classroom teachers and adult volunteers. Each classroom established an independent classroom STEM learning center related to the exploration, growth, and reflection of student knowledge of and interest in STEM subjects and careers and computational thinking skills. Students participated in this center as part of their classroom activities three days per week for 20 minutes per day. Students were encouraged to use the Use-Modify-Create learning progression during weekly building and coding sessions and classroom STEM learning centers. A student robotics showcase was held at the end of the WLR program. Student-pairs built and coded a novel robotics project to be presented during this showcase.

The teachers and researcher worked together to conduct this research to examine ways to improve student outcomes related to interest in STEM subjects and careers and development of computational thinking skills. Upon completion of this research, an AR report was written and shared with colleagues and a broader audience. This was undertaken in an effort to influence and improve practices in the local school context and beyond.

Preparation for Robotics-Based Intervention

Prior to student participation in WLR, teachers and volunteers participated in a training session conducted by the researcher (Appendix A). The goals of this training were to: 1) explain the goals of this research, which were to facilitate student development of interest in STEM subjects/careers and computational thinking skills, 2) familiarize adults with the context of this research, 3) explain the Use-Modify-Create learning progression, which was used to scaffold and facilitate student exploration and growth, and 4) provide adults with ideas to aid in explaining robotics concepts, discussing STEM subjects and careers, and promoting computational thinking skills.

Prior to student participation in WLR, each student completed the following: 1) obtained parent consent to participate (Appendix B), 2) assented to participation (Appendix C), 3) completed the Student Attitudes toward STEM (S-STEM) Survey: Upper Elementary School Students (Friday Institute for Educational Innovation, 2012), 4) completed an assessment of computational thinking skills (Computational Thinking Skills Test (CTt); Roman-Gonzalez, 2015), and 5) completed a career interest writing/drawing activity (Appendix D).

WeDo Lego Robotics

During this sixteen-week study, students worked in static pairs to complete up to twelve scripted building and coding activities. Research indicates working with a partner fosters collaboration, self-expression, problem-solving, and critical and innovative thinking (Brigman & Campbell, 2003; Eguchi, 2014; Larkin, 2011; National Research Council, 2011; Werner et al., 2012). Each pair of students had one laptop with the 2009589 LEGO Education Activity Pack software and one Lego Education WeDo Construction Set (9580). Students followed the on-screen building and coding directions provided by the software. Teachers and volunteers guided students through this process using the curriculum provided in the 2009580 LEGO Education WeDo Teacher's Guide (The LEGO Group, 2009). According to The LEGO group,

> The WeDo Activity Pack enables teachers to provide learning opportunities for developing these broader learning goals:
>
> - Think creatively to make a working robot
> - Develop vocabulary and communication skills to explain how the robot works
> - Establish links between cause and effect
> - Reflect on how to find answers and imagine new possibilities
> - Brainstorm ideas and endeavor to bring some of them to fruition
> - Make fair tests by changing one factor and observing or measuring the effect
> - Make systematic observations and measurements
> - Display and communicate data using tables

- Follow 2D drawings to build a 3D robot
- Think logically and create a program to produce a specific behavior. (2009, p. 3)

Building sessions occurred once per week and lasted approximately one hour each.

<u>Use-Modify-Create Learning Progression</u>

During the first eleven one-hour building sessions, students used the step-by-step building and coding instructions as presented in the 2009580 LEGO Education WeDo Construction Set Software to complete up to twelve activities: Dancing Birds, Smart Spinner, Drumming Monkey, Hungry Alligator, Roaring Lion, Flying Bird, Goal Kicker, Goal Keeper, Cheerful Fans, Airplane Rescue, Giant Escape, and Sailboat Storm (Appendix E). Each activity typically required less than one hour to complete all of the building and coding steps as presented in the WLR software. During the first week, all students completed Project 1, Dancing Birds. During subsequent weeks, students completed an activity of choice during each of the WLR sessions. Projects were not sequential and did not require prerequisite skills. This flexibility allowed students to self-direct and self-pace their learning. All projects included the opportunity for students to build, program, and test robots, brainstorm to find creative solutions, display teamwork to communicate, share ideas, work together, and modify a robot’s behavior. Robots could be modified by changing the mechanical system and/or programming code or by adding a sensor to provide feedback. Students utilized the following programming concepts: basic sequencing skills, conditional statements, sensors, and repeat loops. Students used the instructions as presented for each project. Following completion of each project, teachers and volunteers encouraged students to modify the design and/or code of their robots. As modification is critical to the development of student ownership and computational thinking skills, projects were stored from week to week to allow students time to complete modifications. Skills taught in the twelve projects overlap, making it unnecessary for students to complete all twelve to learn the desired coding concepts and computational thinking skills. It was more important for students to have time to modify their building and coding than to complete all twelve projects. However, it was possible for students to do both within the time allotted. At the conclusion of the eleven-week period, students used what they had learned to create novel robotics projects to present during a student robotics showcase. Four building sessions were allotted for students to design, create, test, analyze, and refine their creations, prior to presentation.

Independent Classroom STEM Learning Center

Independent classroom STEM learning centers were established in each participating classroom. Students participated in the STEM learning center three days per week (Tuesday, Wednesday, and Thursday) for approximately 20 minutes each day during classroom center rotations. Typically, three or four students worked concurrently at a center. The STEM learning center included a variety of reading material and video clips related to STEM subjects and careers, as well as online activities designed to promote interest in STEM and development of computational thinking skills. Additionally, students were required to write a reflection about each week's WLR building and coding activity and share their understanding of their use of the Use-Modify-Create learning progression. Each student recorded their thinking and learning in a STEM notebook (Appendix F).

Tuesday's STEM learning center activities were buddy reading activities. Students had a wide variety of STEM subject, career, and biography books from which to select. Buddies pair-read a book, chapter, or passage of choice. Students used the provided graphic organizer prompts to discuss their understanding of what they had read (Appendix G). The buddy reading and discussion activities completed each week during classroom STEM learning centers were designed to expand students' understanding of STEM subjects and careers and their importance in the world. Additionally, these activities were designed to help students see STEM applications for their interest and/or learn about STEM fields aligned with their interest, as well as explore unfamiliar STEM careers. These activities were designed with the idea that even if a child's career interest does not change, they will realize STEM is an important part of many careers and that STEM education will help them achieve their future career goals.

On Wednesday during STEM learning center time, students used Chromebooks to view videos related to STEM subjects and careers and/or play online games designed to promote computational thinking skills. Students had a variety of web-based activities from which to choose (Appendix H).

Students participated in weekly WLR building and coding sessions on Wednesday afternoons. During STEM learning center time on Thursday, students complete a reflection activity designed to promote and examine their use and understanding of the Use-Modify-Create learning progression as it related to their WLR building and coding sessions (Appendix F).

<u>Student Robotics Showcase</u>

The last four building sessions of the WLR program were devoted to student-pair creation of a novel robot to present during the student robotics showcase. During the showcase, students had the opportunity to demonstrate and explain their robots to visitors, who included parents, teachers, and peers. They also had the opportunity to view the robotics projects created by other students (see Figure 2).

Figure 2. Photograph of student robotics showcase.

Description of Stakeholders and Context

Stakeholders included two classroom teachers, General Electric (GE) volunteers, a GE volunteer coordinator, school volunteers, WLR project leadership team (which included the researcher), second and third grade students, and school administration. The classrooms participating in this study represented a self-selected sample of teachers eager to incorporate robotics into their classrooms. Both teachers had experience with WLR, as they had incorporated WLR into their classrooms during prior school years. Classrooms were racially, academically, and socio-economically diverse, resulting in groups of learners with varied backgrounds, experiences, and abilities. Students participated in WLR building and coding sessions for one hour per week. These sessions were supported by classroom teachers, GE volunteers (the majority of whom are engineers), and school volunteers (the majority of whom are parents or grandparents of students). Typically, classrooms had the support of two to three volunteers per week.

Context strengths included the fact that the researcher had the authority and autonomy to make changes to the implementation of the WLR program. Teacher and volunteer training was an established component of the WLR program and was easily enhanced to facilitate the goals of this research. Additional strengths included supportive and engaged stakeholders, particularly volunteers and teachers who were willing to implement program features and enhancements. Additionally, findings from previous research provided direction for program improvement. The WLR program was established and ongoing, which provided established best practices in terms of procedures and protocols, as well as the opportunity for further research if indicated.

Participants

Thirty-seven students from two regular-education classrooms participated in this study. Nineteen participants were female and eighteen were male. Twenty-nine participants were in the second grade and eight were in the third grade. All participants were seven to ten years of age and enrolled at a rural Title I elementary school in the Southeastern United States during the 2017-2018 school year. All students had prior exposure to coding activities through participation in Code.org's Hour of Code videos and games.

Seventy-five percent of students in this school qualified for free/reduced lunch. The school was racially diverse with 57% of students identifying as White, 24% Hispanic, 13% African American, and 6% Other. Classrooms were intentionally diverse and included academically gifted and talented children, as well as children who had been identified as exceptional based on academic, developmental, and/or emotional deficits and/or needs.

Data Collection and Instrumentation

To analyze the impact of the robotics-based intervention used in this research, pre-test and post-test data were collected using the Student Attitudes toward STEM Survey: Upper Elementary School Students (Friday Institute for Educational Innovation, 2012), Computational Thinking Test (Roman-Gonzalez, 2015), and a career interest writing/drawing activity. Following the sixteen-week intervention, post-test data from student work in STEM notebooks used during classroom STEM learning centers and artifact-based student interviews were collected, transcribed, and analyzed. Research questions, data collection instruments, and data analysis procedures are described in Table 3.

Table 3 Data Collection and Instrumentation and Procedures

<table>
<tr><th>Research Question</th><th>Data Collection Instruments</th><th>Data Analysis</th></tr>
<tr><td rowspan="2">What is the impact of a robotics-based intervention on elementary-aged students’ interest in STEM subjects and careers?

Subquestions
● Does the intervention have an effect on student attitude toward STEM subjects?
● Does the intervention have an effect on student attitude toward STEM careers?</td><td>Student Attitudes toward STEM Survey: Upper Elementary School Students (Friday Institute for Educational Innovation, 2012)</td><td>Paired-samples t-test was used to analyze results obtained pre- and post-intervention; Eta squared was used to calculate the effect size for the paired-samples t-test.</td></tr>
<tr><td>Student career interest writing/drawing activity</td><td>Paired pre- and post-intervention responses were recorded and analyzed using McNemar’s Test to examine changes in student attitude toward STEM subjects and careers (Appendix I).</td></tr>
</table>

• How did the intervention impact student attitude toward STEM subjects and careers?		Pre- and post-intervention free response answers were coded and thematically analyzed to look for patterns and trends in the data (Appendix D).
	Artifact-based student interviews using students' STEM notebooks, career interest writing/drawing activity, and student robotics showcase projects	Student artifact-based interviews were used to collect qualitative data regarding changes in student attitudes toward and/or understanding of STEM subjects and careers and how those changes occurred (Appendix J). Data were coded and themes were identified. Data were analyzed and results reported using descriptive statistics and student quotations.
What is the impact of a robotics-based intervention on elementary-aged students' computational thinking skills? Subquestions • Does the intervention have an effect on student development of computational thinking skills? • How did the intervention impact student development of computational thinking skills?	Computational Thinking Test (Roman-Gonzalez, 2015)	Paired-samples t-test was used to analyze results obtained pre- and post-intervention; Eta squared was used to calculate the effect size for the paired-samples t-test.
	Student work in STEM notebooks used during independent STEM learning centers	Two sets of data were collected from STEM notebooks: 1) Weekly Lego Reflection activity data and 2) robotics showcase project creation data. Data were coded and themes were identified. Data were analyzed and results reported using descriptive statistics and student quotations.
	Artifact-based student interviews using students'	Student artifact-based interviews were used to

	STEM notebooks and student robotics showcase projects	collect qualitative data regarding changes in student computational thinking skills and how those changes occurred (Appendix I). Data were coded and themes were identified. Data were analyzed and results reported using descriptive statistics and student quotes.

Student Attitudes Toward STEM Subjects and Careers

To examine student interest in STEM subjects/career and answer the research question, What is the impact of a robotics-based intervention on elementary-aged students' interests in STEM subjects and careers? the following instruments were used.

Student Attitudes Toward STEM (S-STEM) Survey.

The Student Attitudes toward STEM Survey: Upper Elementary School Students (Friday Institute for Educational Innovation, 2012) was used to measure changes in students' attitudes toward STEM subject, postsecondary pathways, and career interests. In its original form, the S-STEM Survey is a 56 item, untimed, paper/pencil test. However, the authors granted permission for the test to be modified. To meet the goals of this research, two sections of the test (21st Century Skills and About You) were omitted, resulting in a 38 item, untimed, paper/pencil test measuring students' attitudes toward STEM subjects and interest in STEM careers. This modified version of the S-STEM Survey was administered, pre- and post-intervention, to all participating students in their regular classroom setting by their classroom teacher. Test items were read to students and explained as needed.

The modified S-STEM survey is divided into four sections, 1) Math Attitudes, 2) Science Attitudes, 3) Engineering and Technology Attitudes, and 4) Your Future. Based on analysis of administration of the surveys to over 10,000 fourth through twelfth grade students in North Carolina, reliability, validity, and fairness have been established for this instrument (Unfried, Faber, Stanhope & Wiebe, 2015). The first three sections of the survey include 26 items, which have been validated at the construct-level. A five-point Likert-type response scale (strongly disagree to strongly agree) is used to measure student attitudes toward each construct. Student responses for each of these sections should be averaged to attain a “score” for each section. The higher the score, the more positive the student’s attitude is toward the construct examined in that section. Some items are negatively worded and should be assigned scoring values in the reverse order of all other questions. The fourth section of the survey, “Your Future” uses a four-point Likert-like scale (Not at all Interested to Very Interested) to examine student interest in twelve STEM career pathways. Content validity has been established through subject-matter expert and literature reviews. Reliability levels were found to be high (Cronbach’s alpha; .83-.87) and evidence of invariance across grade levels, races/ethnicities, and genders has been demonstrated. Change in comparative fit index (Delta CFI) did not exceed .003 (Unfried et al., 2015). According to the authors, the survey is effectively free from bias and the results are fair and trustworthy. These findings support the validity of interpretations and inferences made from scores. According to Unfried, Faber, Stanhope, and Wiebe (2015),

> The S-STEM surveys are robust instruments that elementary, middle, and high school STEM education program leaders can use to understand students’

> psychological states and the impact programs may have on student attitudes toward STEM disciplines and 21st century skills and interest in STEM careers. Researchers can use these surveys to collect data that are important for expanding understanding of student participation and persistence in STEM career pathways. (p. 636)

In the current study, student responses for the first three sections of the survey (Math Attitudes, Science Attitudes, Engineering and Technology Attitudes) were averaged to create a composite STEM Attitudes score. A composite STEM Attitudes score was used to measure students' attitudes toward STEM as an integrated concept because robotics does not teach science, technology, engineering, or math in isolation, but rather, teaches STEM as a single construct. In the current study, the Cronbach alpha coefficient at the construct level was .81-.85 and .85 when the STEM attitude constructs were analyzed together, demonstrating sufficient levels of reliability.

Item from the S-STEM can be found in "Student attitudes toward STEM: The development of upper elementary school and middle/high school student surveys" (Faber, M., Unfried, A., Corn, J., & Townsend, L. W.; 2013).

<u>Student Career Interest Writing/Drawing Activity.</u>

Pre- and post-intervention quantitative and qualitative data were collected using a student career interest writing/drawing activity (see Figure 3 and Appendix D). Questions were as follows:

- When I grow up, I want to be a __________.
- Will you need to know science, technology, engineering, or math to do this career? Explain your answer.

- What can you do to prepare for this career?
- Write about or draw yourself in this career.

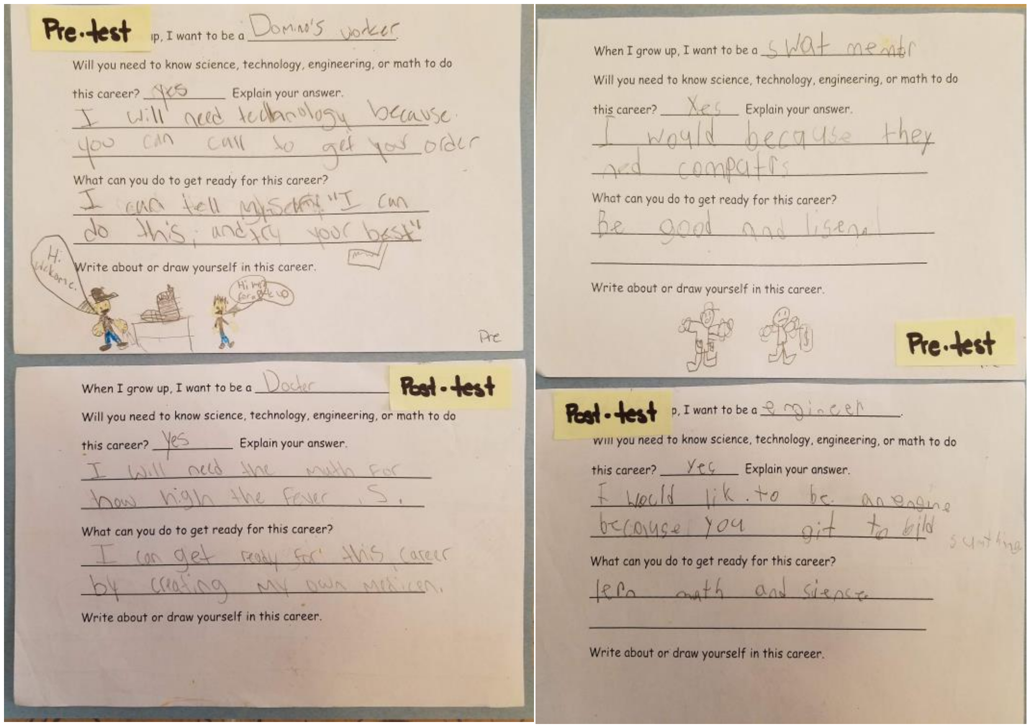

Figure 3. Photographs of completed career interest writing/drawing activities.

<u>Artifact-Based Interviews.</u>

Students' pre- and post-intervention career interest writing/drawing activities (see Figure 3 and Appendix D), robotics showcase projects (see Figure 4 and Appendix K), and STEM notebooks (Appendix F) were used to conduct artifact-based interviews to examine how the intervention impacted student attitude toward STEM subjects and careers. Research indicates the use of artifact-based interviews using robotics designs and code allows students to move beyond product descriptions and explain the processes and reasoning employed (Brennan & Resnick, 2012).

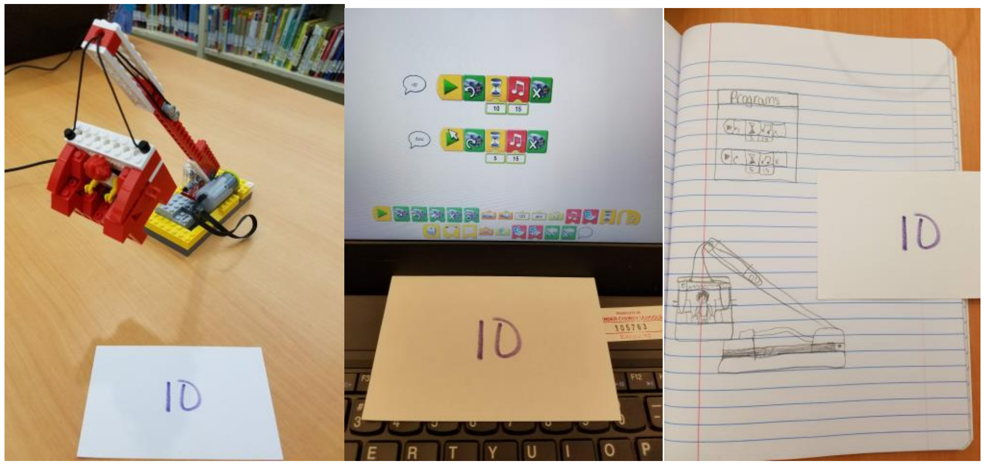

Figure 4. Photographs of robotics showcase projects artifacts.

Interviews were conducted to collect participants’ experiences and views related to the intervention and their learning (Turner, 2010). A standardized open-ended interview format was used (Turner, 2010) (Appendix J). This allowed the participants to contribute as much detail as they desired and allowed the researcher to ask unscripted follow-up questions as needed.

Twelve students were interviewed by the researcher. Research has shown theoretical saturation typically occurs within the first six to twelve interviews (Guest, Bunce, & Johnson, 2006). Students were selected using purposive sampling methods, which sought to identify students who were best and most broadly able to inform the research questions (Sargeant, 2012). Teachers were each asked to supply the researcher with the names of six to ten students who they felt were most eager and/or engaged and who they believed could articulate what they had learned and how they had learned it. Additional students were added to the list of potential interviewees based on the researcher’s review of student STEM notebook responses and robotics showcase projects. This selection method was used to interview the students best able to think about and explain their thinking and learning. Sixteen names were included on the list of potential interviewees. Students were then interviewed based on availability, until six from each class, for a total of twelve, had been interviewed.

All twelve students consented to participate in a one-on-one interview with the researcher. Each interview lasted approximately 20 minutes and was conducted during the regular school day in a private, yet familiar, setting at the school. Student STEM notebooks, career interest writing/drawing activities, and showcase projects and coding were used as artifacts students could reference as they responded to interview questions. Parts one and three of the interview related to STEM subjects and careers. In part one of the interview, questions were related to student understanding of and attitude toward STEM subjects and careers. In part three, questions were related to student attitudes and learning corresponding to each facet of the intervention. Tables 4 and 5 include the concepts examined, interview questions asked, and indicators which showed student attainment of each concept or attitudes and/or learning related to each. Evidence and narrative responses were recorded by the researcher (see Appendix J) and by an audio recording device. Interviews were transcribed to aid in coding and theme identification, as well as to ensure accuracy of student quotations used.

Table 4 Artifact-based Interview Concepts, Questions, and Indicators: Part 1: STEM

STEM Subjects and Careers	Interview Questions	Indicators
Questions are designed to determine student understanding of, interest in, and attitude toward STEM subjects and careers, as well as student perception of how they gained this knowledge.	• How do you feel about STEM subjects and careers?	• Student has positive attitude toward STEM subjects and careers.
	• Can you tell me any jobs that require STEM training?	• Student can identify jobs that require STEM training.
	• Do you think it's important to learn STEM in school? Why or why not?	• Student demonstrates an understanding of the value of STEM subjects in school.
	• Do you think STEM jobs are important? Why or why not?	• Student demonstrates an understanding of the value of STEM jobs.
	• You've said you want to be a ________________. Is STEM important in this job? Why or why not?	• Student indicates interest in pursuing a STEM career or using STEM knowledge in a non-STEM career.
	• What can you do or learn to prepare for this job?	• Student demonstrates understanding of ways STEM subjects can prepare them for a job.
	• How did you learn so much about STEM?	• Thoughtful reflection is evident.

Table 5 Artifact-based Interview Concepts, Questions, and Evidence: Part 3: Intervention

Intervention	Interview Questions	Indicators
Questions are designed to examine student attitudes and learning.	• What did you think of your weekly Lego building session? What was best? Hardest? • What did you think of the activities you did in your classroom STEM center? What was best? Hardest? • What did you think of the showcase? What was best? Hardest? • Is there anything else you'd like to share about STEM or robotics?	• Positive attitude is evident. • Positive attitude is evident. • Positive attitude is evident. • Positive attitude is evident.

Computational Thinking Skills

To examine student computational thinking skills and answer the research question, What is the impact of a robotics-based intervention on elementary-aged students' computational thinking skills? the following instruments were used.

Computational Thinking Test (CTt)

The Computational Thinking Test created by Marcos Roman-Gonzalez (2015), is designed to assess student computational thinking skills. This 28 item, untimed, online test was administered, pre- and post- intervention, to thirty-six of the thirty-seven participating students in the school's computer lab by their classroom teacher with the assistance of the researcher. Test items were read to students and explained as needed.

The CTt is a 28 item test designed to measure the development level of the computational thinking in the subject. The target population is students in grade seven and eight (12 and 13 years of age), but can be used for 5th through 12th graders. The test consists of multiple choice questions with four answer options, only one of which is correct. Answer options are either visual arrows or visual blocks. Test items are arranged by increasing difficulty and include four items for each of the following concepts: 1) basic directions and sequences, 2) for loop, 3) while loop, 4) if - simple conditional, 5) if/else - complex conditional, 6) while conditional, and 7) simple functions. Questions require students to complete one of three cognitive tasks: sequencing commands, completion of incomplete commands, or debugging incorrect commands. Test completion requires about 45 minutes. The content validation process included twenty subject-matter experts who assessed the length, difficulty, and relevance of the test and test items and participated in refinement of the instrument (Roman-Gonzalez, 2015). To assess content validity and reliability, 1,251 Spanish students participating in an elective computer science course, completed the CTt as a pre- and post-test. Results confirmed the appropriateness of item difficulty and the progressive difficulty of the CTt. Performance on the CTt was found to increase as students' grade increased. Likewise, a progressive gender gap was found beginning at seventh/eighth grade. Internal consistency reliability was found to be good (Cronbach's alpha; 0.793). Reliability was found to increase as grade increased and was higher when students completed the CTt on a mobile device that allowed images to be rotated, reducing the spatial cognitive load. CTt results were found to have a positive statistically significant correlation ($p < 0.01$) with moderate intensity, relative to the Primary Mental Abilities battery, and positive, statistically significant, and moderately-strong intense correlation ($r = 0.669$; $p < 0.01$) with the RP30 problem-solving test. Triangulation of results led Roman-Gonzalez, Perez-Gonzalez, and Jimenez-Fernandez (2016) to conclude there is powerful evidence of the criterion concurrent validity of the CTt. Results provide evidence of reliability and criterion validity of the CTt. These findings support the validity of interpretations and inferences made from scores.

Sample items from the CTt can be found in "Computational Thinking Test: Design guidelines and content validation" (Roman-Gonzalez, 2015).

<u>Student work in STEM notebooks</u>

Each week students were asked to reflect on their building and coding activities and their use of the Use-Modify-Create learning progression. Self-reported data were used to examine student understanding and use of computational thinking skills. These data were used to determine how this intervention impacted student development of computational thinking skills.

Students participated in weekly WLR building and coding sessions on Wednesday afternoons. During STEM center time on Thursdays, students completed a Weekly Lego Reflection activity. Student notebooks included the names of the programming blocks and a key for the sounds, as well as the code and a picture for each activity. Students used these to aid them in answering seven questions about their weekly building and coding experiences (see Figure 5 and Appendix F). Each week, student responded to the following reflection questions:

1. What did you build?
2. What did it do?
3. What was hard?
4. What was easy?
5. What did you learn?
6. Did you Use, Modify, or Create? Explain.

7. How could you modify your project or create something new from what you've learned? Use your imagination! Draw your design on the back.

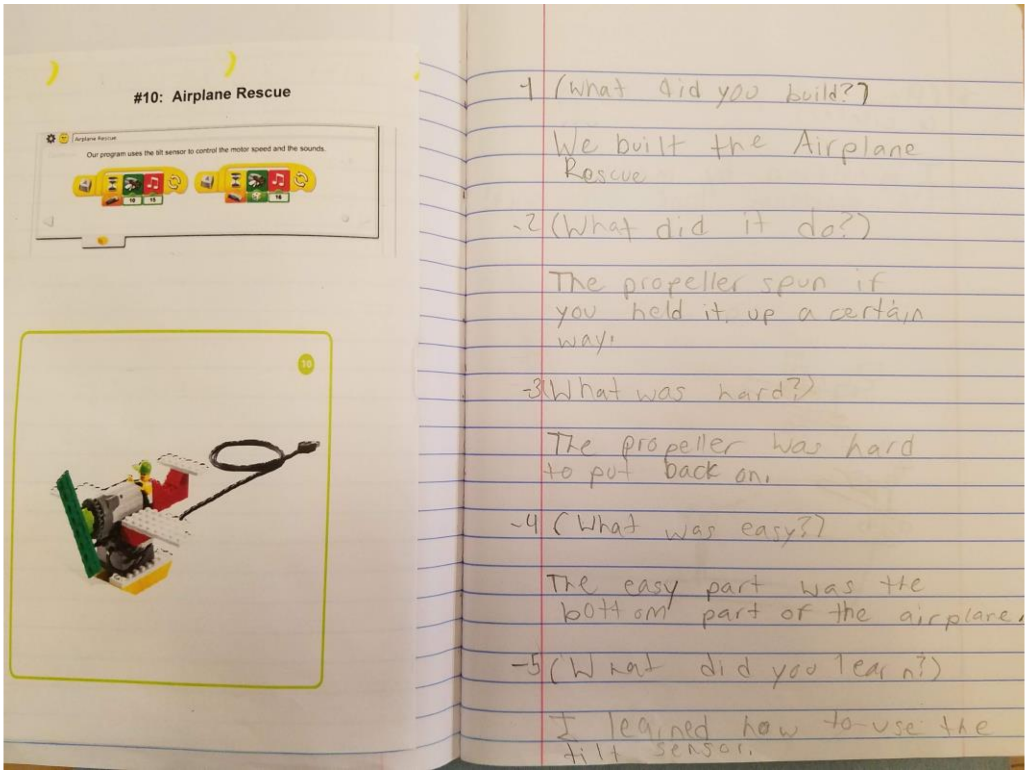

Figure 5. **Photograph of student WeDo Lego Robotics reflections in STEM notebook.**

Artifact-Based Student Interview Questions and Evidence

Twelve students participated in a one-on-one interview with the researcher. Students' STEM notebooks (see Figure 5 and Appendix F) and robotics showcase projects (see Figure 4 and Appendix K) were used to conduct artifact-based interviews (Brennan & Resnick, 2012) to examine how the intervention impacted student development of computational thinking skills. The 12 student interviewed represented one or both partners from 10 student-pairs.

Parts two and three of the interview related to computational thinking skills. In part two of the interview, questions were related to student understanding and development of computational thinking skills. In part three, questions were related to student attitudes and learning corresponding to each facet of the intervention. Tables 5 and 6 include the concepts examined, interview questions asked, and indicators which showed student attainment of each concept or attitudes and/or learning related to each. Evidence and narrative responses were recorded by the researcher (see Appendix K) and by an audio recording device. Interviews were transcribed to aid in coding and theme identification, as well as to ensure accuracy of student quotations used.

Table 6 Artifact-based Interview Concepts, Questions, and Indicators: Part 2: Computational Thinking

Computational Thinking Concept	Interview Questions	Indicators
Abstraction	• Explain your idea for your robot. • Which did you plan first? Your robot or your story? • How did you plan the way your robot would look? • Did you use, modify, or create the Lego design for your robot?	• Ability to think abstractly is evident in robot's description. • Ability to break down a problem into smaller parts is evident in planning. • Ability to identify and focus on the most important information is evident in plan description. • Ability to make generalizations is evident in use of Use-Modify-Create in design creation.
Automation	• How did you make your robot move the way you wanted it to move? • Did you use, modify, or create code?	• Ability to use, modify, and/or create computer code that results in desired outcomes is evident. • Ability to use, modify, and/or create code which results in desired outcomes is evident.

	• Can you explain what your code does?	• Ability to understand computer coding is evident.
Analysis	• Did you have any problems? • How did you solve them? • Did you test and improve your design or code? • What did you do when you got stuck and didn't know what to do? • What are you most proud of? • If you built another robot, what would you do differently?	• Ability to identify problems is evident. • Ability to solve problems is evident. • Ability to identify and solve problems is evident • Solution seeking behavior is evident. • Thoughtful reflection is evident. • Ability to thinking beyond current goal is evident.
Robotics Experience	• Did you like creating your robot? • Have you worked with robots before? Please explain. • How did you learn so much about robots?	• Positive attitude is evident. • Establish Previous Experience. • Thoughtful reflection is evident.

Data Analysis and Procedures

Pre- and post-test data collected using the Student Attitudes toward STEM Survey: Upper Elementary School Students (Friday Institute for Educational Innovation, 2012), Computational Thinking Test (Roman-Gonzalez, 2015), and a career interest writing/drawing activity, were used to examine student growth related to student development of interest in and attitude toward STEM subject and careers and development of computational thinking skills. Post-intervention data collected from student work in STEM notebooks and artifact-based interviews were used to summatively examine student understanding of and interest in STEM subjects and careers and development of computational thinking skills.

Student Attitude Toward STEM Subjects and Careers

The following quantitative and qualitative analyses were used to answer the research question, What is the impact of a robotics-based intervention on elementary-aged students' interests in STEM subjects and careers?

Student Pre/Post Student Attitudes Toward Stem Survey.

A paired-samples t-test was used to compare pre- and post-test results from the Student Attitudes toward STEM Survey to determine if the multifaceted robotics-based intervention described herein impacted student attitudes toward and interest in STEM subjects and careers. It is appropriate to treat the data from this Likert survey as interval data because multiple items were used to measure each construct (Hatcher, 2013). The paired-samples t-test was appropriate for this analysis as it allowed examination of the change in mean scores for the same group of students on two different occasions (pre- and post-intervention). Eta squared was used to calculate the effect size for the paired-samples t-test.

Student Career Interest Writing/Drawing Activities

Student career interest writing/drawing activities were used to collect quantitative and qualitative data regarding student attitude toward STEM subjects and careers. Pre- and post-intervention free response answers were coded and thematically analyzed to look for patterns and trends in the data. Paired pre- and post-intervention responses were analyzed using McNemar’s Test to examine changes in student attitude toward STEM subjects and careers. McNemar’s Test was appropriate for this analysis as it allowed examination of the change in categorical variables, with only two response options, over time (pre- and post-intervention). This analysis allowed the researcher to determine if there was a pre- and post-intervention change in the proportion of the sample who were interested in STEM careers and who believed STEM was valuable in their chosen career. Descriptive statistics and narrative evidence were also used to share findings.

Student Artifact-Based Interviews

Student artifact-based interviews utilizing STEM notebooks, career interest writing/drawing activities, and robotics showcase projects and code were used to collect qualitative data regarding student attitude toward STEM subjects and careers. Student responses were recorded, transcribed, coded, and examined (see Appendix J). Descriptive statistics and narrative evidence were used to share findings.

Computational Thinking Skills

The following quantitative and qualitative analyses were used to answer the research question, What is the impact of a robotics-based intervention on elementary-aged students' computational thinking skills?

Student pre/post Computational Thinking Test

A paired-samples t-test was used to compare pre- and post-test results from the Computational Thinking Test to determine if the multifaceted robotics-based intervention described herein impacted student development of computational thinking skills. Results from the computational thinking test were calculated by assigning one point for each correct answer, resulting in scores from 0-28. Therefore, this score is a ratio-scale variable. The paired-samples t-test was appropriate for this analysis as it allowed examination of the change in mean scores for the same group of students on two different occasions (pre- and post-intervention). Eta squared was used to calculate the effect size for the paired-samples t-test.

Student Work in STEM Notebooks

Student activities completed in STEM notebooks were used to collect qualitative data regarding student understanding of and use of computational thinking skills. Two sets of data were collected from STEM notebooks: 1) Weekly Lego Reflection activity data and 2) robotics showcase project creation data. Data were recorded and themes were identified.

Each week students answered seven questions related to their building and learning for that week (Appendix F). Student responses were recorded, transcribed, coded, and examined (see Appendix I). Descriptive statistics and narrative evidence were used to share findings

Student Artifact-Based Interviews

Student artifact-based interviews utilizing STEM notebooks and showcase projects and code were used to collect qualitative data regarding student development of computational thinking skills. Student responses were recorded, transcribed, and examined (see Appendix L). Descriptive statistics and narrative evidence were used to share findings.

Ethical Considerations

To ensure confidentiality of data, each student worked independently to complete pre- and post-testing and interviews were conducted in a private location. Electronic data were securely stored and shared only with the researcher and co-researcher. Hard copy data were stored in a locked room at the research site. Student responses were coded to protect the identity of respondents. Student names and other identifiable information were excluded in the analysis to maintain confidentiality.

Pre-tests may have caused students discomfort, as they may have been unable to answer the questions prior to their participation in the robotics-based intervention. Students were encouraged to do their best, but told they were answering questions about subjects they may not have learned yet. School culture is based on a growth mindset. Students were familiar and comfortable with the concept of “not yet”.

Role of Researcher and Biases

The researcher facilitated all stages of this research. Prior to the start of weekly WLR building and coding session, the researcher: 1) provided teachers with forms and instructions to obtain parent consent and student assent, 2) provided training for all participating teachers and adult volunteers, 3) assisted classroom teachers with the creation of classroom STEM learning centers and activities, and 4) provided teachers with instructions, materials, and support for student pre-tests. During the sixteen-week intervention period, the researcher: 1) worked collaboratively with classroom teachers to evaluate student center-work, 2) documented any changes made to the intervention and the reasons for the changes, 3) monitored WLR sessions and implementation of classroom STEM learning centers for consistency between classrooms, and 4) supported teachers and volunteers as needed. Following completion of the intervention period, the researcher: 1) provided teachers with instructions, materials, and support for student post-tests, 2) conducted artifact-based interviews with selected students, 3) examined student work in STEM notebooks, 4) conducted data collection and analysis as described, 5) prepared AR report, and 6) shared research findings with stakeholders.

All participants in this study were current or former students of the researcher. It is the ongoing goal of the researcher to provide students with as many opportunities, advantages, and experiences as possible to prepare them for the future. This had the potential to create bias, as the researcher wanted what is best for all students. However, the researcher was aware of this potential conflict and avoided research-related interactions with students during the study period. All participants had previously participated in coding activities taught by the researcher. During the study period, the researcher continued to teach library and technology skills to the second grade participants in this study. However, to avoid confounding the study variables, coding, computational thinking skills, and information about STEM careers were not taught by the researcher during the research period. The researcher worked with teachers and volunteers, but remained separate from student participation in weekly WLR building and coding sessions and classroom STEM learning center activities during the study period.

Summary

Action research was ideally suited for this research as it allowed the researcher to implement and examine a multifaceted robotics-based intervention to determine the most effective means of supporting student learning. The desired output of this AR was the examination of a practical intervention to determine its ability to impact student interest in STEM subjects and careers and student development of computational thinking skills. Developing this knowledge, awareness, and interest is important for student current and future success, and ultimately college and career readiness. Empirical testing of the effectiveness of the intervention contributes to theoretical understanding of the ways in which the inclusion of robotics in education can be used to facilitate student growth in interest in STEM subjects and careers and computational thinking skills, and promote future student academic and career success. Data analysis and findings will be presented in Chapter Four.

CHAPTER FOUR: RESULTS

Data analysis and findings are presented in this chapter.

STEM Subjects and Careers

To answer the following research question and subquestions, quantitative and qualitative data analysis was conducted and the results are presented below.

Research Question 1 - What is the impact of a robotics-based intervention on elementary-aged students' interest in STEM subjects and careers?

Subquestions

- Does the intervention have an effect on student attitude toward STEM subjects?
- Does the intervention have an effect on student attitude toward STEM careers?
- How did the intervention impact student attitude toward STEM subjects and careers?

<u>The Student Attitudes Toward STEM Survey</u>

Pre- and post-intervention quantitative data were collected using a modified version of The Student Attitudes toward STEM Survey (S-STEM Survey): Upper Elementary School Students (Friday Institute for Educational Innovation, 2012). Pre- and post-intervention student scores were analyzed using the paired-samples t-test.

<u>STEM Attitude Scores Increased Significantly</u>

A paired-samples t-test was conducted to examine the impact of the intervention on students' composite STEM Attitude scores from the S-STEM Survey. There was a statistically significant increase in composite STEM Attitude scores from pre-test (M =

3.70, *SD* = .63) to post-test (*M* = 3.92, *SD* = .54), *t* (36) = 2.79, *p* < .008 (two-tailed). The mean difference in composite STEM Attitudes scores was .22 with a 95% confidence interval ranging from .06 to .38 (see Table 7). The eta squared statistic (.099) indicates a moderate to large effect size (Cohen, 1988).

Table 7 Paired Samples Test - Composite STEM Attitude

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Post-Test - Pre-test	.22	.48	.08	0.6	.38	2.79	36	.008

STEM Career Attitudes Did Not Change Significantly

A paired-samples t-test was conducted to examine the impact of the intervention on students' scores on the STEM Career Attitudes portion of S-STEM Survey. There was no statistically significant change in STEM Career Attitude scores from pre-test (*M* = 2.84, *SD* = .63) to post-test (*M* = 2.96, *SD* = .58), *t* (36) = 1.29, *p* = .205 (two-tailed) (see Table 8).

Table 8 Paired Samples Test - STEM Career Attitude

Paired Samples Test - STEM Career Attitude

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Post-test - Pre-test	.12	.57	.09	-.07	.31	1.29	36	.205

Student Career Interest Writing/Drawing Activity

Pre- and post-intervention quantitative and qualitative data were collected using a student career interest writing/drawing activity.

Interest in STEM careers increased significantly

Student responses to question one, "When I grow up, I want to be a __________.", were coded as STEM careers or Non-STEM careers as shown in Table 9. The designation of STEM or Non-STEM was assigned based on the degree the primary job function required STEM knowledge. Some jobs were discussed with individual students to determine their perception of the primary job function. For example, students said Youtubers need to use and understand computers and technology like cameras, as well as science and math. None of these students mentioned the content they would be sharing, only the knowledge and process required to create and share the videos. The student who wanted to be a sword maker said he would be a helper, responsible for "putting tools on the desk". And, the student who said he wanted to be a Beyblade designer mentioned understanding shapes, spinning, and engineering.

Table 9 Student Pre- and Post-test Career Interest Responses

Pre-Test		Post-Test	
Non-STEM (27)	STEM (7)	Non-STEM (19)	STEM (15)
Teacher (12) Police/Military (7) Pro Sports (2) Artist/Musician (2) Car Worker (1) Construction (1) Fashion Designer (1) Fast Food (1)	Youtuber (2) Veterinarian (2) Discoverer (1) Beyblade Designer (1) Engineer (1)	Teacher (8) Pro Sports (4) Police/Military (3) Author (1) Dancer (1) Chef (1) Sword maker (1)	Scientist (5) Engineer (4) Youtuber (3) Doctor (1) Video Game Maker (1) Beyblade Designer (1)

McNemar's test was used to determine if there were differences in this dichotomous variable between pre- and post-intervention responses. Test results revealed the number of students who indicated interest in a STEM career increased from pre- to post-intervention, increasing from seven to fifteen students. Ten students who originally indicated interest in a non-STEM career, changed their career choice to a STEM career. Two student who originally indicated interest in a STEM career changed their career choice to a non-STEM career. Based on the 34 participants who completed the pre- and post-intervention career interest writing/drawing activity, McNemar's test determined there was a statistically significant difference in the proportion of students who selected STEM careers pre- and post-intervention, $p = .039$ (see Table 10).

Table 10 STEM Career Pre-test * Post-test Crosstabulation

			STEM Career Post-test		
			Non-STEM Career	STEM Career	Total
STEM Career Pre-test	Non-STEM Career	Count	17	10	27
		% within STEM Career Pre-test	63.0%	37.0%	100.0%
		% within STEM Career Post-test	89.5%	66.7%	79.4%
	STEM Career	Count	2	5	7
		% within STEM Career Pre-test	28.6%	71.4%	100.0%
		% within STEM Career Post-test	10.5%	33.3%	20.6%
Total		Count	19	15	34
		% within STEM Career Pre-test	55.9%	44.1%	100.0%
		% within STEM Career Post-test	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	Exact Sig. (2-sided)
McNemar Test		.039[a]
N of Valid Cases	34	

a. Binomial distribution used.

Examination of Table 9 showed the number of students who indicated they wanted to become scientists increased from zero on the pre-test to five on the post-test. Examination of these students' responses revealed four of the five were minorities (three

Hispanic females, one white female, and one white male). Examination of Table 9 also showed the number of students who indicated they wanted to become engineers increased from one on the pre-test to four on the post-test. Examination of the responses of the three students who changed their career choice to engineer revealed all three were minorities (one white female and two black males).

Understanding of STEM in Careers Increased Significantly

Student responses to question two, “Will you need to know science, technology, engineering, or math to do this career?” were coded as Yes or No. McNemar’s test was used to determine if there were differences in this dichotomous variable between pre- and post-intervention responses. Test results revealed the number of students who indicated STEM skills are required for their future career interest (STEM and non-STEM careers) increased from pre- to post-testing, increasing from eighteen students to twenty-nine students. Eleven students who originally indicated their career choice would not require STEM skills changed their beliefs and indicated STEM skills would be necessary in their future careers. No student who originally indicated STEM skills would be necessary in their future career changed their belief. Based on the 34 participants who completed the pre- and post-intervention career interest writing/drawing activity, McNemar’s test determined there was a statistically significant difference in the proportion of students who believe STEM skills will be required for their future career pre- and post-intervention, $p = .001$ (see Table 11).

Table 11 Need for STEM Pre-test * Post-test Crosstabulation

			Need STEM Post-test		
			Job Does Not Need STEM Skills	Job Needs STEM Skills	Total
Need STEM Pre-test	Job Does Not Nee STEM Skills	Count	5	11	16
		% within Need STEM Pre-test	31.3%	68.8%	100.0%
		% within Need STEM Post-test	100.0%	37.9%	47.1%
	Job Needs STEM Skills	Count	0	18	18
		% within Need STEM Pre-test	0.0%	100.0%	100.0%
		% within Need STEM Post-test	0.0%	62.1%	52.9%
Total		Count	5	29	34
		% within Need STEM Pre-test	14.7%	85.3%	100.0%
		% within Need STEM Post-test	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	Exact Sig. (2-sided)
McNemar Test		.001[a]
N of Valid Cases	34	

a. Binomial distribution used.

Pre- and post-intervention student responses to Question two, part two, which asked students to explain their answer to part one, “Will you need to know science, technology, engineering, or math to do this career?”, revealed increased student understanding of the ways in which STEM knowledge is used in a wide variety of jobs.

A female student who indicated both pre- and post-intervention that she wanted to be a gymnastic teacher, responded pre-test that she did not need STEM, "...because all you have to do [is] flips and stuff." Post-intervention, she wrote that she will need math "...to be a gymnastic teacher because you need to know the steps and how high when you land on your feet."

A male student who indicated he wanted to be an artist on his pre-test and a video game maker on his post-test provided responses which indicated he planned to use his art in his career as a video game maker. Pre-test he said he would not need STEM because "Art is something when you can do what ever [sic] you like!" Post-test he wrote, "I will need to know about technology because I need to work on a computer. [I will] keep working on drawing and getting better at the computer."

A female student who indicated both pre- and post-intervention that she wanted to be a teacher, responded pre-test that she did not need STEM, "...because I will not have to fix computers." Post-intervention she indicated she will need to know STEM because, "I will need to know those things because I will have to teach [them].

A female student who indicated both pre- and post-intervention that she wanted to be a horseback riding instructor, responded pre-test, "No!!!" she did not need STEM, "because I'm teaching kids how to ride horses." Post-intervention she indicated she will need to know STEM, "Because you need to count money that you get for teaching kids how to ride a horse."

A male student who indicated he would need STEM in both his pre- and post-intervention careers, police and race car driver, respectively, indicated pre-test that he needed STEM because police have tasers. His post-intervention response indicated an increased understanding of STEM when he wrote, “I need to build my car and it takes math.”

A male student who indicated both pre- and post-intervention that he wanted a career in the police/military, responded both pre- and post-test that his chosen career requires STEM. Pre-test he wrote, “I would need technology for using computers.” Post-intervention he wrote, “I will need science, technology, engineering, or math to do my career. I will need engineering if a ship is broken. I will know how to fix the ship.”

Each of these responses demonstrates increased understanding of and positive attitude toward STEM and an increased understanding of the need for STEM knowledge in both STEM and non-STEM careers.

Data Collected from Artifact-Based Interviews

Twelve students were interviewed and asked seven questions related to STEM subjects and careers. Questions were designed to elicit data related to students’ understanding of STEM subjects and careers and how the robotics-based intervention implemented in this research impacted their understanding.

All Students Expressed Positive Attitudes Toward STEM

When asked, “How do you feel about STEM subjects and careers?” all twelve students’ responses were positive. Seven students’ responses included awareness of current uses for STEM such as, “I feel comfortable. I like it. It’s fun,” and “I think that it’s kinda cool because you can make stuff and do like a lot of stuff with STEM.” Five student responses demonstrated awareness of future uses for STEM, such as, “I think I'm going to have to use it for my career when I grow up because I might have to build something new so the kids will be safe when they ride the horses," and "I'm going to be a robot engineer and I will have to use all those things from STEM."

All Students Identified Jobs Which Require STEM Training

When asked if they knew any jobs that require STEM training, all twelve students were able to identify at least three jobs that required STEM. Most jobs mentioned were in STEM fields, such as chemist, engineer, and mathematician. However, students also identified careers in non-STEM fields, such as librarians, teachers, artists, and chefs.

Students Understood the Value Of STEM Subjects In School

When asked if they thought STEM is important to learn in school, all twelve students said yes. Three themes emerged from student responses (see Figure 6). Students said they need STEM for college, for future careers, and to learn more. Three students mentioned needing STEM for college, "Because when you grow up and you go on to college, you're gonna learn about science, technology, engineering, and math. So, you need to learn it now so you can get, so you can be like, ready." Seven students mentioned needing to learn STEM for their future careers, "If you want to grow up and be an engineer, you have to know what engineers do," "So one day when we get a job, it will help us in our career," "Yes, because math is one of the letters in STEM and you need to know math in many jobs," and "You may use it in your future career." One student said, "Yes! Most jobs involve STEM!" Four students mentioned needing to learn STEM so they could learn more, "Wherever you go, they can help you with a lot of different things," and "Because you can learn more things with those four things. You can use math to learn how to solve problems and when you're doing engineering you learn how to build stuff." One student mentioned all three themes, "So you can get smart and go to college and get jobs."

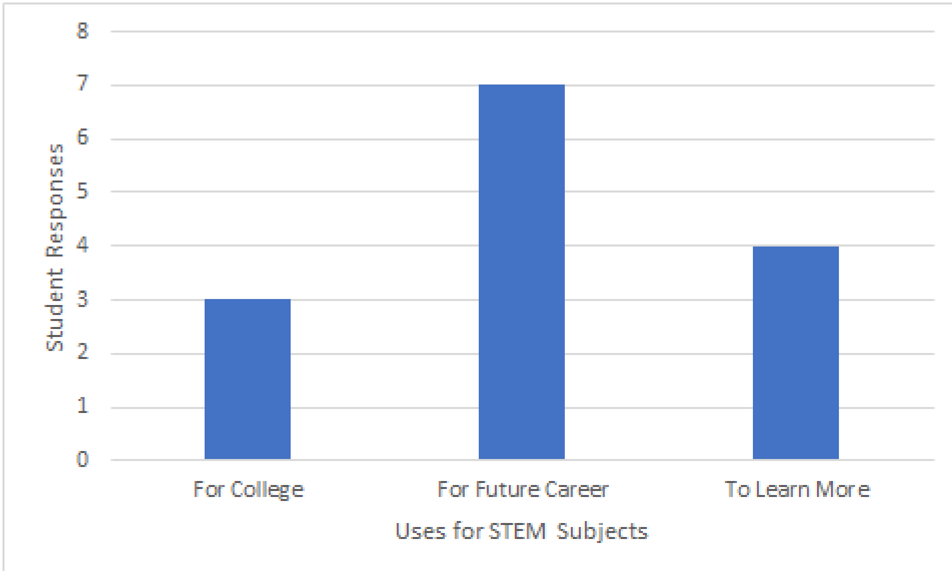

Figure 6. **Bar graph of perceived importance of learning STEM in school.**

Students Understood the Value of Stem Jobs

When asked if they thought STEM jobs were important, all twelve students said yes. Three themes emerged from student responses, students believe: STEM jobs are important because they make the world better, because they benefit you personally, because they help people learn. Five students said they were important, but did not provide a specific reason (see Figure 7). Students said, "Engineers can build stuff to make the world a better place and scientists, they test things and try to use it to make the world a better place," "Because engineers, they have to make stuff like, because maybe a lunch box was never made if somebody didn't invent it," and "Because they all help people." One student who thought a STEM job would be important to his own future said, "They pay a lot of money. I could probably have a mansion!" Related to needing STEM jobs for learning, students said, "A teachers has to teach stuff so kids know what to do" and "Teachers teach the students, so they'll know STEM when they grow up."

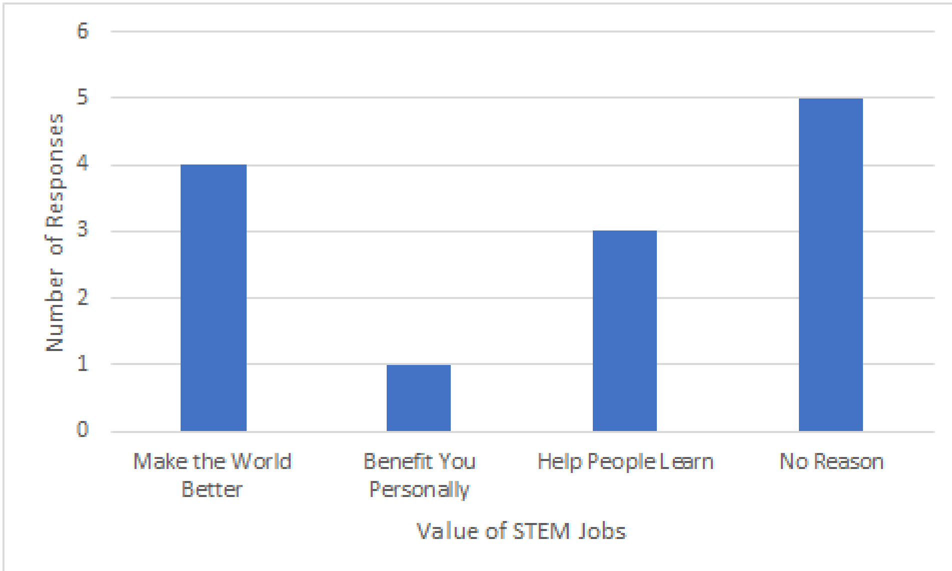

Figure 7. Bar graph of perceived importance of STEM jobs.

Most Students Were Interested in A Stem Career.

Of the twelve students interviewed, seven expressed interest in a career traditionally viewed as STEM and five expressed interest in a career traditionally viewed as non-STEM. STEM careers were youtuber, video game animator, robotics engineer, engineer, scientist, chemist, and Beyblade designer. Non-STEM careers were horseback riding instructor, librarian, soldier, and teacher (two students' choice).

All Students Indicated Stem Would Be Needed for Their Future Career

When asked if STEM is important for their future career choice, eleven students said yes and one said "kind of." The one student who said "kind of" was the student interested in becoming a librarian. She said, "Kind of because it's in the books." Explanations related to STEM careers included, "Video game animators need to know the technology and need to know math," and "Yes, because [Beyblade designing] is engineering and because you need to know how the shape is going to be and how big." Explanations related to non-STEM careers included, "I have to know engineering because I'm trying to build my own farm and I'll have to build like, a little gate that will open. And, then I also have to learn science so I could actually know how to work with the animals" and "Teachers need to know STEM so they can teach it to the students, who need to know it so when they grow up they can get good careers."

Most Students Understood Stem Subjects Prepare Them for A Future Career

When asked what they can do now to prepare for their future career, ten students mentioned learning more STEM and two did not. The two who did not were interested in non-STEM careers (teacher and librarian). The future robotics engineer said, "I can try to make a robot out of things at my house...practice and use actual material like metal." The future chemist said, "I could learn more science and it could help me by doing more science and learning about different chemicals." A future teacher said, "I could learn more math," and the future engineer said, "Do more Lego Robotics!"

Most Students Said They Learned Stem at School

When asked how they learned so much about STEM, only one student could not supply a response. Five themes emerged from the responses of the remaining eleven students. Eleven responses indicated students learned about STEM at school and five responses indicated students learned about STEM at home. Of the eleven who mentioned learning STEM at school, six mentioned intervention-related learning; four said they learned about STEM from the books in their STEM classroom learning center and two said they learned about STEM from building and coding during WeDo Lego Robotics (WLR) (see Figure 8). "We would read books about robots. And in every books, it will say, like in one book it said STEM on the Baseball Field. And, then there's like, STEM at Home." Another student mentioned reading, STEM and Cooking, STEM and the Music Box, and STEM at the Circus. Additionally, five students mentioned learning STEM from their teachers. Of the five responses related to learning STEM at home, two students mentioned learning from their parents and three mentioned learning from TV, video, or technology.

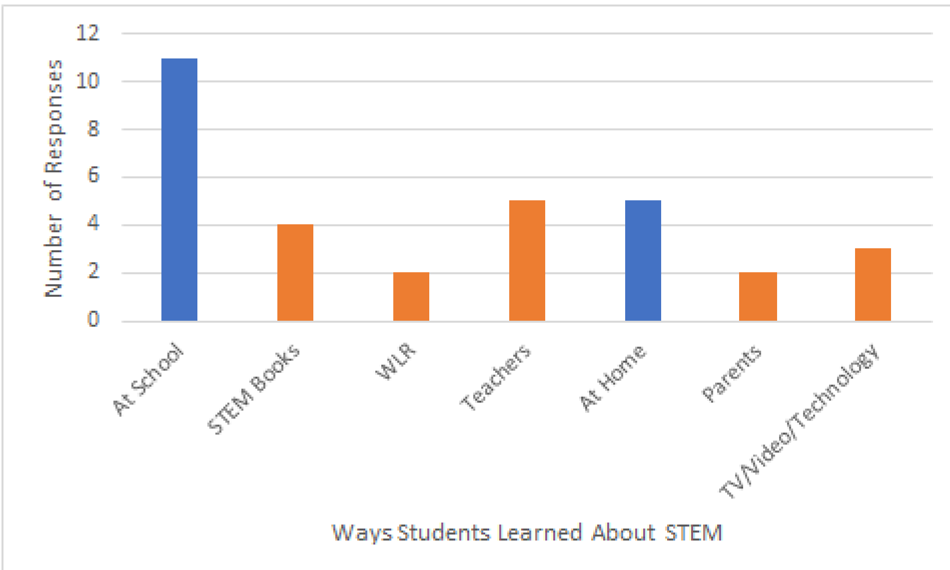

Figure 8. **Bar graph of ways students reported learning about STEM.**

Computational Thinking Skills

To answer the following research question and subquestions, data analysis was conducted as described below.

Research Question 2 - What is the impact of a robotics-based intervention on elementary-aged students' computational thinking skills?

Subquestions

- Does the intervention have an effect on student development of computational thinking skills?

- How did the intervention impact student development of computational thinking skills?

The Computational Thinking Test

Pre- and post-intervention quantitative data were collected using the Computational Thinking Test created by Marcos Roman-Gonzalez (2015). Pre- and post-intervention student scores were analyzed using the paired-samples t-test.

Computational Thinking Scores Increased Significantly

A paired-samples t-test was conducted to examine the impact of the intervention on students' computational thinking scores from the Computational Thinking Test. There was a statistically significant increase in scores from pre-test (M = 11.7, SD = 4.2) to post-test (M = 13.5, SD = 3.6), t (36) = 3.9, p < .000 (two-tailed). The mean difference in Computational Thinking Test scores was 1.81 with a 95% confidence interval ranging from .86 to 2.75 (see Table 12). The eta squared statistic (.099) indicates a moderate to large effect size (Cohen, 1988).

Table 12 Paired Samples Test - Computational Thinking Test

Paired Samples Test - Computational Thinking Test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Post-test - Pre-test	1.81	2.79	.46	.86	2.75	3.89	35	.000

STEM Notebook Data

Data collected from student STEM notebooks were used to qualitatively examine student use of the Use-Modify-Create learning progression, understanding of computational thinking skills, and intervention experiences.

Most Students Completed More Than Half of the Reflection Activities

Thirty-seven students completed at least one weekly reflection activity. The number of completed weekly reflection activities per student ranged from 1 to 10 with a mean of 7.78 (Figure 9). Partially completed entries were not included in these statistics. As part of their weekly reflection, students were asked to draw a design which represented a modification of their project or something new they had learned. The number of drawings completed per student ranged from two to ten with a mean of 7.27 (Figure 10). These data indicated most students completed more than half of the possible weekly reflection activities and included drawings of ways their robots could be further modified.

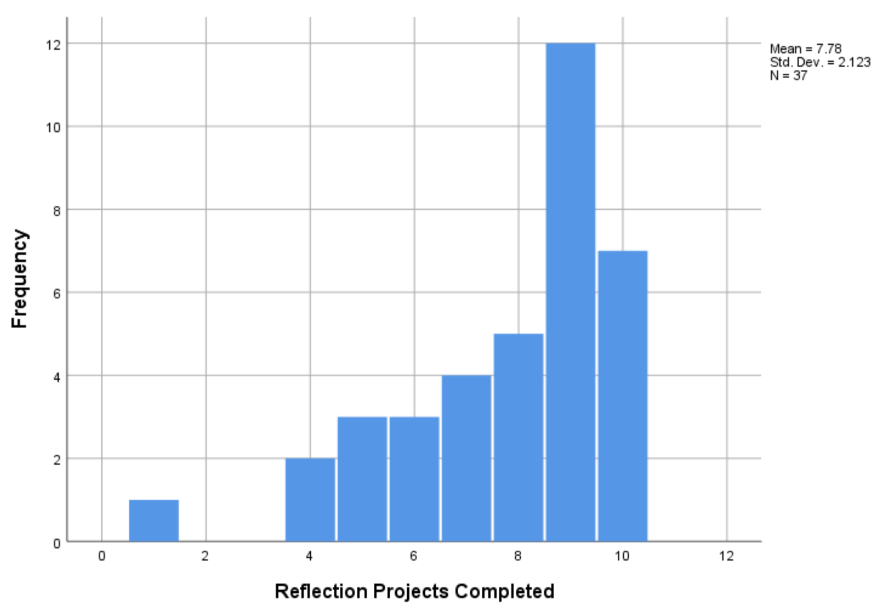

Figure 9. Histogram of completed reflection activities per student.

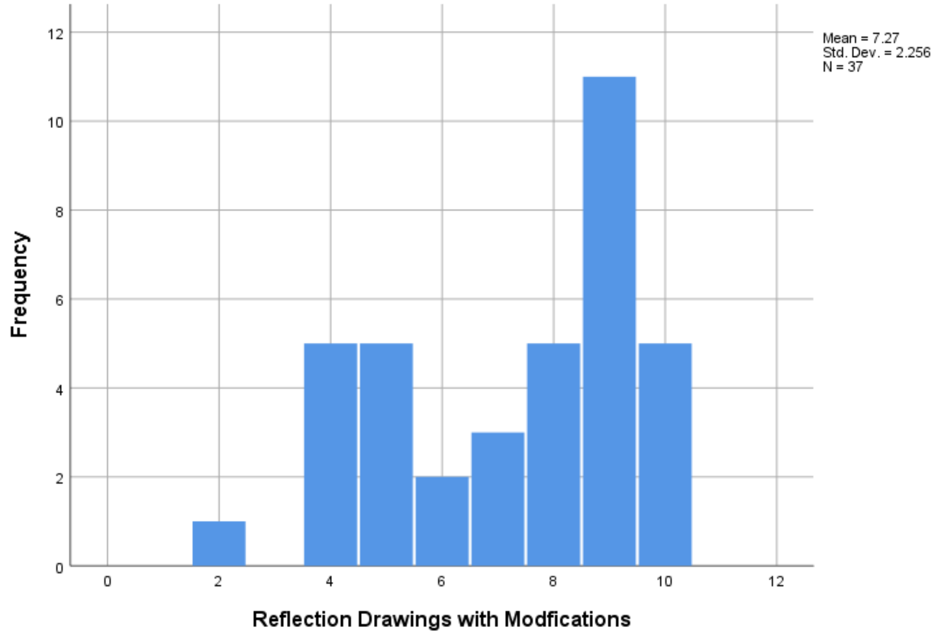

Figure 10. Histogram of completed drawing modification activities per student.

Most Students Made Multiple Modifications to Their Robots

As part of the weekly reflections activities, students were asked if they used, modified, or created during their WLR building and coding sessions. The number of weeks students indicated they made modifications to their robot ranged from 0 to ten per child, with a mean of 4.62 (see Figure 11). These data indicated that 92% of students made at least one modification to their robots. When asked to explain the modifications they made, 32 students (87%) included specific explanations of modifications. Of these students, 18 reported making modifications to both their Lego design and their programming. Eleven reported modifying their Lego design only and three reported modifying their programming only (see Figure 12).

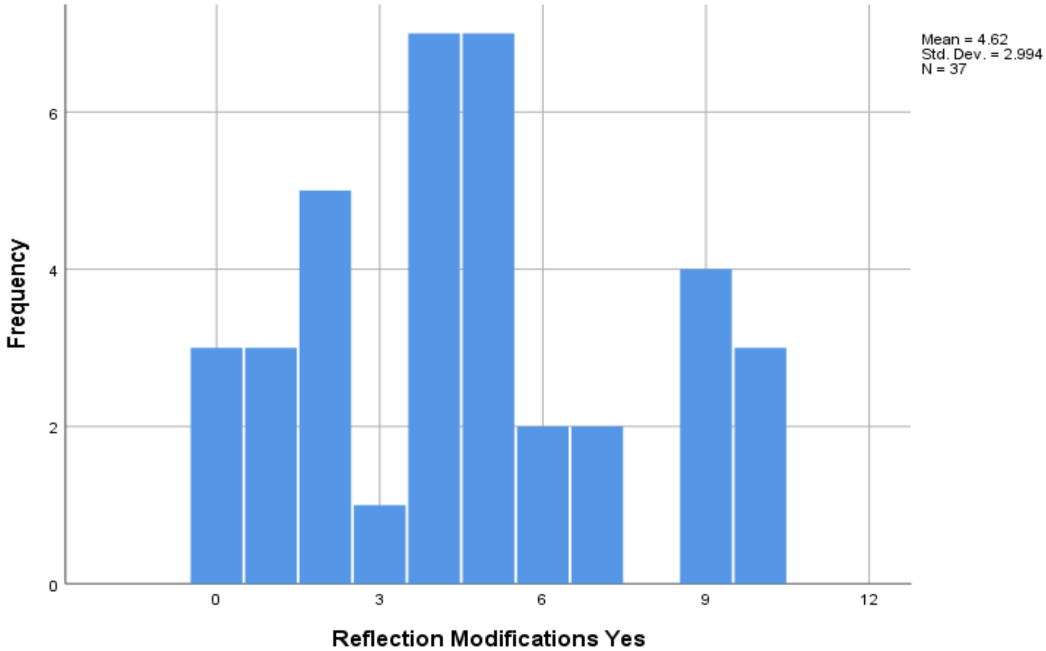

Figure 11. Histogram of completed modifications to robots per student.

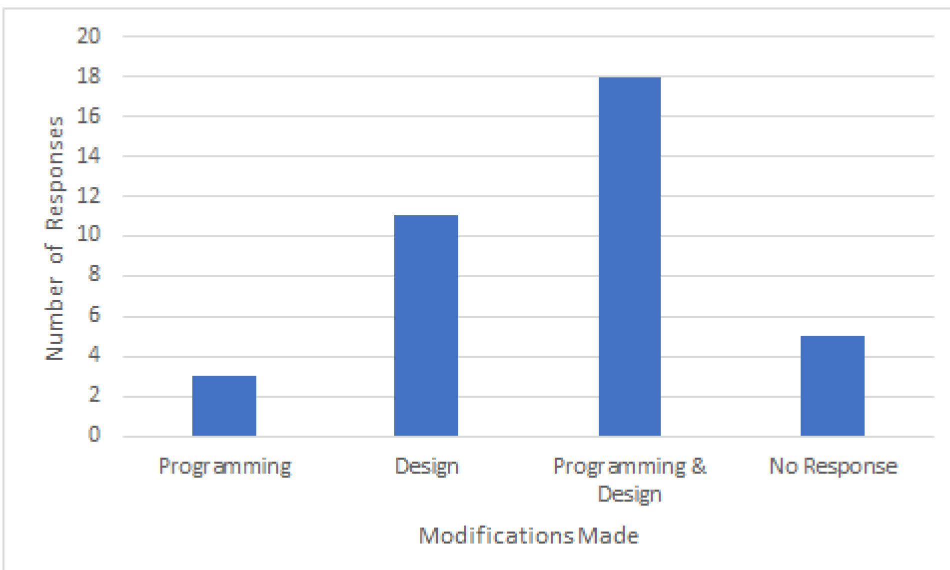

Figure 12. Bar graph of types of modifications made by students.

<u>All students Could Explain Their Robots' Purposes</u>

When asked, "What did you build" and "What did it do?" all students were able to respond appropriately and explain what they built and what their robots did.

Building and Programming Robots Was Both Easy and Hard

When asked, “What was hard?” and “What was easy?”, 36 students responded that at least one thing was easy and 34 students responded that at least one thing was hard. The most common responses for both questions were building and programming. Thirty-one students said building was hard at least once and 31 students said building was easy at least once. Of these students, 29 said building was hard in one reflection and easy in another. The same was true of programming. Sixteen students said programming was hard, while 15 said it was easy. Of these, 10 said it was both hard and easy. Six students said modifying was hard and two said it was easy. Two students mentioned have computer problems which made their experience difficult and three reported having difficulty finishing their projects during an hour building session due to lack of time. Other answers included: “It was hard to work well with a partner”, “It was hard to work alone”, “It was hard to figure out what we were doing wrong”, “It was easy to follow the steps,” and “It was easy to have fun” (see Figures 13 & 14).

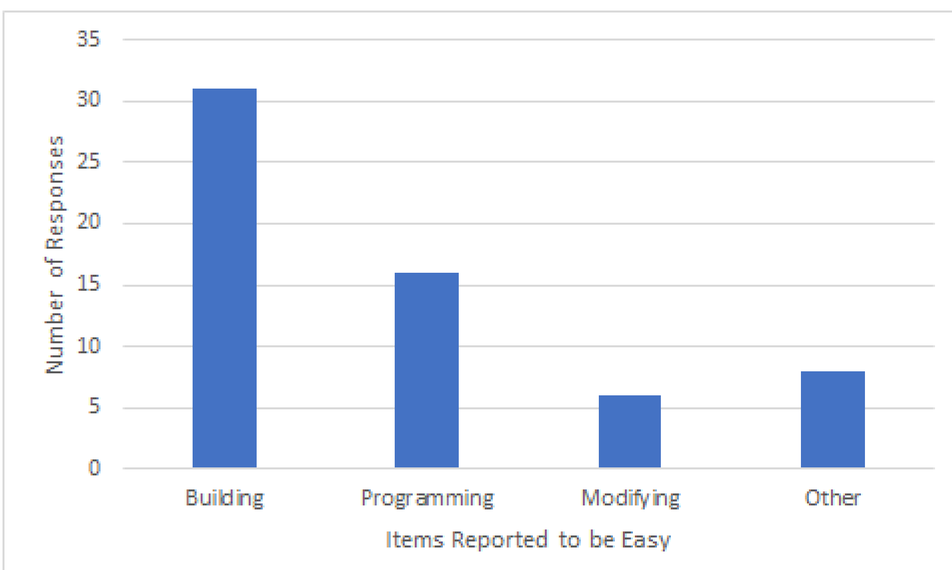

Figure 13. Bar graph of activities students reported to be easy.

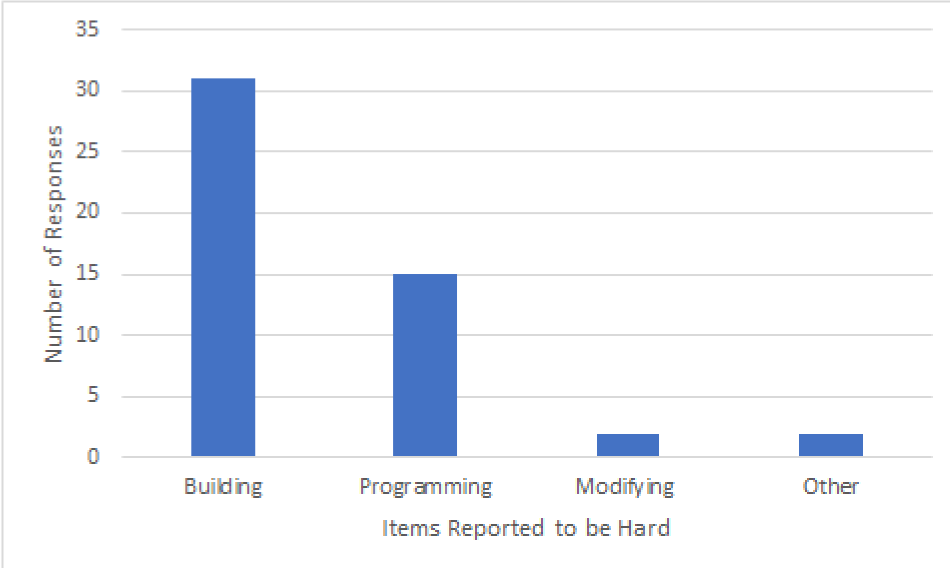

Figure 14. Bar graph of activities students reported to be hard.

Most Students Learned Programming Skills and Soft Skills

Students were asked what they had learned. Responses were coded and were determined to represent four categories: soft skills, programming, modifying, and building (see Figure 15). Twenty-one students indicated they learned to program their robots. Responses included, "I learned all the different commands and codes," "I learned how the coding made the legs kick," I learned that the computer made it move," "I learned how different numbers made different noises," "I learned more about programming," and "We made it move and it was cool. I programmed it." Nineteen students indicated they learned soft skills. Soft skills are skills that help people work well together, such as people skills, social skills, and communication skills. Responses included, "Follow directions," "Always keep trying," "Help your friends," "You can do anything!", "I learned that teamwork makes everything great," "I learned it is easy if you try hard." "I learned not to fight and argue," "I learned to share with others," "I learned that we just need to try," "I learned to try something new," "I learned to take it step by step," and "I learned to never give up." Nine students indicated they learned to build.

Responses included, “I learned how to build a top out of Legos,” “I learned that gears don’t need to spin,” and “I learned if you put gears in different ways, it can move in different ways.” Seven students said they learned how to modify their robots. Responses included, “I learned it is better to modify than leave it plain,” “We learned we could make it different,” “We learned to change stuff,” and “We modified when the arms wouldn’t move.”

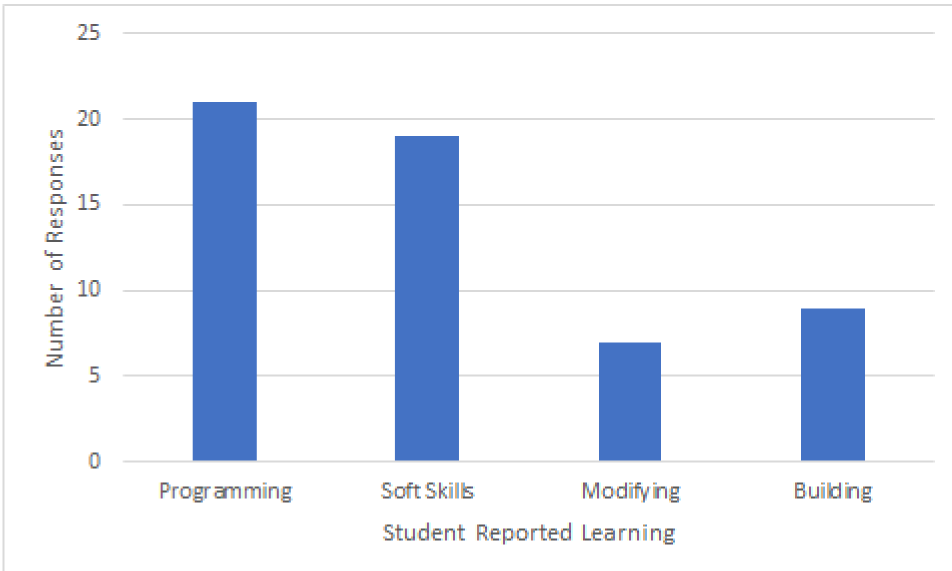

Figure 15. Bar graph of skills students reported learning.

<u>All Student-Pairs Planned Their Robots and Participated in The Showcase</u>

Beginning Week 12 of the intervention, student-pairs began to plan and create a robot to present to peers, teachers, and parents during the student robotics showcase. Student-pairs were asked to include the following items in their STEM notebook: 1) a drawing of their robot, 2) the code for their robot, and 3) a story about their robot. Some students also included a written description of their robot. All pairs recorded their planning in their STEM notebooks. Sixteen pairs included a drawing, code, and story. One pair did not include a written story and two pairs did not include a drawing of their robots (see Figure 16). All student-pairs successfully created and presented a robot for the showcase.

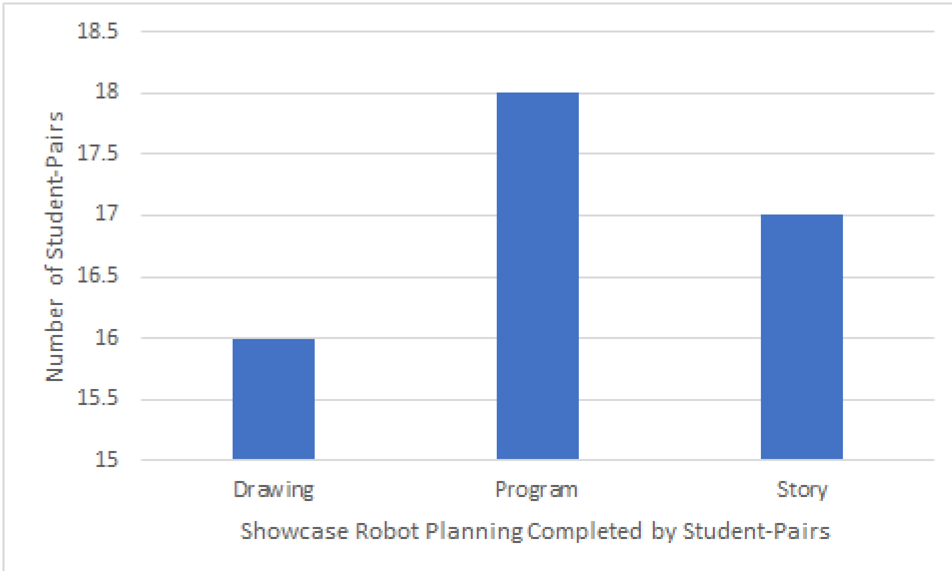

Figure 16. Bar graph of student-pair robotics showcase planning activities.

Data Collected from Artifact-Based Interviews

Twelve students were interviewed and asked twenty questions related to computational thinking skills and how the robotics-based intervention implemented in this research impacted their understanding of computational thinking.

Abstraction.

The following questions were asked to examine students' ability to think abstractly, break down problems into smaller parts, identify and focus on the most important information, and make generalizations.

- Explain your idea for your robot.
- Which did you plan first? Your robot or your story?
- How did you plan the way your robot would look?
- Did you use, modify, or create the Lego design for your robot?

All students displayed abstract thinking when describing their robots.

When asked to explain the idea for their robot, all ten robots' descriptions were unique. All twelve students were able to give detailed descriptions of their robot's design and purpose. Students were eager to share and describe their showcase projects, which were a lava boat trying to escape rising lava, a bakery with an oven, tables, and spinning cupcakes, a flying bird, a spy plane with a broken wing that needed to be fixed and the ground cannon that shot it down, a Ferris wheel that went up and down, a band spinner, a road that bumped up and down and had bikes and a flying pandacorn on it, a pizza restaurant, a beauty salon with a man who is having party and needs to get pretty for the party, and a broken windmill that is stuck going back and forth and needs to be fixed.

Students were able to plan and break down a task into smaller parts.

Nine of the ten teams represented in these interviews wrote a story to go along with their robot. When asked which they planned first, their robot or their story, it was found that nine created their robot first and one wrote their story first. One student explained, "Because if you like, make up a story already you have to design it that way. But, if you don't, you can design however you want and then write a story about it." The student who reported writing his story first said, "The idea was to make a bird and it was an athlete that fell and somebody was supposed to help them up and there was supposed to be a sensor to see him. But, we didn't have enough time. So we just made a flying bird."

Most students focused on the most important information when planning.

Seven students indicated they had a plan prior to building; three reported drawing their robot before building it and four said they had a plan in their head before they started building. When asked how they planned the way their robot would look, it was found that partners did not give the same responses to this question. This indicates they had different views of the ways they planned their robots. Five students said they just started building and did not have a plan at the onset. These students reported changing ideas and designs multiple times. One student said, “We didn’t really plan the way it was going to look. We just kept adding more pieces until it worked out.” Another reported, “So whenever we started building I was just like, hmm, this isn't really going to work out because we don't have enough wheels. If we just use two wheels, it's going to start falling over all the time. So maybe we should just build something else. And I started taking it apart a little bit. And so then we had just the bottom pieces. And then we started building up and I said oh, this really looks like a boat. Let's just make it like a boat. And then [my partner] said that since the bottom’s red, we should be make it a lava boat.”

All students were able to generalize learning and create original robots.

Students were asked if they used an existing robot design, modified an existing robot design, or created a new design for their robot. It was found that partners did not give the same responses to this question. This indicates they had different views of the ways they created their robots. Two students said they modified existing robot designs and ten said they created new designs. No one reported using an existing robot design.

Automation.

The following questions were asked to examine students' ability to use, modify, or create code which results in desired outcomes and their ability to understand and explain their computer code.

- How did you make your robot move the way you wanted it to move?
- Did you use, modify, or create code?
- Can you explain what your code does?

All students created code which resulted in desired outcomes.

When asked how they made their robot move the way they wanted it to, all twelve students said they wrote a program for their robot. When asked if they used, modified, or created the program, two said they modified existing code and ten said they created new code.

When shown their code and asked to explain what it did, all twelve students were able to identify and explain the purpose of each block of their code (see Figure 17). The only exception was one student who included a timer, but was confused about its purpose. This student was able to explain all the other commands used in her program. All twelve students included the start block and a directional motor block. Eight students used the motor speed block. Four students used a timer and eleven used the repeat block. The one student who did not include a repeat block, correctly explained what a repeat block does and why her program did not need to include it. Eight added sound to their robot and two used a pause block. Two students created two programs to control their robot. One of these created one program which caused the robot to go up and a similar program which made the robot go down. The other student had two motors on his robot and wrote a program to control each of them. The programs were similar, but one contained sound and one did not. One group experimented and figured out how to make words pop up on the computer screen. They used this knowledge to popped up the word, "FLOSS." While all students were able to discuss and explain their code, two female students demonstrated an exceptional grasp of automation/coding concepts. These students were able to discuss their code as written, as well as potential changes to their code and the resulting outcomes.

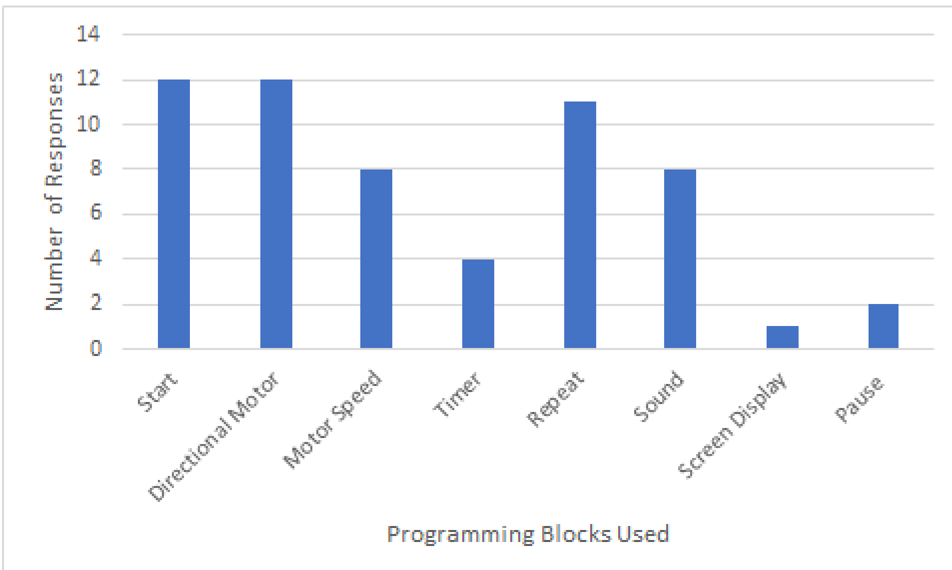

Figure 17. Bar graph of programming commands students used to create their robotics showcase robot's code.

<u>Analysis</u>

The following questions were asked to examine students' ability to identify and solve problems, exhibit solution seeking behavior, demonstrate thoughtful reflection, and think beyond the current goal.

- Did you have any problems?
- How did you solve them?
- Did you test and improve your design or code?
- What did you do when you got stuck and didn't know what to do?
- What are you most proud of?
- If you built another robot, what would you do differently?

All students were able to identify and solve problems.

When asked if they had any problems, all twelve students said they had building problems and one student said he had a problem working with his partner. When asked how they solved their problems, eleven students said they solved them on their own and one said they solved their problem with a volunteer's help. Those who solved their building problems on their own indicated they fixed their problems by thinking about them, building more gently, continuing to try, and experimenting. The student who indicated he had a problem working with his partner said he ended up letting his partner have his way so his partner wouldn't get mad. The student who was helped by a volunteer indicated he was frustrated and couldn't figure out what to do. The volunteer helped him solve the problem.

Students identified and solved problems through testing and improvement.

When asked if they tested and improved their design or code, all students indicated they tested their robots. Nine students said they improved their design after testing and three students said they improved their code. Two students said they did not change anything after testing their robots (see Figure 18). One student said, "We did improve it a little bit because we understood why it kept falling. It was too big. So you see these extra parts right here? That's what we took off because it made it too big and after we took off that stuff it worked perfectly fine." Another student said, "We had to make changes because we didn't have these pieces that are surrounding it, so it kept on falling over. So we put the pieces under and over it and now it's really still. [A classmate] helped us out because whenever she saw it keep falling over, she helped us a little."

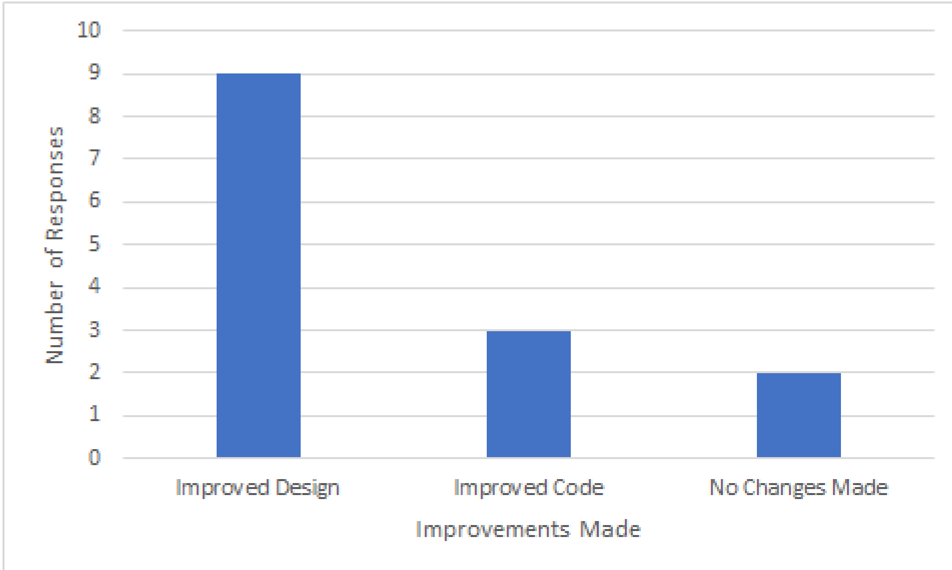

Figure 18. Bar graph of showcase robot improvements made based on testing.

Students who got stuck exhibited solution seeking behaviors.

Eight of the twelve students interviewed reporting getting stuck. When asked what they did if they got stuck and didn't know what to do, responses fell into seven categories, students said they didn't get stuck (4), kept trying (3), changed things (2), asked for help (3), figured it out (2), thought about it (1), and got ideas from other people's projects (1). The eight students who reported getting stuck, all exhibited solution seeking behaviors which allows them to solve their problems.

Students were reflective and proud of their work.

Students were asked what they were most proud of. Three replied they were proud of the way they worked together with their partner. Three were proud they were able to make their robots work the way they wanted it to work. One was proud they figured out how to keep it all together. Two were proud of the way their robots looked. Two were proud that their robots actually worked. One was proud of the way they improved their robot, another was proud that she learned something new, and one was proud of the story he wrote about his robot (see Figure 19).

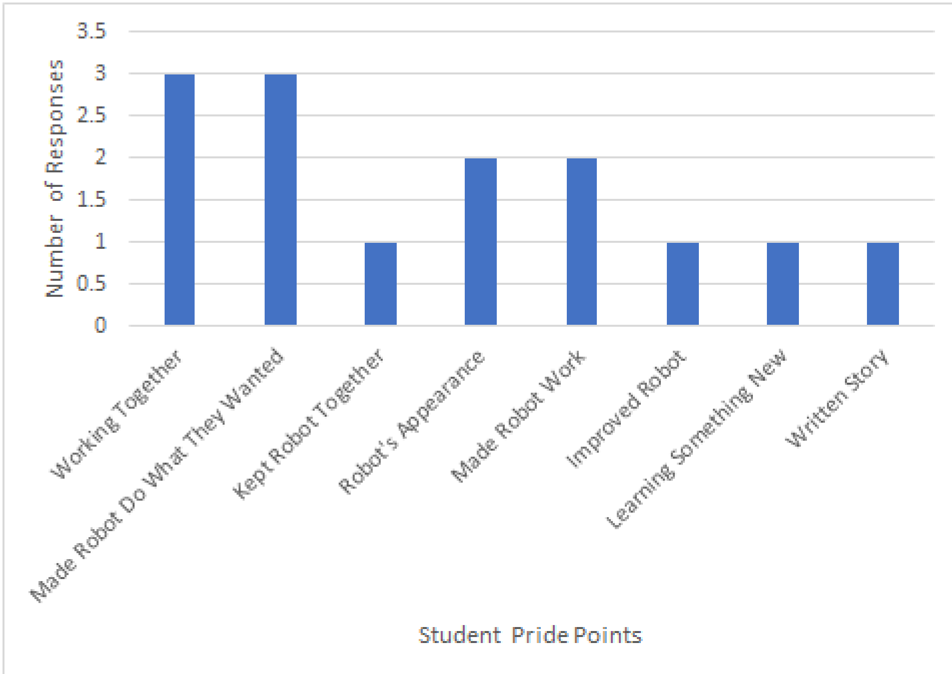

Figure 19. **Bar graph of activities and/or learning for which students felt pride.**

Students were able to think and plan beyond their current goal.

When asked what they would do differently if they built another robot, seven students said they would change the design, five said they would add to their current design, one said they would change their code, one said they would add to their code, and one said they would not change anything (see Figure 20).

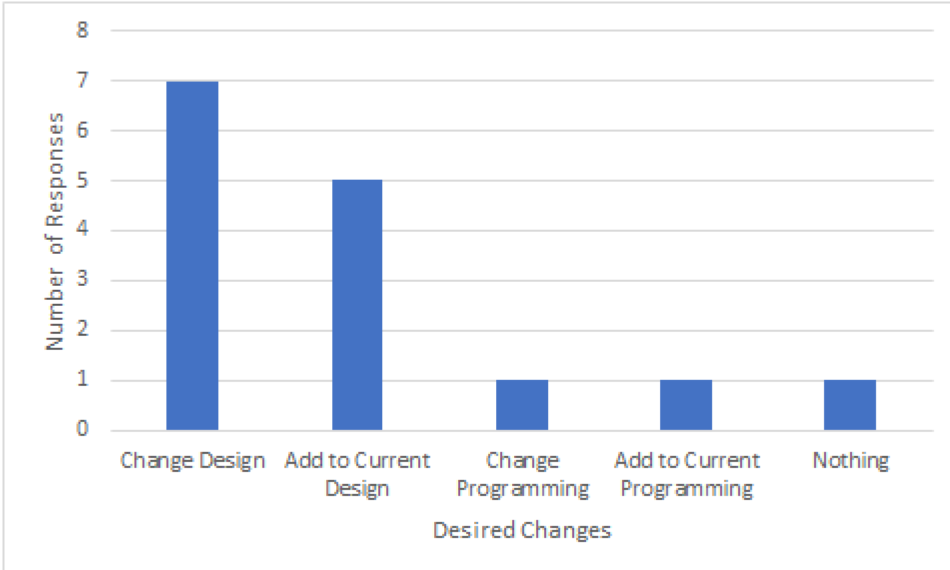

Figure 20. Bar graph of changes students would make to future robots.

Attitude Toward Robotics

The following questions were asked to examine students' feelings about robots, prior experience, and perceptions about how they learned so much about robotics.

- Did you like creating your robot?
- Have you worked with robots before? Please explain.
- How did you learn so much about robots?

All students were very positive about their experiences with robots.

When asked if they liked creating their robots, all students said, "Yes!" When asked what was the best part, five themes emerged from the data. The most commonly mentioned "best parts" were working with their partner (4), building (5), and creating a successful robot (5). Other themes included coding (2) and learning (1) (see Figure 21).

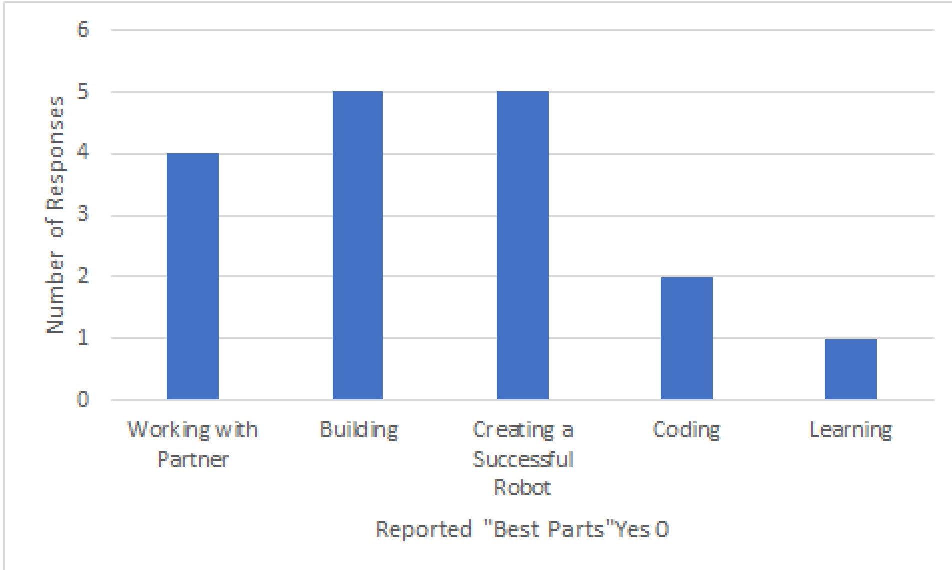

Figure 21. Bar graph of the best parts of student experiences with robotics.

Students did not have prior robotics building experiences.

When asked if they had ever worked with robots before, ten students said they had not. Three students said they had played with robotics toys before, but never created a robot.

Students were reflective and most said they learned about robots at school.

When asked how they learned so much about robots, nine students reported their knowledge of robotics was learned at school. Four students reported learning about robotics outside of school. Students who reported learning about robotics at school mentioned intervention-related activities including teachers, weekly building sessions, volunteers, robotics books, and WLR partners. One student said he learned to program by copying programs from the instructions. When this student was asked if he could have built a robot at the beginning, he said, “No. Because we wouldn’t know what we were doing.” Another student reported she started out hating the WLR building and coding sessions, but ended up loving it and wants to be an engineer. Non-school related ways of learning mentioned by four students included parents, museums, TV/games, and playing with Legos at home.

Intervention

The following questions were asked to examine students' thoughts and feelings about the intervention and elicit any further thoughts they might have about their experiences during this sixteen-week intervention.

All Students Had a Positive Attitude Toward WLR Sessions

Students were asked what they thought of their weekly Lego building and coding sessions and what were the best and hardest parts. All students were very positive about their WLR building and coding sessions. Best parts included working with their partner (3), creating and modifying robots (7), programming (1), and seeing and understanding how robots work (2) (see Figure 22). Hardest parts included working with their partner (3), building and fixing broken robots (5), not having enough time (1), coming up with ideas (2), and one student said nothing was hard (see Figure 23). Of these students, two said working with their partner was both the best and hardest parts. One explained their difficulties, but said they learned to compromise. Four other students followed their responses regarding the hardest part with information indicating that even though it was hard, they had improved. One student said building was hard, "...because of so many technical pieces, but I'm better with technical pieces now." Another said," ...it was really cool to build and sometimes it would be hard, but usually we would find a way to do it and it would be easier." And, another said, "We weren't doing something right and I couldn't figure it out. I looked at the instructions really closely and then I figured out what I did wrong."

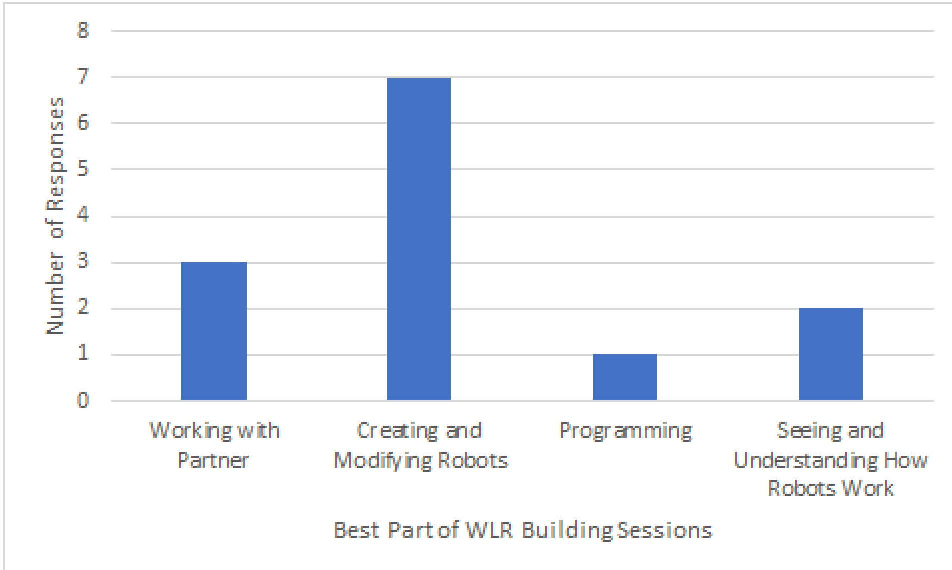

Figure 22. Bar graph of the best parts of the weekly WLR building and coding sessions.

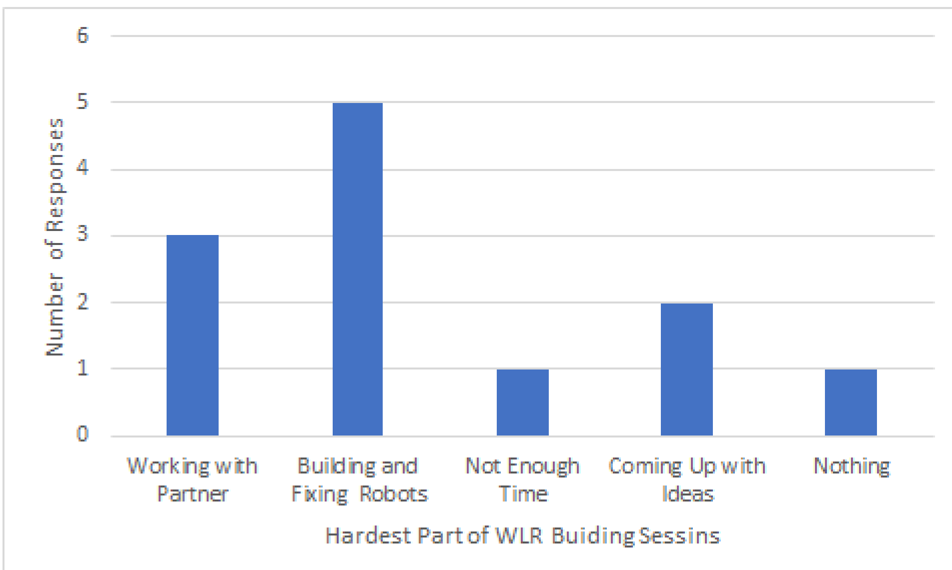

Figure 23. Bar graph of the hardest parts of the weekly WLR building and coding sessions.

<u>Students Had Mixed Attitudes Toward the Stem Classroom Learning Center</u>

Students were asked what they thought of the activities they did in their classroom learning center and what were the best and hardest parts. Most students said they liked drawing ideas for modifying their projects (8). Others said they liked writing about their weekly projects (3), being able to see the programs and instructions in their notebooks

(2), using their imagination (1), reading STEM books (1), and looking back at their work and remembering what they had built (1) (see Figure 24). Most students said the hardest part was writing about their weekly projects (6) or having enough time to write (2). Others said the hardest part was drawing modifications (2), getting it right (1), thinking of new ideas (1), remembering what they had worked on (1), and one student said nothing was hard (see Figure 25). One student who said he didn't like writing added, "Well, it was basically just going over what we did. It made me understand why we were doing this because it was STEM, but I just didn't like it."

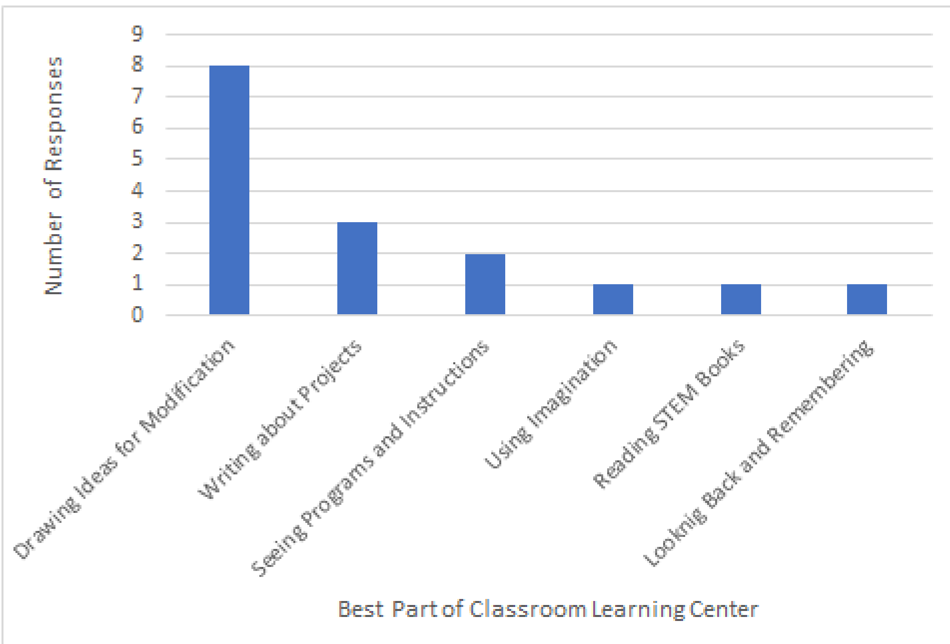

Figure 24. Bar graph of the best parts of the classroom learning center.

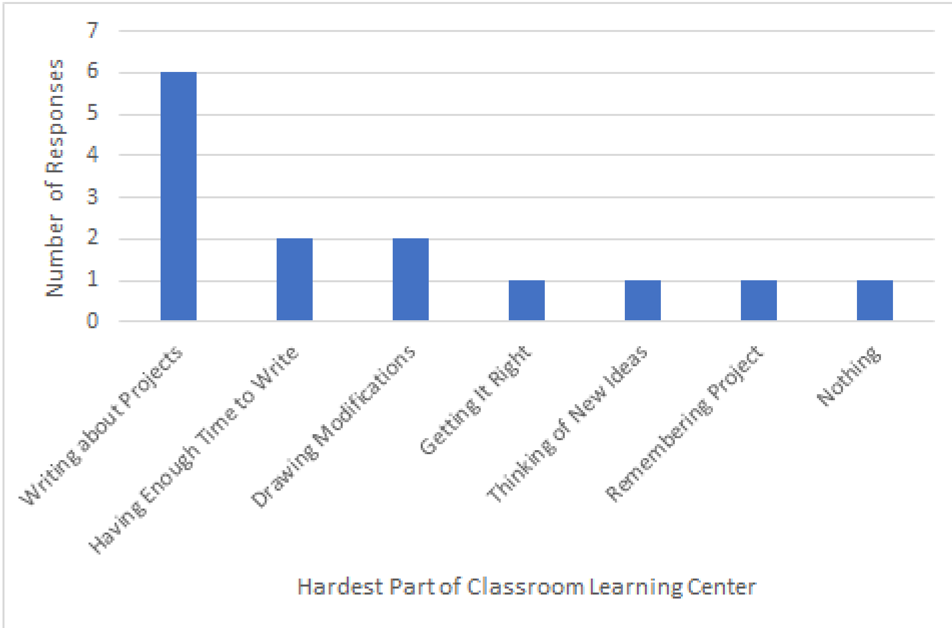

Figure 25. Bar graph of the hardest parts of the classroom learning center.

<u>All Students Had a Positive Attitude Toward the Robotics Showcase</u>

Students were asked what they thought about the robotics showcase and what were the best and hardest parts. All student responses about the showcase were very positive. The best thing about the showcase was evenly split between the twelve students. Six said they liked seeing all of the other projects and six said they liked showing visitors their projects and receiving compliments on their projects. One students said, “I thought like two or three classes would come, but it was like five. Yeah, and like a lot of parents came. Like both of our [my partners’ and my] parents came. They thought it was pretty cool. The best part was making it move and stuff and showing it to our parents.” Another said, “The best part about the showcase was that I got to show off my project to other classes.” Another said, “I liked it because I can go to other people and see their stuff and when I saw most people’s I’m like, WOW!” And, another said, “The best part was when some people came up and said, ‘Wow, I really like this. You guys really worked good as a team’.” And, another said, “It was really fun because we got to go around and see several different cool inventions and we got to see all of the fun little things that people built." Four students didn't think anything about the showcase was hard. The remainder mentioned that it was hard to keep their robot working properly for the whole hour (4), not having enough time to see all the projects (2), being left to demonstrate their robot when their partner looked around (2), and feeling nervous about all the people coming to look at their robot (1) (see Figure 26).

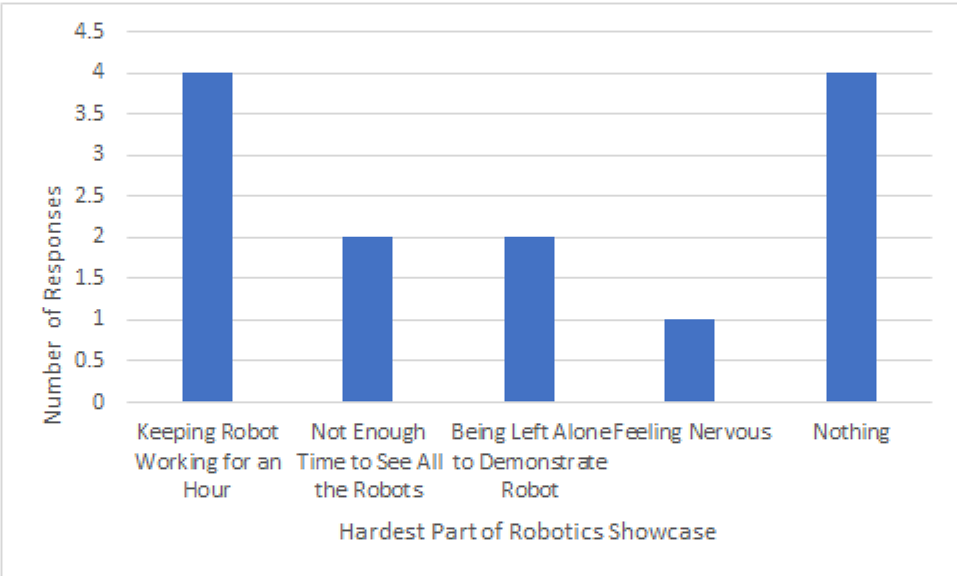

Figure 26. Bar graph of the hardest parts of the robotics showcase.

<u>We Can Learn from Doing It</u>

The final question asked of students was, Is there anything else you'd like to share about STEM or robotics? All students reported positive feelings about participating in WLR, by indicating they liked it. One student said he knew what cyborg meant because he read a book about it. When asked if he read other books about robots he said, "Some. They were great." He indicated the books came from the school library and his classroom. Additional responses included, "It inspired me and now I want to like actually do engineering and stuff," "I want to be an engineer. I could teach Lego robotics and STEM." and "That we can learn from doing it."

Summary

Data analysis and findings were presented in this chapter. Data sources included pre- and post-test data collected using the Student Attitudes toward STEM Survey: Upper Elementary School Students (Friday Institute for Educational Innovation, 2012), Computational Thinking Test (Roman-Gonzalez, 2015), and a career interest writing/drawing activity, as well as post-test data collected from student work in STEM notebooks and artifact-based interviews. Findings based on these quantitative and qualitative data sources will be used to answer the research questions presented in this study and draw conclusions about the impact of the intervention presented in this research.

CHAPTER FIVE: CONCLUSIONS AND IMPLICATIONS

This chapter includes a summary of the study and discussion of the findings presented in Chapter Four. Implications and limitations are also identified and discussed. Finally, suggested areas for additional research are shared.

Summary of the Study

This sixteen-week intervention was rooted in constructionist principles and implemented during the regular school day. The intervention included hands-on robotics building and coding experiences facilitated by STEM-speaking adults trained in the goals of the research and the use of the Use-Modify-Create learning progression, student participation in a classroom learning center with non-robotic materials and activities that promoted exploration of STEM subjects and careers, use of the Use-Modify-Create learning progression to scaffold student development of computational thinking skills, and exploration of computational thinking, and a robotics showcase during which students presented novel robotics projects to parents, peers, and teachers. AR was used to examine the impact of this robotics-based intervention on elementary-aged students' interest in STEM subjects and careers and development of computational thinking skills.

This intervention was created and this action research undertaken to answer the following research questions.

Research Question 1 - What is the impact of a robotics-based intervention on elementary-aged students' interest in STEM subjects and careers?

Subquestions

- Does the intervention have an effect on student attitude toward STEM subjects?
- Does the intervention have an effect on student attitude toward STEM careers?
- How did the intervention impact student attitude toward STEM subjects and careers?

Research Question 2 - What is the impact of a robotics-based intervention on elementary-aged students' computational thinking skills?

Subquestions

- Does the intervention have an effect on student development of computational thinking skills?
- How did the intervention impact student development of computational thinking skills?

Discussion

Data analysis indicates the multifaceted robotics-based intervention implemented and examined in this research had a positive impact on students' interest in STEM subjects and careers and development of computational thinking skills. This intervention, which was created based on constructionist principles, saturated students in resource-rich experiences and included WeDo Lego Robotics (WLR) building and coding activities facilitated by trained, STEM-speaking teachers and volunteers, classroom STEM learning center activities, the use of the Use-Modify-Create learning progression to scaffold student development of computational thinking skills, and a robotics showcase. This multifaceted robotics-based intervention encouraged students to use and explore STEM subjects and careers and computational thinking skills. The structure of this intervention is supported by the theory of constructionism (Papert, 1980) and prior research which suggests robotics is an ideal constructionist tool to expose children to integrated STEM concepts (Altin & Pedaste, 2013; Barak & Zadok, 2009; Barker & Ansorge, 2007; Beer et al., 1999; Benitti, 2012; Eguchi, 2014; Kandlhofer & Steinbauer, 2015; Nugent et al., 2010; Petre & Price, 2004) and computational thinking skills (Bers et al., 2014; Kabatova & Pekarova, 2010; Lee et al., 2011; Papert, 1993; Sullivan & Heffernan, 2016; Voogt et al., 2015).

STEM Subjects and Careers

In response to Research Question 1: What is the impact of a robotics-based intervention on elementary-aged students' interest in STEM subjects and careers? data analysis indicates the intervention had a positive impact on elementary-aged students' interest in STEM subjects and careers.

Subquestion 1 asks: Does the intervention have an effect on student attitude toward STEM subjects? Data analysis of S-STEM Survey results indicates a statistically significant increase, with a moderate to large effect size, in composite STEM Attitude scores from pre- to post-test. Likewise, data analysis of data collected from post-intervention artifact-based interviews indicates students had a positive attitude toward STEM subjects. Students indicated they believe it is important to learn STEM in school because STEM knowledge will benefit them in the future. All students who participated in artifact-based interviews believed STEM knowledge is important for their future careers. Together, these data indicate the intervention had a positive effect on students' interest in and attitude toward STEM subjects.

Subquestion 2 asks: Does the intervention have an effect on student attitude toward STEM careers? Data analysis of S-STEM Survey results revealed no statistically significant change in STEM Career Attitude scores from pre- to post-test. However, student responses to a pre-/post-test career interest writing/drawing activity revealed a statistically significant increase in the number of students who expressed interest in STEM careers. This examination also revealed a statistically significant increase in the number of students who believe STEM skills will be required for their future career. Data analysis indicated an increased understanding of STEM and the need for STEM knowledge in both STEM and non-STEM careers. Additionally, artifact-based student interviews indicated students believed STEM careers are important, both for them as individuals and for the world. Together, these data indicate the intervention had a positive impact on student interest in and attitude toward STEM careers.

Subquestion 3 asks: How did the intervention impact student attitude toward STEM subjects and careers? To answer this question, students were asked how they learned so much about STEM. Eleven of twelve students interviewed indicated they learned about STEM at school. Of these, six mentioned intervention-specific learning, including books in their classroom learning center and WLR building and coding sessions. Five also mentioned learning STEM from their teachers.

A number of important findings related to student development of interest in STEM subjects and careers were observed in this research:

- Student attitudes toward STEM subjects increased significantly following the intervention.
- Post-intervention, students indicated positive feels toward learning STEM subjects and awareness of the importance of STEM in their future careers.
- The number of students who indicated interest in a STEM career increased

significantly post-intervention.

- Post-intervention, students indicated they thought STEM careers were important because they make the world better, they benefit students personally, and they help people learn.
- Most of the student interviewed articulated intervention-related ways they had learned about STEM subjects and careers.

The multi-faceted intervention implemented in this research directly contributed to these findings. Because of the constructionist nature of this intervention, students were able to explore STEM at their own pace and through experiences of their own choosing. This was true of the WLR projects they chose to complete during the weekly building and coding sessions, as well as the books they chose to read in their classroom learning centers. Students were saturated in STEM, but allowed to explore at their own pace and based on their own interests. This saturation helped students with no background knowledge to begin learning about STEM at the ground floor and allowed those with background knowledge to advance in areas of personal interest.

All students enjoyed and experienced success with robotics. Students were given the time, tools, and support to discover the joy of building and programming a robot that looked and moved the way they wanted it to. The use of the Use-Modify-Create learning progression help scaffold student building and coding experiences, ensuring they experienced success and developed confidence in their own skills and learning. This, in conjunction with the robotics showcase, which allowed students to share and show-off their learning, was very powerful. Every student interviewed said they enjoyed the building and coding sessions and loved the robotics showcase.

STEM-speaking adults played an important role in these results. For most students, the volunteers were the first engineers or scientists they had met who talked to them about their profession and its value. This exposure, coupled with access to a wide-range of STEM reading materials, allowed students to reimagine and expand their future goals. This was clearly illustrated by the increase in the number of students who indicated they wanted to become scientists (zero to five) and the increase in the number of students who said they wanted to become engineers (one to four). The pre-intervention careers choices of these students represented professions that are very familiar and common, even in a rural community. Following exposure to this intervention, in which students had the opportunity to meet and work with volunteers who are employed in a variety of science and engineering fields, and opportunities to read about a variety of STEM fields, student responses changed.

It is the researcher's experience that young children are typically unable to articulate how they know something. The fact that over half of the students interviewed said they learned about STEM subjects and careers through intervention-specific activities is surprising and encouraging. These responses indicate student participation in this multifaceted robotics-based intervention had a positive impact on student attitude toward STEM subjects and careers. Specifically mentioned by students were access to STEM related reading materials, constructionist building and coding opportunities and STEM-speaking teachers who were focused on the goals of this research. These are critical elements that should be maintained and/or enhanced in future iterations or implementations of this intervention.

These positive outcomes support the need for early student exposure to STEM subjects and careers. This research shows this can be accomplished through the use of a multi-faceted, robotics-based intervention designed to saturate students in STEM and help them develop an understanding of and positive attitudes toward STEM subjects and careers. The multifaceted robotics-based intervention used and analyzed in this research has been shown to have a positive effect on student attitude toward STEM subjects and careers, broadening students' horizons and understanding of the possibilities for their futures. This outcome has the potential to positively impact students' future academic and career decisions (Eguchi, 2014; National Math + Science Initiative, n.d.; Nugent et al., 2010; Tsupros et al., 2009).

Computational Thinking

In response to Research Question 2: What is the impact of a robotics-based intervention on elementary-aged students' computational thinking skills? data analysis indicates this multifaceted robotics-based intervention had a positive impact on elementary-aged students' computational thinking skills.

Subquestion 1 asks: Does the intervention have an effect on student development of computational thinking skills? Quantitative data analysis revealed a statistically significant increase, with a large effect size, in Computational Thinking Test scores from pre-test to post-test. Student qualitative responses, both written and oral, indicated student use of computational thinking skills in the form of abstraction, automation, and analysis. Together, these data indicate the intervention had a positive impact on student development of computational thinking skills.

Subquestion 2 asks: How did the intervention impact student development of computational thinking skills? To answer this question, students were asked how they learned so much about robots. None of the students had created robots before participation in this intervention. Nine students mentioned learning about robots through intervention-related activities including teachers, weekly WLR building and coding sessions, volunteers, robotics books, and WLR partners.

A number of important findings related to student development of computational thinking skills were observed in this research:

- Student development of computational thinking skills increased significantly following the intervention.
- All students reported successfully using, modifying, and creating robots.
- Although many students reported disliking it, all students participated in weekly WLR reflections activities during classroom learning centers.
- All students were able to explain how their programs worked and the purpose of the coding blocks they used.
- Most of the student interviewed were able to articulate intervention-related ways they had learned to build and program robots.

The multi-faceted intervention implemented in this research directly contributed to these findings. The development of this intervention was heavily influenced by Seymour Papert's theory of constructionism (Papert, 1980), which promotes learning by making and maintains students can learn deeply when they have access to a resource-rich environment, construct a public, physical artifact, and reflect on their building and learning experience (Papert & Harel, 1991). WLR, which requires the use of computational thinking skills, is an ideal constructionist medium because students can immediately see the results of their decisions. Papert (1993) would describe educational robotics as objects-to-think-with because they provide immediate feedback, which allows students to create and then cyclically test, analyze, and refine their creations, a cycle which promotes deep thinking and construction of knowledge. Learning by reflection is a primary principle of constructionism and has been shown to be an effect way to promote deep thinking and student learning (Mikropoulos & Bellou, 2013: Papert, 1980). Therefore, students participated in classroom learning center, reflective writing and drawing activities following each weekly building session. Evidence of thoughtful reflection can be seen in STEM notebooks and in artifact-based interview responses. This constructionist principle was critical to the success of this intervention, as it encouraged students to think deeply about their learning. The final element of this intervention, a student robotics showcase was implemented to provide students with the opportunity to construct a public, physical artifact. All students enjoyed the showcase and reported creating or modifying robotic designs and programs to display in this showcase. These constructionist elements directly contributed to student development of computational thinking skills. The findings of this research support the appropriateness of grounding this intervention in constructionism.

Evidence of the use of Use-Modify Create learning progression can be seen in STEM notebooks, as well as artifact-based interview questions about weekly WLR building and coding sessions and the robotics showcase. All students completed project modification drawings in their STEM notebooks. When asked about weekly WLR sessions, written responses indicated all students used the instructions provided by the WLR program and all were able to explain what they built and what it did. Most students indicate they made at least one modification to their robots. All student-pairs recorded their robotics showcase robot planning in their STEM notebooks. Likewise, all pairs successfully created and presented a robot for the showcase. Data collected from artifact-based interviews indicated ten of the twelve students interviewed created novel robotic designs for the showcase and two modified existing designs. Likewise, two reported modifying existing code and ten reported creating new code for their robot. All students were able to explain and discuss their programming decisions, indicating understanding of the commands used and development of computational thinking skills (Lee et al., 2014). All students indicated they tested their robots and ten made coding and/or building modifications based on their tests. These findings indicate use of the Use-Modify-Create learning progression promoted student development of computational thinking skills and is a critical facet of this intervention.

While all students were able to explain and discuss their code and programming decisions, two female students demonstrated an exceptional grasp of automation/coding concepts. These students were able to discuss their code as written, as well as potential changes to their code and the resulting outcomes. When asked how she learned so much about creating a robot, one of the students said, “I got used to it from practicing. When we used to do it every Wednesday, I used to be like, ‘I don’t want to do this.” But, then I was like, ‘This is actually very easy.’ I got used to it. I think we got better and better at it.” Computational thinking skills are evident in students’ ability to verbalize ways in which they used abstraction, automation, and analysis while building and coding their robots.

Students reported high levels of engagement with and/or positive attitudes toward weekly WLR building and coding sessions, creating and modifying robots, programming, understanding how robots work, drawing ideas for modifying their projects in their STEM notebook, and participation in the robotics showcase. Students reported low levels of engagement with and/or negative attitudes toward working with the Lego building bricks and time constraints. Students reported mixed levels of engagement and/or attitudes toward working with partners and written reflection activities. Positive and negative responses were equal in terms of working with partners. However, all students who had negative experiences reported being able to work through their problems and work well together in the end. Although students indicated it was hard to work with a partner, they also said working with their partner was one of the best parts of their experience with robotics. Research supports the value of partner activities, as they foster collaboration, self-expression, problem-solving, enhanced social skills and critical and innovative thinking (Brigman & Campbell, 2003; Eguchi, 2014; Larkin, 2011; National Research Council, 2011; Papert, 1993; Ucgul & Cagiltay, 2014; Werner et al., 2012). While some students did not enjoy the written reflection activities, others reported enjoying them and the opportunity to think about and revisit what they had built and learned. Learning by reflection is one of the main principles of constructionism and has been shown to be an effect way to promote deep thinking and student learning (Mikropoulos & Bellou, 2013: Papert, 1980) and a critical element of this intervention.

When asked about the robotics showcase, the best part about the showcase was evenly split between students. Half said they liked seeing all of the other projects and half said they liked showing people their projects and receiving compliments on their projects. Based on the literature, the researcher anticipated students would be highly engaged in participation in the robotics showcase (Altin & Pedaste, 2013; Barak & Zadok, 2009;

Barker & Ansorge, 2007; Kabatova and Pekarova, 2010; Petre & Price, 2004; Ucgul & Cagiltay, 2014). It was unexpected to discover students were equally interested in viewing the projects of other students. While all students who viewed the projects expressed interest and enthusiasm, fellow WLR participants exhibited a deeper level of interest. They enjoyed discussing the projects' designs and coding with their peers. It is the researcher's assertion this stems from their greater understanding of robotics and computational thinking, which peaked their interest and allowed them to appreciate and knowledgeably discuss the various designs and programs created by their peers.

The final question asked of students was, Is there anything else you'd like to share about STEM or robotics? Two students summed up the goal of this research perfectly, when one said creating a robot for the showcase helped her learn more about robots, and another said, "That we can learn from doing it." These students' insights perfectly capture the constructionist basis for this intervention. It is the researcher's belief that the success of this intervention is rooted in its foundation in constructionist theory. These statements are a perfect summation of the constructionist philosophy at the heart of this intervention, students can learn by making and doing (Papert, 1980).

Student responses showed evidence of thoughtful reflection, as well as the use and understanding of the Use-Modify-Create learning progression in the construction and programming of their robots. Students were able to articulate their intervention-related learning and indicated they learned soft skills, programming, modifying, and building. When asked how they learned so much about robots, nine students mentioned intervention related activities, including teachers, weekly building and coding sessions, volunteers, robotics books, and WLR partners. It is the researcher's belief this saturation of students in constructionist-based robotics experiences led to student development of computational thinking skills and should be maintained as critical elements of this intervention.

Student responses indicate participation in this multifaceted robotics-based intervention had a positive impact on student use and development of computational thinking skills. Critical elements that should be maintained and/or enhanced in future iterations or implementations of this research include: access to robotics-related reading materials, constructionist building and coding opportunities, STEM-speaking adults who are focused on the goals of this intervention, opportunities to work with and learn from peers, the Use-Modify-Create learning progression to scaffold student development of computational thinking skills, opportunities for student reflection, and student participation in a robotics showcase.

The positive outcomes presented in this study support the need for early student exposure to computational thinking skills. This research shows this can be accomplished through the use of a multi-faceted, robotics-based intervention designed to saturate students in educational robotics and help them develop computational thinking skills. The multifaceted robotics-based intervention used and analyzed in this research has been shown to have a positive effect on computational thinking skills, broadening students' horizons and understanding of the possibilities for their futures. This outcome has the potential to positively impact students' future academic and career decisions (Eguchi, 2014; National Math + Science Initiative, n.d.; Nugent et al., 2010; Tsupros et al., 2009).

How the Intervention Caused Positive Change

Data analysis indicates this intervention caused positive changes in students' interest in and attitude toward STEM subjects and careers and development of computational thinking skills. Critical elements identified include: trained, STEM-speaking adults who are focused on the goals of this research, constructionist building and coding opportunities, opportunities to work with and learn from peers, classroom learning center activities including access to robotics and STEM reading materials and opportunities for student reflection, use of the Use-Modify-Create learning progression to scaffold student development of computational thinking skills, and student participation in a robotics showcase.

Committed Teachers and Volunteers.

Teachers and trained volunteers who were STEM-speaking adults were vital to the success of this intervention. They encouraged students to utilize the Use-Modify-Create learning progression, which scaffolded and facilitated student development of computational thinking skills. They talked to students about their use of STEM in their personal and professional lives, and they helped students overcome challenges related to building, coding, and interpersonal dynamics. According to Papert (1980) adults who engage in meaningful, content-specific conversations with children help to saturate the environment and promote learning.

WLR Hardware and Software

WLR hardware and software kits were an excellent choice for this research. The product's low-floor, high ceiling ensured students remained engaged and challenged throughout the sixteen-week intervention (Mayerova, 2012; Scaradozzi et al., 2105). There were no student complaints about the difficulty or ease of the robotics elements of WLR. Some students expressed frustration with building with Legos, but in all cases, they were able to resolve and/or overcome these challenges. The value of WLR hardware and software for elementary-aged students is evident in this research and supported by the literature (Atmatzidou & Demetriadis, 2015; Burfoot, 2013; Hudson, 2016; Mayerova, 2012; Romero, Lopez, and Hernandez, 2012; Scaradozzi et al., 2105)

Classroom Learning Center

Use of STEM and robotics books available in classroom learning centers was mentioned by a number of students. Students indicated they enjoyed and learned from these materials, making them a valuable addition to the intervention. Additionally, the availability of these materials was an important part of saturating the classroom and creating a culture of STEM (Papert, 1993). The written reflections required of students in their STEM notebooks were the only aspect of this intervention most students indicated they did not enjoy. For most, their dislike stemmed from the requirement that they write, as many students indicated they do not like to write. Nevertheless, they completed the activities to varying degrees. Based on the data collected from the notebooks, these written responses had the desired effect and caused students to reflect on their building and coding activities from their WLR sessions. Learning by reflection is one of the main principles of constructionism and has been shown to be an effect way to promote deep thinking and student learning (Mikropoulos & Bellou, 2013: Papert, 1980).

Use-Modify-Create Learning Progression

The Use-Modify-Create learning progression (Lee et al., 2011) was ideally suited to the goals of this research. Used with WLR, it provided a solid foundation and appropriately scaffolded structure for student growth. Students said they were able to create a robot for the robotics showcase because they had learned to build and program using WLR during the weekly building sessions. When asked how he learned so much about robots, one student said, he couldn't have created a robot at the beginning of the year and added, "We learned so much about robots because every time we just copied the things and then we learned more of how, like, it works and how it moves and spins and how the commands work. And, then at the end, we just already, like, we already knew how it works, and all the commands and how those work." Prior research supports this student's insight and has found the Use-Modify-Create learning progression is a valuable framework for helping students develop computational thinking skills over time (Lee et al., 2011; 2014).

Robotics Showcase.

Research indicates students are most receptive to learning about integrated STEM concepts and robotics when there is a competition or public display associated with the learning (Altin & Pedaste, 2013; Barak & Zadok, 2009; Barker & Ansorge, 2007; Kabatova and Pekarova, 2010; Petre & Price, 2004; Ucgul & Cagiltay, 2014). These findings were the basis for the culminating activity of this intervention, a student robotics showcase. Student excitement and engagement before, during, and after the showcase, as well as student learning evidenced by student work presented during the showcase, support its inclusion in this intervention. The robots created by students showed clear evidence of student computational thinking skills (Lee et al., 2014). This was further supported by student responses to the artifact-based interview questions about the design and creation of their robots.

Constructionism

Grounding this intervention in constructionist philosophy (Papert, 1980, 1993) was found to be fundamental to its success. This framework ensured students were surrounded by opportunities to experience, experiment with, explore, and engage freely with STEM and computational thinking materials (Papert & Harel, 1991). Additionally, the researcher's assessment that this rich-constructionist environment could be improved by scaffolding students' experiences also proved to be correct. Providing students with guidance in the form of trained, STEM-speaking adults, access to STEM and robotics reading materials, the use of the Use-Modify-Create learning progression to scaffold student development of computational thinking skills, and the guidance provided by thoughtful reflection in the classroom learning center fostered student learning and success. The intervention was designed to saturate students in STEM and computational thinking experiences, supplement student background knowledge, encourage student exploration in areas of interest, encourage student reflection and deep thinking, and maintain STEM and computational thinking as the focus of these activities.

Implications

Based on the findings presented in this research the following recommendations are made:

Robotics as a Regular School Day Extra Activity

Elementary schools should strive to incorporate educational robotics during the regular school day. This current research supports the implementation of a multifaceted robotics-based intervention that can be used to positively impact student interest in STEM subjects and careers and development of computational thinking skills during the regular school day. Prior research supports this finding and has shown regular school day use of robotics as an extra activity promotes student development of computational thinking skills, application of STEM concepts, creativity, persistence, positive social interactions, teamwork skills, and general life skills (Altin & Pedaste, 2013; Barak & Zadok, 2009; Beer et al., 1999; Benitti, 2012; Eguchi, 2014; Kandlhofer & Steinbauer, 2015; Nugent et al., 2010; Petre & Price, 2004; Scaradozzi et al., 2015).

Early Elementary-Aged Students

This research was conducted with second and third grade students and found to be appropriate for this age group. This age group was selected because most students in this age group can read, write, think, and work independently. It is the researcher’s belief that elementary school students of any age, with these characteristics, will benefit from participation in this intervention.

Implementation

To implement this intervention, schools will require time, committed, STEM-speaking teachers and volunteers who have been trained to implement the Use-Modify-Create learning progression to scaffold student development of computational thinking skills, WLR sets and software, laptops (or iPads), a classroom learning center, ability to host a robotics showcase, and a desire and commitment to promote student development of an understanding of and interest in STEM subjects and careers and development of computational thinking skills.

Time

An elementary school day is tightly packed with required activities, making it difficult to add subject matter that is not specifically mandated by the school, school system, or state. However, this research shows students can make large gains with minimal time commitment. This research indicates that as little as two hours per week for sixteen weeks contribute to statistically significant positive changes in student attitude toward STEM subjects and careers and computational thinking skills. Students participated in one hour per week of building and coding activities and one hour per week of STEM classroom learning center activities (20 minutes per day for three days each week). Minimal time commitment is required because this research brings together a number of learning theories and strategies, which have been shown to aid in student learning related to interest in STEM subjects and careers and computational thinking skills, to leverage their power to promote student understanding and growth. When trained, STEM-speaking adults facilitate hands-on, student-directed robotics building and coding activities, situated in a resource-rich constructionist environment designed to promote student exploration, experimentation, and reflection, coupled with the use of the Use-Modify-Create learning progression to scaffold student development of computational thinking skills, and culminating in a public display of knowledge, student growth results.

Committed, Trained, and Stem-Speaking Teachers and Volunteers

Opportunities for student-directed creation and exploration in a STEM and computational thinking in resource rich environment, supported by STEM-speaking adults who are willing and able to support student learning when students request or require just-in-time assistance played an important role in this intervention. Trained, STEM-speaking teachers and volunteers are necessary to ensure a constructionist environment is created, to support student learning, and to encourage student use of the Use-Modify-Create learning progression. Ideally these teachers and volunteers value and are well versed in STEM and computational thinking. However, it is the researcher's belief that commitment to student learning is more important than adult subject-matter knowledge. While, it is helpful if adults have basic coding skills, it is not necessary. Within a constructionist environment, students will explore and learn on their own with adult encouragement, guidance, and support. Therefore, the most important things teachers and volunteers can do are talk to students about STEM and its use and value in the world, establish a resource-rich constructionist learning environment in which students are encouraged to explore, experiment, and reflect without fear of judgement or failure, and encourage students to utilize the Use-Modify-Create learning progression as they explore, experiment, and reflect. Students need time, materials, and scaffolded opportunities to think and to learn. Adults are responsible for ensuring this environment is created and maintained both during weekly building and coding sessions and classroom learning centers.

WeDo Lego Robotics Hardware and Software

WLR, which provides materials, building and coding directions, and suggestions for robot modifications that can be use independently by elementary-aged students, formed the basis of the constructionist learning environment. WLR sets, WLR software, and Lenovo laptops were used during weekly building and coding sessions. These materials were ideally suited for this age-group of learners. Based on previous research and the results of the current research, students should be grouped in static pairs for the sixteen-week session. Pairs reduce the number of kits and computers required to implement this research, and allow students to learn and work together. To replicate this research, one WLR kit and one laptop are required for each pair of students. While this is a large monetary commitment, these are non-consumable resources. The laptops can be used for a wide range of educational purposes, including and beyond robotics. The robotics kits and software are also non-consumable and can be reused throughout the school year. During a typical thirty-six-week school year, this sixteen-week intervention can be implemented twice. A typical classroom with 24 students will require twelve robotics kits and twelve laptops.

Classroom Learning Center

Classroom learning center time should include opportunities for student reflection and exploration. Weekly WLR reflection activities should be completed during classroom learning center time. Reflection is critical throughout the building process. Students should reflect on their building and coding experiences and whether they used instructions as provided, modified building and coding instructions, or created new robots during each session. They should reflect on what they did and the outcome of their building and/or decisions. This reflection encourages deep thinking and assimilation of ideas and concepts into a student's understanding of robotics. Students should also be encouraged to consider ways they can modify existing designs. In this research, this was done during the classroom learning center when students were asked to draw potential modifications to the robot they created each week. Even if students do not actually create the modifications they draw, it is important for them to generate new ideas and recognize they have ideas of their own. Additional materials, such as books from the school library related to STEM, robotics, and coding should be incorporated into the classroom learning center for student independent use. A wide variety of reading levels and materials should be available for student use. Additionally, a collection of websites, included coding games and videos about a wide range of STEM subjects and careers should be made available for student use.

Use-Modify-Create Learning Progression

Use of the Use-Modifying-Create learning progression is a critical component of this intervention. Its use should be incorporated into the weekly building and coding sessions, as well as the classroom learning center. Use-Modify-Create provides students with self-directed, scaffolded learning opportunities, allowing them to use the building and coding instructions as provided, progress to modifying the instructions and observing the results, and finally use the knowledge learned from these experiences to create new and novel robots. The ability to implement this learning progression is an important consideration when selecting robotics kits. Kits should include building and coding instructions students can use. It is important to allow students to have guided experiences prior to attempting to make modifications. This experience allows students who may not have background knowledge to generate such knowledge. The use stage is essential to developing foundational skills upon which students can build as they progress through the modify and create stages of the learning progression.

Robotics Showcase.

The final component of this intervention was student participation in a robotics showcase. As public displays of student creations have been shown to be very motivational, parents, teachers, and peers were invited to this showcase. One hour, on a Friday afternoon, was allotted for the showcase. Student set-up and clean-up extended about 30 minutes before and after the showcase. Teachers arranged the location and time and sent home invitations. Students set up their robots and demonstrate and explained them to visitors. They talked about their design and their code and explained the stories they wrote to go along with their robots. This is an important piece of the intervention, as it provided purpose and motivation for student creation and allows students to view and discuss the work of others.

Limitations

A convenience sample was utilized, making the sample unrepresentative (Womack, 1997). Control may have been sacrificed in favor of responsiveness, experimentation, and innovation (Womack, 1997), making generalizations difficult if not impossible (Willis and Edwards, 2014; Womack, 1997). AR methods may be rejected by some due to a perceived lack of rigor and researcher impartiality (Macintyre, 2000; Baskerville & Wood-Harper, 1996). Ethical concerns may exist in respect for persons, beneficence, and justice. These concerns stem from the close proximity of the researcher and teacher-collaborators to the subjects and their role as teachers who must put the best interests of their students first (Macintyre, 2000; Nolen & Putten, 2007; Wood & Butt, 2014). Reliability of findings is also a concern due to the specificity of the context and problem (Macintyre, 2000). This may limit the ability to generalize findings to other contexts.

Additional limitations may include the difficulty-level of the career section of the S-STEM Survey, the availability of the WLR kits used in this research, and student dislike of the written reflection materials used in the classroom learning centers.

The complexity of the S-STEM test may have contributed to the non-significant finding that resulted from student responses to that portion of the test. The Upper Elementary S-STEM was piloted and tested with fourth and fifth grade students and found to be valid and reliable. In this research, it was used with second and third grade students and may have included vocabulary and passage length that was too advanced for their age. For example, the career, "Physics" was described as follows:" Physics**:** People study motion, gravity and what things are made of. They also study energy, like how a swinging bat can make a baseball switch direction. They study how different liquids, solids, and gas can be turned into heat or electricity*"* (Friday Institute for Educational Innovation, 2012, p. 5).

The WLR product used in this research is no longer sold by Lego, which may make it difficult to generalize or replicate this research. However, Lego has a new WeDo product, WeDo 2.0, which provides learners with more organized, structured, and sequential learning opportunities. WeDo 2.0 may prove to be an improved product for student acquisition of computational thinking skills.

The only element of the multifaceted robotics-based intervention that the majority of students reportedly disliked was the student reflection questions they were required to complete during classroom learning centers. While most students attempted the questions and many answered all of the questions, they did so reluctantly. The negative feelings students expressed about these questions may have reduced the number of students who completed them with fidelity, and therefore reduced their potential positive impact.

Future Research

It would be valuable to replicate this research with newer WLR products (WLR 2.0), as well as other educational robotics platforms. The WLR product used in this research is no longer sold by Lego. A newer version, with the same philosophy, but different projects and computer interface (WLR 2.0) is currently available for purchase. Replicating this research with this new hardware and software would be a valuable continuation of this research. Likewise, replicating this research with other educational robotics platforms has the potential to expand its application and value by determining the interventions effectiveness with a variety of educational robotics platforms.

It would also be valuable to replicate this research with younger and/or older students. It is the researcher’s belief that younger students may require modifications to the structure of the intervention to accommodate for developing skills in terms of reading, writing, thinking, and ability to work independently. The researcher believes it is likely older students will see similar, if not greater, growth in terms of interest in STEM subjects and careers and computational thinking skills. Expanding the age range of students has the potential to expand the application and value of this research by determining the intervention’s effectiveness with a larger population.

It would be valuable to replicate this research using a different career interest survey instrument. Following an exhaustive review of available instruments, The Upper Elementary S-STEM Survey used in this research was determined to be the most appropriate instrument currently available. It is possible newer instruments have been constructed and evaluated. If not, it may be necessary for those wishing to replicate this research to further modify the S-STEM survey or create a new survey instrument.

Finally, it would be valuable to replicate this research with a focus on improving the classroom learning center materials used for student reflection. The researcher would suggest refining, simplifying, and clarifying these reflection questions to reduce the written burden on students. Completion of the written reflection materials was the only element of the intervention a majority of the students disliked. Improving these materials, while maintaining student learning, will result in a more engaging and robust intervention.

Summary

The purpose of this study was to examine the impact of a robotics-based intervention on elementary-aged students' interest in STEM subjects and careers and development of computational thinking skills. This research clearly shows the value of exposing young students to STEM subjects and careers and computational thinking.

Through participation in this intervention, second and third grade students developed computational thinking skills. Computational thinking skills allow individuals to break down and think about problems in a systematic way, devise ways to solve those problems, and then analyze and improve their solutions. Students who possess computational thinking skills possess a powerful set of skills that can be used in many ways and in many situations that will benefit them in school and in life. Students also gained positive interest and attitudes toward STEM subjects and careers. This is a valuable mindset that will benefit students as they progress through school and consider future career options. This intervention made students aware of the value of STEM subjects and careers in their own lives and to the world. Students became aware of and interested in pursuing STEM jobs as a future career because this intervention added information and ideas to student experience. How can you know you want to be a roboticist if you don't know they exist or what they do? Access to STEM reading material and STEM-speaking adults who talked about their jobs and their use of STEM were valuable parts of this intervention. Together, they opened up the idea of STEM careers to students, helping to ensure students have hopes and dreams and understand how to achieve them. Having this knowledge and understanding at such a young age gives students something to build on and work toward as they progress through their education. This is vitally important because dreams inspire us to keep moving forward, growing, and learning. Through participation in this intervention, students have acquired not only dreams, but the knowledge and developing-skills to turn their dreams into reality.

The robotics-based intervention examined in this research was rooted in constructionist learning philosophy, which theorizes students can learn through exploration, creation, and reflection in a resource-rich environment. It is the researcher's belief the positive outcomes of this research are rooted in the creation of an intervention that saturated students in rich STEM and computational thinking experiences. All second and third grades students in two diverse, regular education classrooms were provided a constructionist, robotics environment to explore STEM and computational thinking during the regular school day. They were supported by committed, STEM-speaking teachers and volunteers trained in the Use-Modify-Create learning progression and encouraged to provide student support, rather than direct instruction. In keeping with constructionist theory, students were given objects-to-think-with, in the form of WLR, and encouraged to learn through making, at their own pace, based on their own interests. In addition to one hour a week of WLR building and coding, students participated in a classroom learning center designed to scaffold and support exploration of STEM subjects and careers, thoughtful reflection of weekly building and coding activities, and opportunities to utilize computational thinking. This sixteen-week intervention culminated in four sessions of student creation during which each student-pair created a novel robot to be presented in a student robotics showcase. Students were excited to participate in this showcase, which provided a highly motivating culminating activity for the intervention. Together, the elements of this multifaceted robotics-based intervention provided students with a rich, supportive, constructionist learning environment that facilitated their development of interest in STEM subjects and careers and computational thinking skills, attitudes and knowledge that will lay the groundwork for future success.

Teachers who have the desire and commitment to promote student development of an understanding of and interest in STEM subjects and careers and development of computational thinking skills, can implement this intervention with confidence that it will positively impact student learning. Time and money are common barriers. However, this research provides a strong case for committing both time and funding to this endeavor. Research indicates students' attitude toward and interest in STEM subjects and careers and development of computational thinking skills can be positively impacted through participation in this intervention. These outcomes and their potential positive impact on student academic and career success can be used to make a strong case for committing time and resources to the implementation of this multifaceted robotics-based intervention.

The findings from this research clearly elucidate the value of young students' participation in a multifaceted robotics-based intervention designed to develop students' positive attitudes toward STEM subjects and careers and development of computational thinking skills. Although the value of these attitudes and skills are clearly supported in the literature, prior to this research, an easy to implement, cost-and time-effective method for promoting young students' learning of these concepts has not been examined and presented in the literature. This research provides practitioners with an intervention that can be integrated into elementary classrooms in as little as two hours per week for sixteen weeks and result in student acquisition of positive attitudes toward STEM subjects and careers and computational thinking skills.

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APPENDIX A

Training Script and PowerPoint Slides

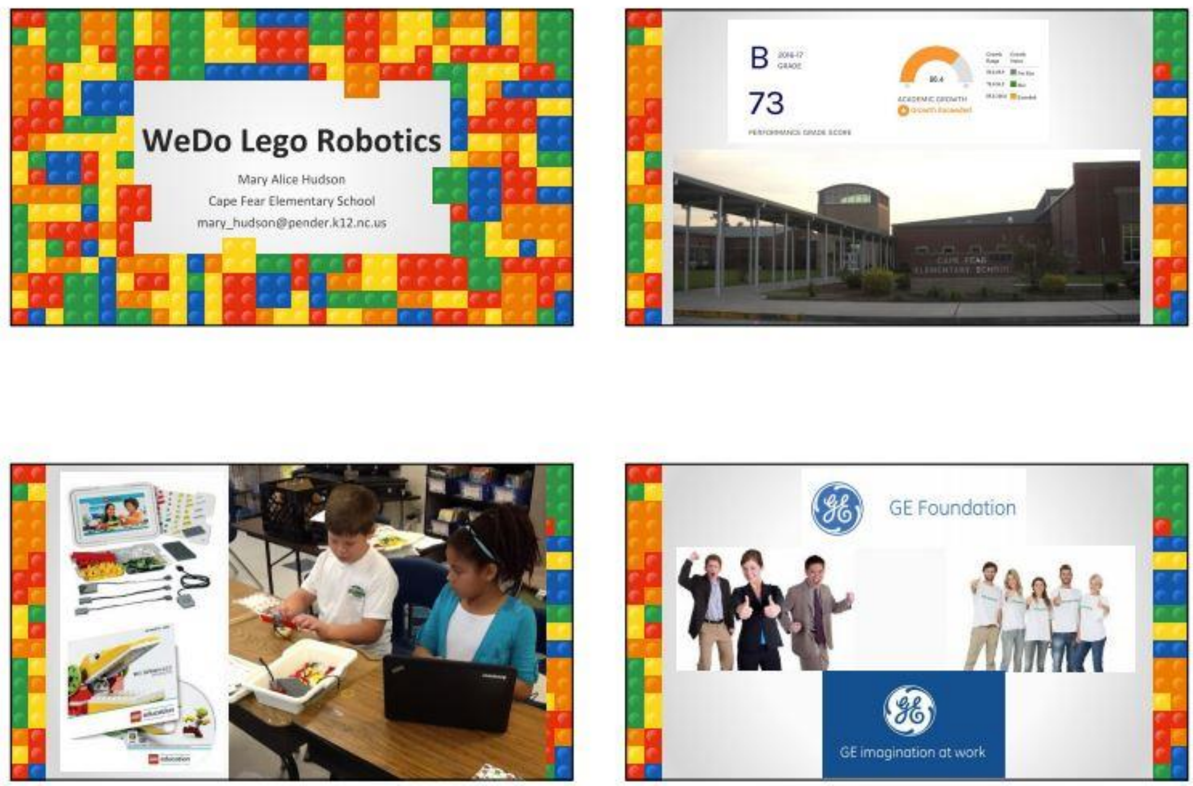


Figure A1. Teacher and volunteer training slides 1-4.

Slide 1: Hi everyone! My name is Mary Alice Hudson and I'm the librarian at Cape Fear Elementary. I've been coordinating Cape Fear's WeDo Lego Robotics program since its beginning, in January of 2016. I am also a doctoral candidate in Educational Technology at Boise State University and I will be using the data collected from our upcoming semester of WeDo Lego Robotics as the basis for my dissertation. So, I'd like to thank you all for being willing to work with our students, but also for helping me implement some specific interventions to help our students grow and learn through WeDo Lego Robotics. I'm really excited to see what kinds of outcomes we will achieve. And, after the data is collected and analyzed, I will gladly share my findings with all of you. So...here we go!

Slide 2: First, some background about Cape Fear Elementary. As you probably know, we are a Title I school in Pender County. Our Title I status is based on the high number of students in our school who qualify for Free or Reduced Lunch. If you've seen information about the NC School report cards, you probably also know that typically high poverty equals low school performance grades. Cape Fear is an exception to this. Despite our status as a Title I school, for the past three years, our students have exceeded expected growth and increased overall grade level proficiency, resulting in a B rating from the state of North Carolina. We are very proud of our students and their accomplishments and we believe that programs such as WeDo Lego Robotics have contributed to their success. So, we've thrilled you are willing to help us and we look forward to working together to do great things for our students!

Slide 3: So, what is WeDo Lego Robotics? WeDo Lego Robotics (WLR) is a robotics hardware and software platform specifically designed for second to fourth grade students. It includes step-by-step building and coding instructions for twelve robotic models. Students follow on-screen directions for building and coding. Students are also encouraged to explore building and coding possibilities by modifying the presented designs. Our hope is that you will serve as a support, a sounding-board, and a guide as students learn and grow through participation in this program.

Slide 4: How did we start using WeDo Lego Robotics at CFE. Our Physical Education teacher, Dr. Chris Wirszyla applied for a GE Foundation grant back in 2015. We were awarded about $7,000 to purchase the materials to implement WeDo Lego Robotics in our school. Chris is an awesome grant writer, but not really a tech guy...which is how I got involved.

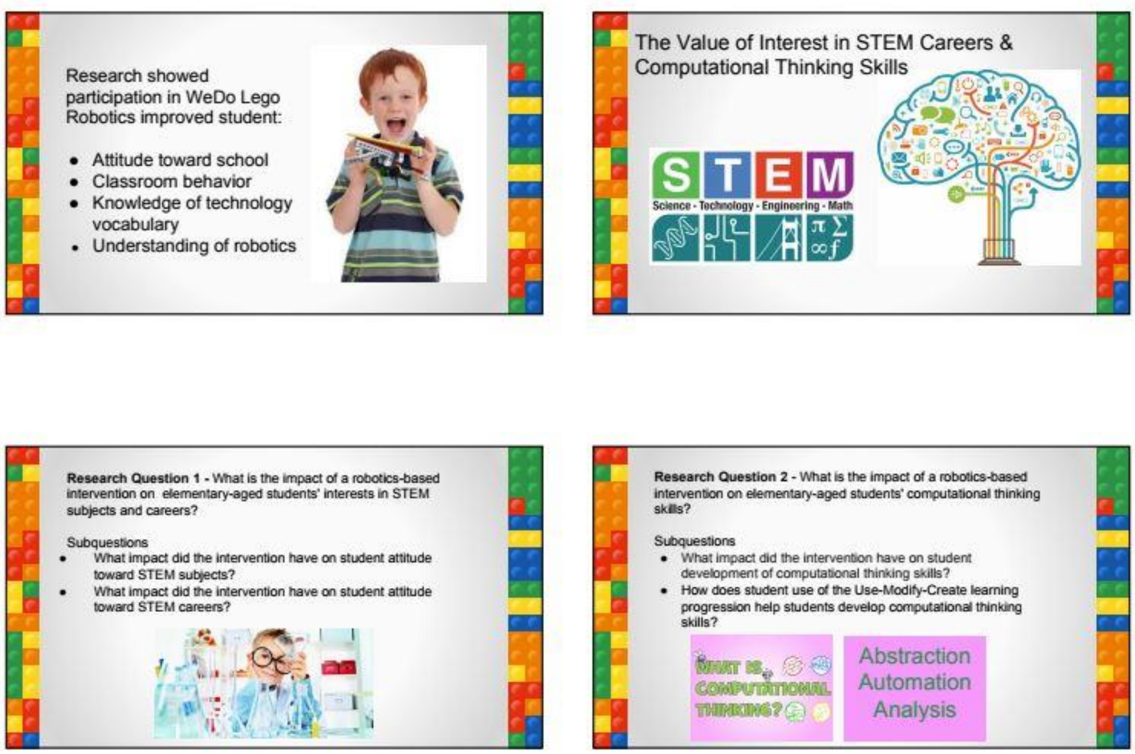


Figure A2. Teacher and volunteer training slides 5-8.

Slide 5: Chris asked me to help create and facilitate our initial WeDo Lego Robotics program. This was perfect timing for me because I was looking for an innovative experience I could use to fulfill a requirement of my doctoral program. Prior to this I had absolutely no robotics experience or aspirations and I would have vehemently protested if you'd told me I would be doing my dissertation on the use of robotics in schools. But, once we got started, I was hooked because the student outcomes were so amazing and wonderful! My first round of research showed participation in WeDo Lego Robotics improved students' attitude toward school, classroom behavior, knowledge of technology vocabulary, and understanding of robotics. These outcomes gave us the evidence and the desire to continue and expand our program. Which leads us to the present...and my research...

Slide 6: My research seeks to promote student interest in STEM (which I'm sure you know is Science, technology, engineering, and math) subjects and careers and to develop student computational thinking skills. I hope to achieve these outcomes through the use of a robotics-based intervention which includes multiple components, many of which you will be a part of. The first component is the hour long WLR building and coding sessions. The second component is the use of the Use-Modify-Create learning progression, which I will explain in a moment. The third is exposure to information about STEM subjects and careers via books, videos, and contact with adults who value STEM, and the last is a STEM learning center that students will be participating in during their regular class time three days per week (see Note 1). So, let me break all of this down for you...

Slide 7: My first research question is: **Research Question 1 -** What is the impact of a robotics-based intervention on elementary-aged students' interests in STEM subjects and careers (see Note 2)?

Subquestions

- What impact did the intervention have on student attitude toward STEM subjects?
- What impact did the intervention have on student attitude toward STEM careers?

Previous research has shown that students don't connect WLR to STEM subjects and careers. And, we want them to make that connection. We want them to understand that people with STEM skills are in high demand in the job market, that the number of STEM careers is growing rapidly, and that having a strong STEM background is necessary in virtually every field, whether the job you're doing is viewed as STEM or not. We want students to see STEM as something important that they can learn now and use in the future. So, I would ask that you help them make that connection. Please talk to students about your life and your job. The ways you use STEM recreationally and occupationally. Why STEM is important to you and how it will be important to your future...and theirs. We want students to understand they have the opportunity to experience success in the future because they have invested in STEM during their school careers. WLR is a perfect springboard to these conversations. As you talk about the STEM skills students are using during WLR, please leverage this conversation to promote student interest in STEM subjects and careers.

Slide 8: My second research question is: **Research Question 2** - What is the impact of a robotics-based intervention on elementary-aged students' computational thinking skills (see Note 3)?

Subquestions

- What impact did the intervention have on student development of computational thinking skills?
- How does student use of the Use-Modify-Create learning progression help students develop computational thinking skills?

Let’s start with computational thinking. Computational thinking is the use of abstraction, automation, and analysis to take a complex problem, understand what the problem is, and develop possible solutions using a computer. So, there are three pieces to computational thinking...abstraction, automation, and analysis. Abstraction is the ability to solve a problem by striping it down to its essence. Problem decomposition and pattern recognition are important components of abstraction. Automation is the ability to develop a step-by-step solution to a problem by creating a computer program. And, analysis is the ability to troubleshoot and debug the thought processes and programming used to solve a problem or perform the task. Research has shown that computational thinking skills can be developed through exposure to educational robotics. This is a skill set that is and will continue to be in high demand in the workforce and will benefit students as they pursue future educational opportunities and career prospects. So, how can we promote student development of computational thinking skills?

Figure A3. Teacher and volunteer training slides 9-12.

Slide 9: To help students develop computational thinking skills, we are going to use the Use-Modify-Create learning progression during WLR building and coding sessions. The Use-Modify-Create learning progression is designed to support student learning as students develop computational thinking skills and move from being consumers to producers. Students first interact with an existing computational artifact (the “Use” stage). Students develop computational thinking skills by modifying and iteratively refining someone else’s project to make it their own (the “Modify” stage). As students gain skill and confidence, they can be encouraged to develop ideas for new computational projects of their own design that address issues of their choosing (the “Create” stage).

Slide 10: During the first 12 sessions/weeks of WLR we are going to focus on Use and Modify. The students will use the WLR instructions as provided to build and code their robots. The instructions promote some degree of modification, but your goal will be to help students explore further. We would like you to encourage them to think about ways they can modify their existing robot and code. Please use the word modify when you talk to students about this. We want them this word to become part of their vocabulary. As I said before, the idea behind the Use-Modify-Create learning progression is that students develop computational thinking skills by modifying and iteratively refining someone else’s project to make it their own. There are twelve sets of instructions students can use to create robotics projects. However, students do not need to complete all twelve during the twelve building sessions. The skills taught through each project are overlapping. So, students will be exposed to all of the coding concepts even if they don't finish all of the projects. Students will be able to store their projects from week to week, so they don't need to rush through each design. It is more important for them to explore and modify than to finish all twelve.

Slide 11: At the end of the 12 weeks, we will move to the create stage. Students will have four building sessions to create a novel robot with novel coding. During this stage, you will be encouraging students to test, analyze and refine their ideas. Some students will be able to do this, some may struggle. It is perfectly fine for students to use or modify designs or code they have utilized during the past twelve weeks, but the goal is to move students beyond these stages and encourage them to use what they have learned to actually create. Their robotics creations will be displayed in a robots showcase event during which they will be able to share their robots with other students and community members (see Note 1).

Slide 12: As all of this is going on, students will also be participating in a STEM learning center during their regular class time, three days a week. On Tuesdays, students will be reading and watching videos about STEM subjects and careers. They will be completing a graphic organizer in their STEM notebooks about what they learn. So, please feel free to ask them about it. They will be able to show you their notebooks. On Wednesday, students will be going online to practice computational thinking through coding games and activities. And, on Thursday, they will be reflecting on their building and coding activities from their time with you, by answering questions about what they are working on during their building and coding sessions. Please discuss these questions with them, so they will be able to respond thoughtfully. They will be asked:

What did you build?
What did it do?
What was hard?
What was easy?
What did you learn?
Did you Use, Modify, or Create? Explain.

How could you modify your project or create something new from what you've learned? Use your imagination! Draw your design on the back.

Figure A4. Teacher and volunteer training slides 13-15.

Slide 13: And, that is pretty much all of it. There are a few more bits of information...

Students will be working in pairs - two students with one computer and one kit

Encourage students to be careful with their bricks. There are no extras!

Refer student behavior issues to teachers.

Help students with construction and programming, but use your words, not your hands.

Talk to students about STEM subjects and careers.

Promote the use of the Use-Modify-Create learning progression.

Ask guiding questions to facilitate real world connections.

Connect with students

Assist with clean-up if you are able to stay.

Slide 14: Questions?

Slide 15: Thank you!

Notes

Note 1 - Although the robotics showcase was included in this intervention from the beginning, its importance became increasingly apparent. It was added as a component of the intervention after the training occurred. As it had been discussed with teachers and volunteers during the training, no additional training was required.

Note 2 - Research Question 1: Sub-questions one and two were reworded to better align with the pre-and post-test design used in this research. A third subquestion was added. These modification did not change the intent of the research or the intervention. The changes were made to clarify the goals of the research and aid in data collection. The updated Research Question 1 is as follows:

Research Question 1 - What is the impact of a robotics-based intervention on elementary-aged students' interest in STEM subjects and careers?

Subquestions

- Does the intervention have an effect on student attitude toward STEM subjects?
- Does the intervention have an effect on student attitude toward STEM careers?
- How did the intervention impact student attitude toward STEM subjects and careers?

Note 3 - Research Question 2: Sub-question one was reworded to better align with the pre-and post-test design used in this research. The second subquestion was deleted and replaced with the subquestion below. These modifications did not change the intent of the research or the intervention. The changes were made to clarify the goals of the research and aid in data collection. The updated Research Question 2 is as follows:

Research Question 2 - What is the impact of a robotics-based intervention on elementary-aged students' computational thinking skills?

Subquestions

- Does the intervention have an effect on student development of computational thinking skills?
- How did the intervention impact student development of computational thinking skills?

APPENDIX B

Cover Letter and Consent – English & Spanish

Cover Letter English

January, 2018

Thanks to a grant from General Electric, your child's class will be participating in WeDo Lego Robotics during the second semester of this year. We are very excited about this opportunity and know the students will love working with teachers and GE volunteers to learn about robotics and computer programming. We will be conducting a research study to explore the impact participation in WeDo Lego Robotics has on student interest in science, technology, engineering, and math (STEM) subjects and careers and development of computational thinking skills (the ability to understand and create computer code). Your child is being invited to take part in this research study. There will be approximately 40 participants in this study.

Who Is Doing The Study?

The person in charge of this study is Mary Alice Hudson, Cape Fear Elementary School Librarian and Doctoral Candidate at Boise State University. Mrs. Hudson will be gathering and analyzing the information for the study.

Where Is The Study Going To Take Place And How Long Will It Last?

The research will be conducted at Cape Fear Elementary School during regular school hours. The Lego Robotics Groups and the research study will begin in January and will last approximately 16 weeks.

What Will My Child Be Asked To Do?

Students will be asked to complete pre- and post-tests related to STEM interest and computational thinking skills. Select students will be interviewed to assess their understanding of computational thinking skills

Who Will See The Information My Child Gives?

Your child's information will be combined with information from others taking part in the study. When we write up the study to share it with other researchers, we will write about the combined information. Your child will not be identified in these written materials.

Does My Child Have To Take Part In This Study?

While we would like for all children to participate in this research, it is not required. There will be no penalty if your child does not participate in this study. He or she will be allowed to participate in the WeDo Lego Robotics Group.

What If I Have Questions Or My Child Has Questions?

Please call if you have any questions. You can contact Mary Alice Hudson at 910-602-3767.

Please read and return the accompanying form indicating whether or not you will allow your child to participate in this research study.

Cover Letter Spanish

enero de 2018

Gracias a una subvención de General Electric, la clase de su niño va participar en "WeDo Lego Robotics" durante el segundo semestre este año escolar. Estamos muy emocionados para esta oportunidad y sabemos que les van a encantar a los niños a trabajar con los maestros y voluntarios de GE para aprender sobre la robótica y programación de computadoras. Estaremos haciendo un estudio de investigación para explorar el impacto de participación en "WeDo Lego Robotics" tiene en el interés estudiantil en las materias y carreras de ciencia, tecnología, ingeniería y matemáticas (STEM) y el desarrollo de habilidades de pensamiento de computación (la habilidad de entender y crear códigos de computadoras). Su niño está siendo invitado a tomar parte de este estudio de investigación. Habrá aproximadamente 40 participantes en este estudio.

¿Quién está haciendo este estudio?

La persona encargada de este estudio es Mary Alice Hudson, la bibliotecaria de Cape Fear Elementary School y candidata a doctorado en Boise State University. Sra. Hudson estará juntando y analizando la información para este estudio.

¿Dónde va tomar lugar el estudio y cuánto tiempo va durar?

La investigación será hecha en Cape Fear Elementary School durante los horarios escolares. Los grupos de Lego Robotics y el estudio de investigación van a comenzar en enero y durará aproximadamente 16 semanas.

¿Qué le van a pedir a mi niño?

Se les va a pedir a los estudiantes a completar exámenes previos y después relatados a interés en STEM y habilidades de pensamiento de computación. Algunos estudiantes serán seleccionados para ser entrevistados para evaluar su entendimiento de habilidades de pensamiento de computación.

¿Quién verá la información que de mi niño?

La información de su niño será combinada con la información de otros tomando parte de esta investigación. Cuando escribimos el estudio para compartir con otros investigadores, vamos a escribir sobre la información combinada. Su niño no será identificado en este material escrito.

¿Mi niño tiene que tomar parte de esta investigación?

Mientras que queremos que todos los niños participen en esta investigación, no es requerido. No habrá ningún castigo si su niño no participar en esta investigación. Él o ella podrá participar en el Grupo de "WeDo Lego Robotics."

¿Si tengo preguntas o si mi niño tiene preguntas?

Por favor de llamar si tienen preguntas. Pueden comunicarse con Mary Alice Hudson at 910-602-3767.

Por favor de leer y regresar la hoja adjunta indicando si permitirá que su niño participe o no en este estudio de investigación.

Request for Parent/Guardian Informed Consent English

BOISE STATE UNIVERSITY

INFORMED CONSENT

Study Title: Using Robotics to Increase Student Computational Thinking Skills and Interest in STEM

Principal Investigator: Mary Alice Hudson

Faculty Adviser: Dr. Young Baek

Dear Parent/Guardian:

My name is Mary Alice Hudson and I am a doctoral student in the Educational Technology program at Boise State University. I am asking for your permission to include your child in my research. This consent form will give you the information you will need to understand why this study is being done and why your child is being invited to participate. It will also describe what your child will need to do to participate as well as any known risks, inconveniences or discomforts that your child may have while participating. I encourage you to ask questions at any time. If you decide to allow your child to participate, you will be asked to sign this form and it will be a record of your agreement to participate. You will be given a copy of this form to keep.

PURPOSE AND BACKGROUND

As you may know, WeDo Lego Robotics is on-going program at Cape Fear Elementary School. My research is designed to evaluate ways to improve this program and to increase the positive impact it has on student learning. As part of my dissertation, I will be testing all participating students and interviewing select students. This, along with analysis of student work, will be conducted to evaluate the effectiveness of modifications to our WeDo Lego Robotics program.

PROCEDURES

This study will take place during a sixteen week period beginning in early 2018. If you choose not to allow your child to participate, s/he will remain in their classroom and be allowed to participate in WeDo Lego Robotics, but they will not be tested or interviewed, and copies of their work will not be analyzed.

RISKS/DISCOMFORTS

Your child should not experience any risks or discomforts during this research. However, you are able to remove your child from the study at any time and your child will continue to participate in WeDo Lego Robotics instruction.

EXTENT OF CONFIDENTIALITY

Reasonable efforts will be made to keep the personal information collected during this research private and confidential. Any identifiable information obtained in connection with this study will remain confidential and will be disclosed only with your permission or as required by law. The members of the research team and the Boise State University Office of Research Compliance (ORC) may access the data. The ORC monitors research studies to protect the rights and welfare of research participants.

Your student's name will not be used in any written reports or publications that result from this research. Data will be kept for three years (per federal regulations) after the study is complete and then destroyed.

BENEFITS

There will be no direct benefit to your child from participating in this study. However, the information gained from this research may help education professionals better understand how students engage in educational robotics learning activities.

PAYMENT

There will be no payment to you or your child as a result of your child taking part in this study.

QUESTIONS

If you have any questions or concerns about participation in this study, you should first talk with the investigator Mary Alice Hudson at 910-602-3767, or her advisor, Dr. Young Baek, at 208-426-1023.

If you have questions about your child's rights as a research participant, you may contact the Boise State University Institutional Review Board (IRB), which is concerned with the protection of volunteers in research projects. You may reach the board office between 8:00 AM and 5:00 PM, Monday through Friday, by calling (208) 426-5401 or by writing: Institutional Review Board, Office of Research Compliance, Boise State University, 1910 University Dr., Boise, ID 83725-1138.

DOCUMENTATION OF CONSENT

I have read this form and decided that my child will participate in the project described above. Its general purposes, the particulars of involvement and possible risks have been explained to my satisfaction. I will discuss this research study with my child and explain the procedures that will take place. I understand I can withdraw my child at any time.

____

Printed Name of Child

____________________________ ______________________________________

Printed Name of Parent/Guardian **Signature** of Parent/Guardian Date

____ __________

Signature of Person Obtaining Consent Date

Request for Parent/Guardian Informed Consent Spanish

BOISE STATE UNIVERSITY

CONSENTIEMIENTO INFORMADO

Título del Estudio: Usado Robótica para Aumentar las Habilidades Computacionales e Interés en STEM de los Estudiantes

Investigadora principal: Mary Alice Hudson **Asesor de Facultad:** Dr. Young Baek

Estimados Padres/Guardián:

Mi nombre es Mary Alice Hudson y son una estudiante de doctorado en el programa de Tecnología Educativa en la Universidad en Boise State. Estoy pidiéndole su permiso para incluir su niño en mi investigación. Esta hoja de consentimiento le dará la información que necesitará para entender por qué este estudio está siendo hecho y por qué su niño está siendo invitado a participar. También va describir lo que su niño necesita hacer para participar as como saber cualquier riesgo, inconveniencias o incomodidades que su niño podrá tener mientras participando. Les animo a hacer preguntas en cualquier momento. Si decide a dejarle a su niño participar, se le pedirá a firmar esta hoja y será guardada como muestra de su acuerdo de participar. Se le dará una copia esta hoja para guardar.

PROPOSITO E INFORMACION DE FONDO

Como a lo mejor saben, hacemos "WeDo Lego Robotics" es un programa en curso que hacemos en Cape Fear Elementary School. Mi investigación es diseñada a evaluar modos para mejorar este programa y para aumentar un impacto positive que tiene en el aprendizaje estudiantil. Como parte de mi disertación, evaluaré a todos los participantes estudiantiles y entrevistaré a selectos estudiantes. Esto, junto con el análisis del trabajo de los estudiantes, se llevará a cabo para evaluar la efectividad de las modificaciones a nuestro programa WeDo Lego Robotics.

PROCEDAMIENTOS

Este estudio va tomar lugar durante un periodo de dieseis semanas comenzando al principio de 2018. Si decide que su niño no participe, él/ella va a permanecer en el salón y ser permitidos en participar en "WeDo Lego Robotics", pero no serán evaluados o entrevistados y copias de su trabajo no serán analizados.

RIESGOS/INCOMODIDADES

Su niño no debe de experimentar cualquier riesgo o incomodidades durante esta investigación. Sin embargo, usted puede remover su niño de este estudio en cualquier momento y su niño va seguir participando en la instrucción de "WeDo Lego Robotics."

ALCANCE DE LA CONFIDENCIALIDAD

Esfuerzos razonables serán hechos para mantener la información personal coleccionada durante esta investigación privada y confidencial. Cualquier información identificable obtenida en conexión con este estudio va permanecer confidencial y será relevada solamente con su permiso y como requerido por ley. Los miembros del equipo de investigación y Boise State University Office of Research Compliance (ORC) (Oficina de Cumplimiento de Investigación) pueden acceder los datos. La ORC monitorear estudios de investigación para proteger los derechos y bienestar de los participantes de investigación.

El nombre de su estudiante no será usado en los reportes escritos o publicaciones que resultaron de esta investigación. Los datos serán mantenidos por tres años (por regulaciones federales) después de que se completa y entonces destruidos.

BENEFICIOS

No habrá ningunos beneficios directos a su niño en participar en este estudio. Sin embargo, información ganada de esta investigación a lo mejor ayudará profesionales educativos entender mejor como los estudiantes se involucran en actividades de aprendizaje de robótica educativa.

PAGO

No habrá pago a usted o su niño como resultado que su niño está tomando parte de este estudio.

PREGUNTAS

Si tienen preguntas o preocupaciones sobre la participación de este estudio, primero debe de hablar con la investigadora Mary Alice Hudson al 910-602-3767, o su asesor, Dr. Young Baek, al 208-426-1023.

Si tienen preguntas sobre los derechos de su niño como un participante de investigación, pueden comunicarse con Boise State University Institucional Review Board (IRB) (Bordo de Revisión Institucional), lo cual se preocupa con la protección de voluntarios en proyectos de investigación. Puede comunicarse con la oficina del bordo entre las 8:00 AM y 5:00 PM, el lunes a viernes, en hablar (208) 426-5401 o por escrito: Institutional Review Board, Office of Research Compliance, Boise State University, 1910 University Dr., Boise, ID 83725-1138.

DOCUMENTACION DE CONSENTIEMIENTO

He leído esta hoja y decidido que mi niño va participar en el proyecto descrito arriba. Los propósitos generales, los detalles de participación en lo proyecto descrito encima y los posibles riesgos ha sido explicados y esto satisfecho. Voy hablar con mi niño de este estudio de investigación y explicar los procedimientos que van a tomar lugar. Entiendo que puedo sacar a mi niño en cualquier momento.

____

Nombre escrito del niño

Nombre Escrito del Padre/Guardián | **Firma** del Padre/Guardián | Fecha

Firma de persona obtenido consentimiento | Fecha

APPENDIX C

Student Assent

The following will be provided to teachers to guide their explanation of the study to students and gain students' verbal assent. The first part is a list of talking points teachers are asked to cover and the second is a script which may be read to students or used as a guide.

Talking Points

Please cover the following information as you discuss this study with your students:

- Students will be participating in WeDo Lego Robotics (WLR) for the rest of the school year.
- If their parents returned the permission slip, they will be participating in a study to find out if doing WLR changes the way they feel about STEM subjects and careers and the way they think and understand computer programming.
- All students will take two test before starting WLR.
    - One test measures career interests
    - The other test measures computational thinking skills...or student ability to think like a computer programmer and understand the way computer programs work.
- All students will take the same two tests at the end of year to measure what they have learned.

- All students will participate in a STEM learning center during center time. Students will keep track of their thoughts and ideas in a STEM notebook. This will also be used to examine what they have learned.
- At the end of the year, students will build a robot to show to other students.
- Some students will be interviewed about their robot - students will be asked how they came up with the idea for it, how they designed it, and how they wrote the computer code to make it work.
- WLR is going to be fun and students are going to learn a lot.
- Ask students if they have any questions about what they will be doing or learning.
- Ask students if they agree to participate in the study. Ask if there is anyone who isn't sure they want to participate. Address questions about students' concerns. Explain that students can still participate in WLR even if they don't want to participate in the study. Speak privately to any student who expresses uncertainty or confusion about participating.

Sample Script - This may be read to students or used as a guide.

As you know, we will be doing WeDo Lego Robotics in class for the next couple of months. If your parents returned the permission slip, you will be participating in a study to find out if doing WeDo Lego Robotics changes the way you feel about STEM subjects and careers and the way you think and understand computer programming. As part of this study, you will take two tests before we start Legos. One test measures your career interests and the other measures your computational thinking skills...or your ability to think like a computer programmer and understand the way computer programs work. You will take the same two tests at the end of the school year to see what you have learned. You will also participate in a STEM center during center time and keep track of your thoughts and ideas in a STEM notebook. This will also be used to see what you have learned. At the end of the year, you will get to build a robot to show to other students in a robotics showcase. Some of you will be interviewed about your robot...you will be asked how you came up with the idea for it, how you designed it, and how you wrote the computer code to make it work. We are going to have a lot of fun and learn a lot as we do WeDo Lego Robotics. Does anyone have any questions about the what you're going to be learning and doing? Is there anyone who isn't sure if they want to participate?

APPENDIX D

Career Interest Writing/Drawing Activity

Students completed a student career interest writing/drawing activity pre- and post-intervention. Questions were as follows:

- When I grow up, I want to be a __________.
- Will you need to know science, technology, engineering, or math to do this career? Explain your answer.
- What can you do to get ready for this career?
- Write about or draw yourself in this career.

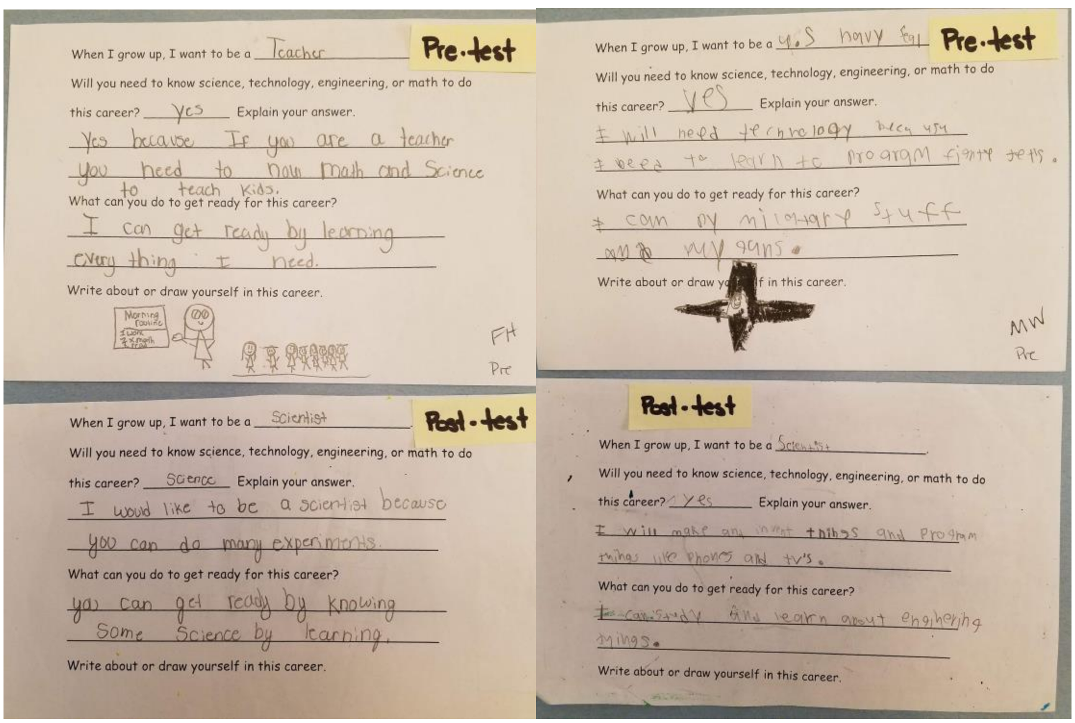


Figure D1. Photographs of completed pre- and post-test career interest writing/drawing activities.

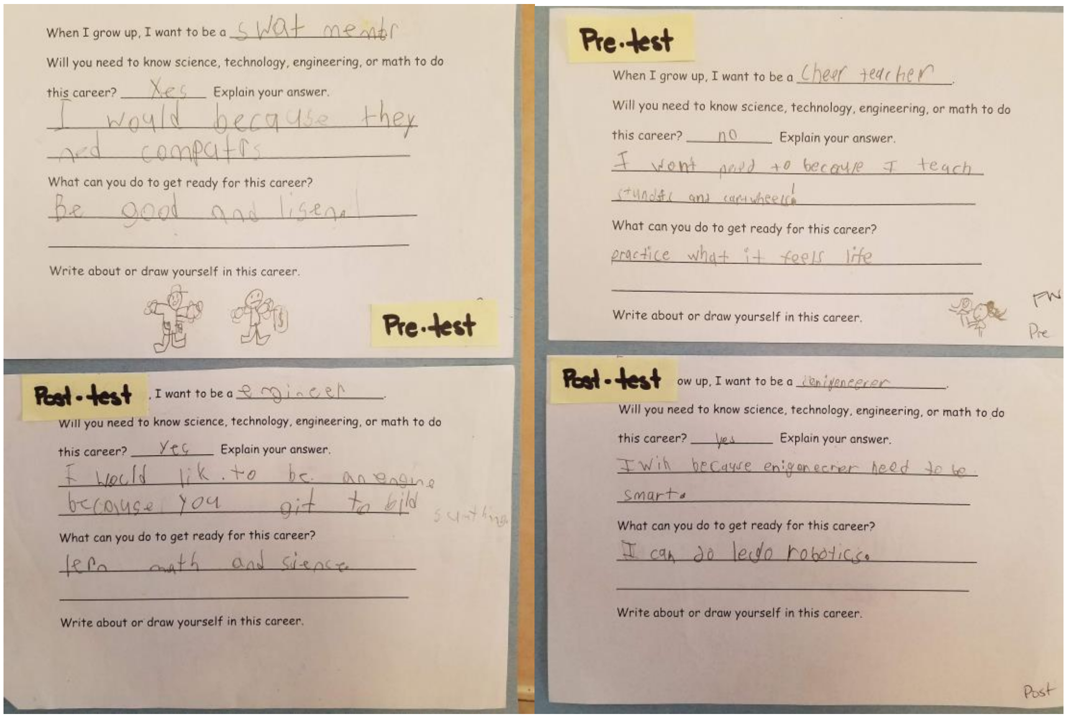


Figure D2. Photographs of completed pre- and post-test career interest writing/drawing activities.

APPENDIX E

WLR Activities

#1: Dancing Birds

Figure E1. Photograph of Dancing Birds program that makes birds spin and play music.

Figure E2. Photograph of Dancing Birds robot.

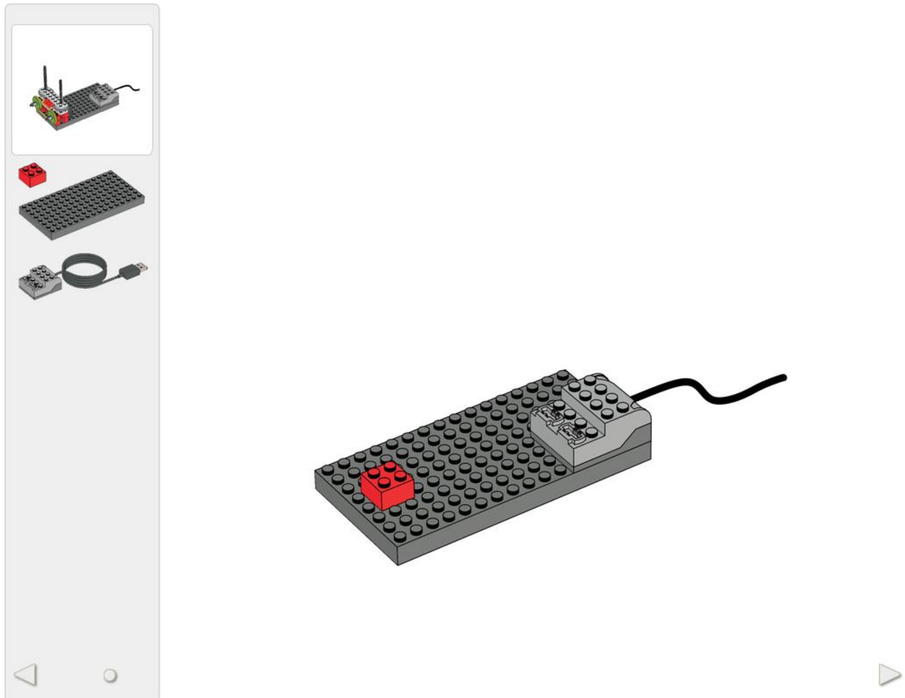


Figure E3. Photograph of WLR instructions for Dancing Birds (step 1 of 26).

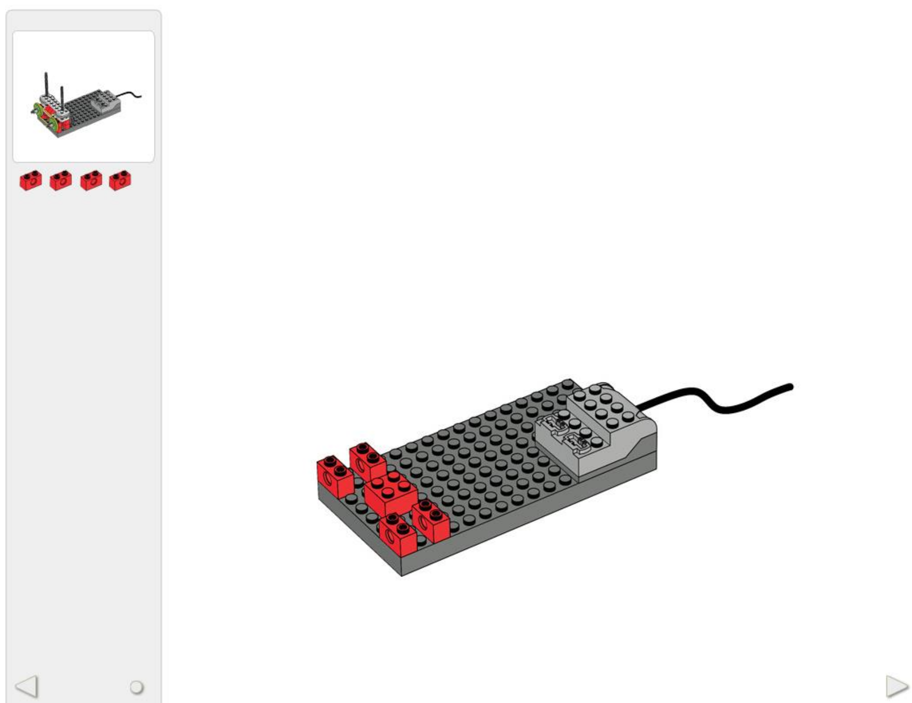


Figure E4. Photograph of WLR instructions for Dancing Birds (step 2 of 26).

APPENDIX F

Stem Learning Center Reflection Activity

Students participated in an independent classroom STEM learning center three days per week (Tuesday, Wednesday, and Thursday) for 20 minutes per day.

Thursday - Students participated in weekly WeDo Lego Robotics building and coding activities on Wednesday afternoons. During STEM center time on Thursday, students completed a building and coding reflection activity. Student notebooks included the names of the programming blocks (see Figure F1) and a key for the sounds (see Figure F2), as well as the code (see Figure F3) and a picture for each activity (see Figure F4). Students used these to aid them in answering the following questions.

Reflect on this Week's Lego Project

What did you build?____

____

What did it do? ____

____

What was hard? ____

____

What was easy? ____

____

What did you learn? _______________________________________

____

Did you Use, Modify, or Create? __________ Explain. ___________

____

How could you modify your project or create something new from what you've learned? Use your imagination! Draw your design on the back.

Figure F1. **List of WeDo Lego Robotics software commands.**

Sound List

This list shows the type of sound that is made when you use the Play Sound Block with the Number Input shown. Click the Play Sound Block to hear the sound. See Getting Started 8. Crossed Belts for help recording your own sound.

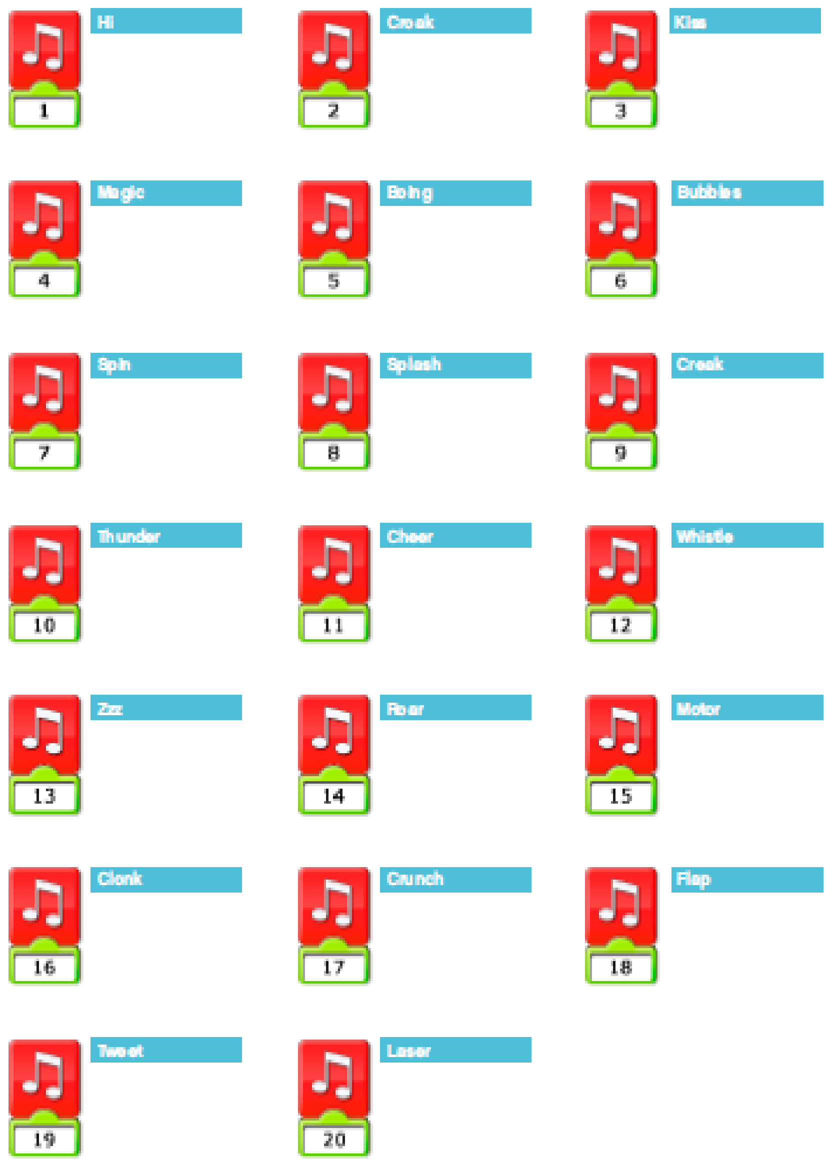


Figure F2. **List of WeDo Lego Robotics software sounds.**

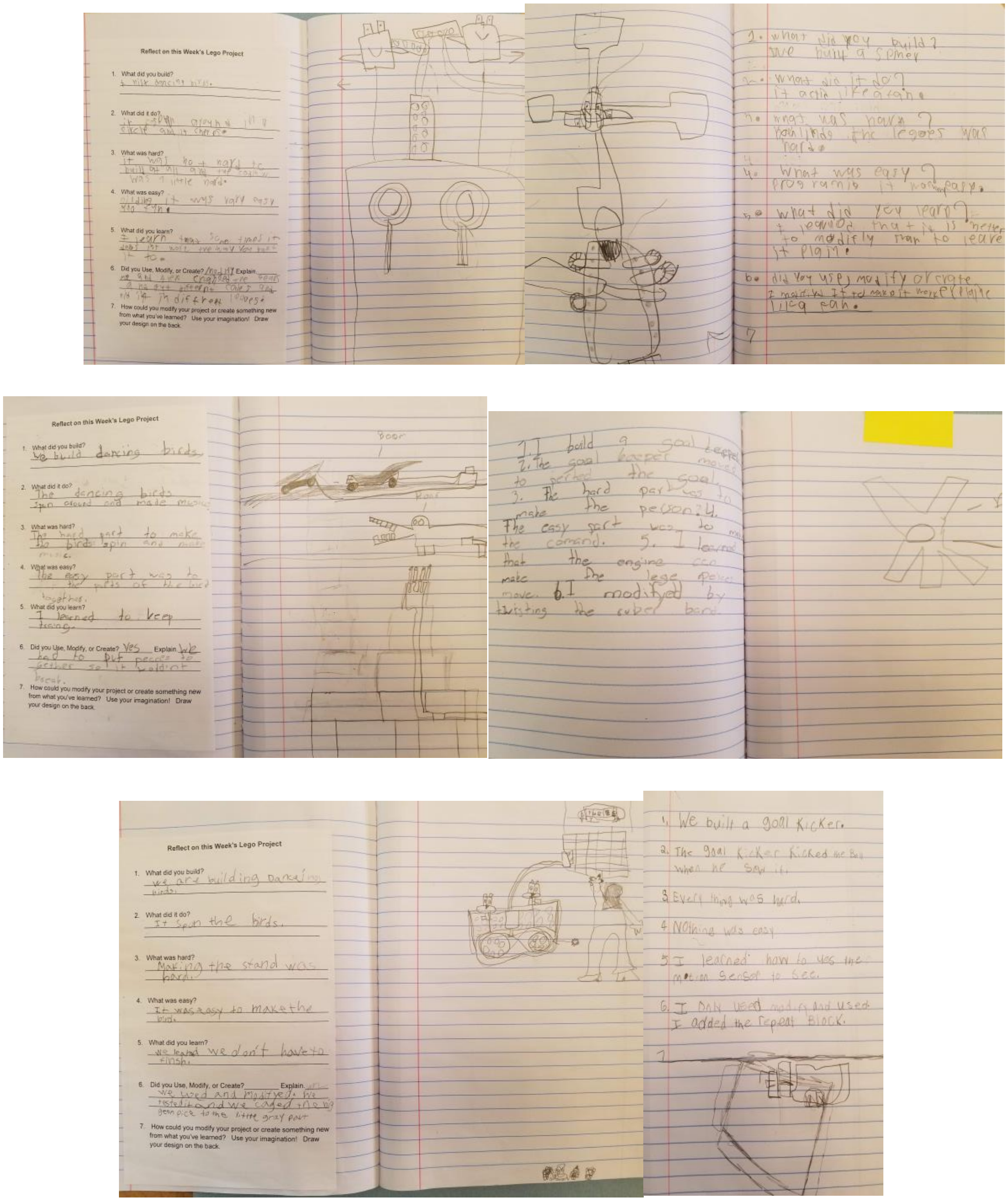


Figure F3. Photographs of completed WeDo Lego Robotics reflections from STEM notebooks.

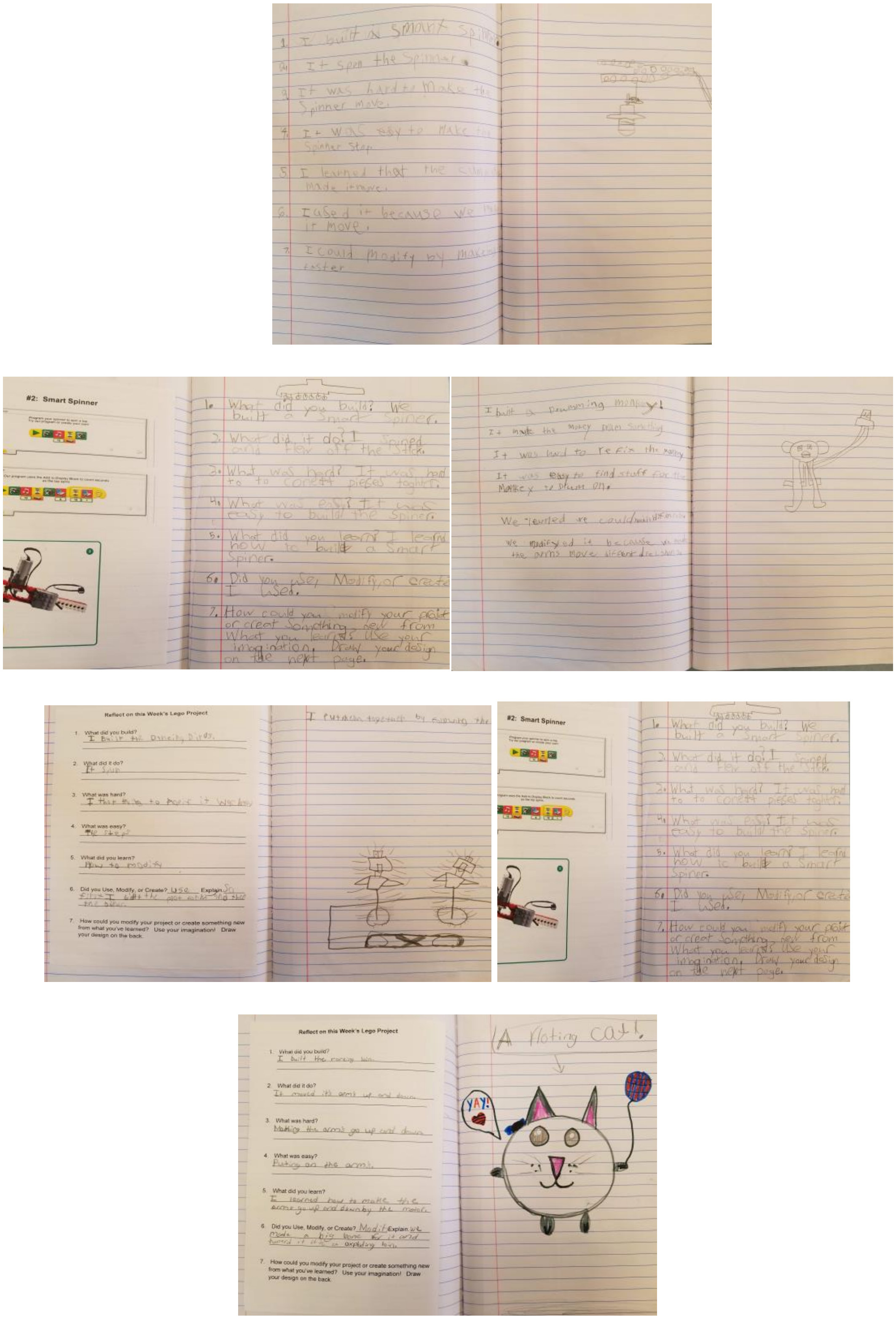


Figure F4. **Photographs of completed WeDo Lego Robotics reflections from STEM notebooks.**

APPENDIX G

Stem Learning Center Buddy Reading Activity

Students participated in an independent classroom STEM learning center three days per week (Tuesday, Wednesday, and Thursday) for 20 minutes per day.

Tuesday

Tuesday's activities were buddy reading activities. Students had a wide variety of STEM subject, career, and biography books from which to select. Buddies pair-read a book, chapter, or passage of choice. Students used a graphic organizer to guide their discussion of what they read (see Figure G1).

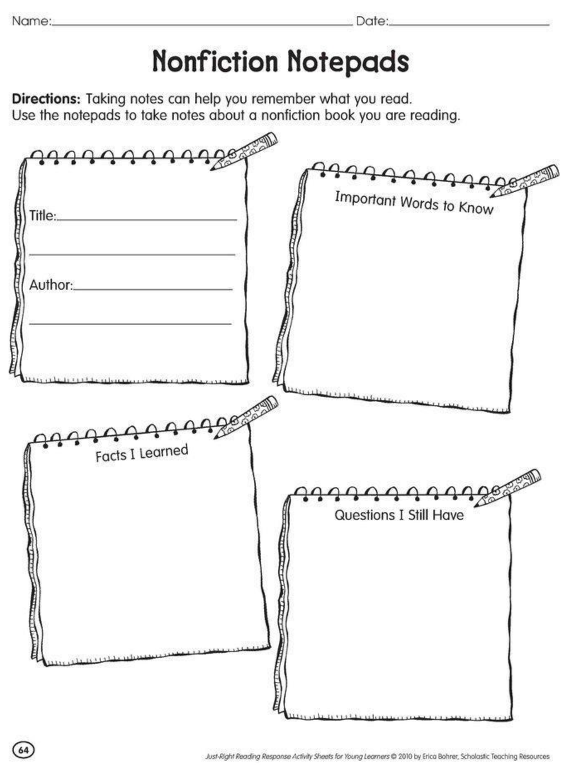


Figure G1. Graphic organizer used by students to guide discussion of reading selections.

Titles of Books Included in Classroom Learning Centers

The magic school bus gets programmed : a book about computers
[Book] Call #: 004 Mag White, Nancy.
Published 1999
Accelerated Reader® Level: 4.3 / 0.5 pts.

Girls who code : learn to code and change the world
[Book] Call #: 005.1 SAU Saujani, Reshma.
Published 2017
Accelerated Reader® Level: 6.7 / 4.0 pts.

Secret coders
[Book] Call #: 741.5 YAN Yang, Gene Luen.
Published 2015
Accelerated Reader® Level: 2.9 / 1.0 pts.

Secret coders. 2, Paths & portals
[Book] Call #: 741.5 YAN Yang, Gene Luen.
Published 2016
Accelerated Reader® Level: 3.2 / 1.0 pts.

Secret coders. 3, Secrets & sequences
[Book] Call #: 741.5 YAN Yang, Gene Luen.
Published 2017
Accelerated Reader® Level: 3.3 / 1.0 pts.

Mathematician and computer scientist Grace Hopper
[Book] Call #: 921 HOP Pelleschi, Andrea, 1962-
Series: STEM trailblazer bios
Published 2017
Accelerated Reader® Level: 5.8 / 0.5 pts.

Programming pioneer Ada Lovelace
[Book] Call #: 921 LOV Bodden, Valerie.
Series: STEM trailblazer bios
Published 2017
Accelerated Reader® Level: 5.9 / 0.5 pts.

Hello Ruby : adventures in coding
[Book] Call #: E LIU Liukas, Linda.
Published 2015
Accelerated Reader® Level: 4.4 / 0.5 pts.

The homework machine
[Book] Call #: FIC GUT Gutman, Dan.
Published 2006
Accelerated Reader® Level: 4.8 / 4.0 pts.

Girls who code : learn to code and change the world
[Book] Call #: 005.1 SAU Saujani, Reshma.
Published 2017
Accelerated Reader® Level: 6.7 / 4.0 pts.

The mighty Mars rovers : the incredible adventures of Spirit and Opportunity
[Book] Call #: 523.43 RUS Rusch, Elizabeth.
Series: Scientists in the field
Published 2012
Accelerated Reader® Level: 6.4 / 3.0 pts.

Military robots
[Book] Call #: 623 ALP Alpert, Barbara.
Series: Pebble plus : military machines
Published 2012
Accelerated Reader® Level: 2.5 / 0.5 pts.
Fountas and Pinnell: K

Mighty military robots
[Book] Call #: 623.7 STA Stark, William N.
Series: First facts. Military machines on duty
Published 2016
Accelerated Reader® Level: 4.0 / 0.5 pts.

Space robots
[Book] Call #: 629.4 Vog Vogt, Gregory.
Series: Explore space!
Published 1999
Accelerated Reader® Level: 3.4 / 0.5 pts.

Robots in space
[Book] Call #: 629.43 CLA Clay, Kathryn.
Series: Cool robots
Published 2015
Accelerated Reader® Level: 2.9 / 0.5 pts.

Robots in space
[Book] Call #: 629.43 FRE Fretland VanVoorst, Jenny, 1972-
Series: Robot world
Published 2016
Accelerated Reader® Level: 2.9 / 0.5 pts.

Robots in space
[Book] Call #: 629.43 FUR Furstinger, Nancy.
Series: Lightning bolt books. Robots everywhere!
Published 2015
Accelerated Reader® Level: 3.7 / 0.5 pts.

Zoobots : wild robots inspired by real animals
[Book] Call #: 629.8 BEC Becker, Helaine.
Published 2014
Accelerated Reader® Level: 6.4 / 1.0 pts.

My first guide to robots
[Book] Call #: 629.8 CLA Clay, Kathryn.
Series: First facts. My first guides
Published 2015
Accelerated Reader® Level: 4.3 / 0.5 pts.

Robots on the job
[Book] Call #: 629.8 CLA Clay, Kathryn.
Series: Cool robots
Published 2015
Accelerated Reader® Level: 2.6 / 0.5 pts.

Tiny robots
[Book] Call #: 629.8 CLA Clay, Kathryn.
Series: Pebble plus
Published 2015
Accelerated Reader® Level: 2.3 / 0.5 pts.

Guinness world records. Remarkable robots
[Book] Call #: 629.8 FIN Finnegan, Delphine.
Series: I can read! 2, Reading with help
Published 2017

It could still be a robot
[Book] Call #: 629.8 FOW Fowler, Allan.
Series: Rookie read-about science
Published 1997
Accelerated Reader® Level: 4.2 / 0.5 pts.

Robots at home
[Book] Call #: 629.8 FRE Fretland VanVoorst, Jenny, 1972-
Series: Robot world
Published 2016
Accelerated Reader® Level: 2.9 / 0.5 pts.

Robots in the factory
[Book] Call #: 629.8 FRE Fretland VanVoorst, Jenny, 1972-
Series: Robot world
Published 2016
Accelerated Reader® Level: 2.9 / 0.5 pts.

Robots in the field
[Book] Call #: 629.8 FRE Fretland VanVoorst, Jenny, 1972-
Series: Robot world
Published 2016
Accelerated Reader® Level: 2.9 / 0.5 pts.

Helper robots
[Book] Call #: 629.8 FUR Furstinger, Nancy.
Series: Lightning bolt books. Robots everywhere!
Published 2015
Accelerated Reader® Level: 3.4 / 0.5 pts.

Robots
[Book] Call #: 629.8 HAY Hayes, Susan L., 1966-
Series: Really?
Published 2015

I can make remarkable robots
[Book] Call #: 629.8 HOL Holzweiss, Kristina.
Series: Rookie star. Makerspace projects
Published 2018

Cool robots
[Book] Call #: 629.8 KEN Kenney, Sean.
Published 2010

Robot scientist
[Book] Call #: 629.8 MAN Manatt, Kathleen G.
Series: 21st century skills library. Cool science careers
Published 2008

Robotify it! Robots you can make yourself
[Book] Call #: 629.8 OLS Olson, Elsie.
Series: Cool makerspace
Published 2018

Legends of Zita the spacegirl
[Book] Call #: 741.5 HAT Hatke, Ben.
Published 2012
Accelerated Reader® Level: 2.5 / 1.0 pts.

Lunch lady and the cyborg substitute
[Book] Call #: 741.5 KRO Krosoczka, Jarrett.
Published 2009
Accelerated Reader® Level: 2.2 / 0.5 pts.

Revealed!
[Book] Call #: 741.5 LEM Lemke, Donald B.
Series: Graphic sparks. Zinc Alloy
Published 2009
Accelerated Reader® Level: 2.0 / 0.5 pts.

Zinc Alloy : coldfinger
[Book] Call #: 741.5 LEM Lemke, Donald B.
Published 2010
Accelerated Reader® Level: 2.1 / 0.5 pts.

Zinc Alloy : super zero
[Book] Call #: 741.5 LEM Lemke, Donald B.
Series: Graphic sparks
Published 2009
Accelerated Reader® Level: 2.4 / 0.5 pts.

Zinc Alloy vs Frankenstein
[Book] Call #: 741.5 LEM Lemke, Donald B.
Series: Graphic sparks
Published 2009
Accelerated Reader® Level: 2.1 / 0.5 pts.

Robot rampage : a Buzz Beaker Brainstorm
[Book] Call #: 741.5 Nic Nickel, Scott.
Series: Graphic sparks. Buzz Beaker Brainstorm
Published 2007
Accelerated Reader® Level: 2.2 / 0.5 pts.

T. rex vs Robo-Dog 3000
[Book] Call #: 741.5 NIC Nickel, Scott.
Series: Graphic sparks : time blasters
Published 2009
Accelerated Reader® Level: 2.3 / 0.5 pts.

Hilo. Book 4, Waking the monsters
[Book] Call #: 741.5 WIN Winick, Judd,
Series: Hilo ; book 4
Published 2018
Accelerated Reader® Level: 2.4 / 1.0 pts.

Secret coders. 2, Paths & portals
[Book] Call #: 741.5 YAN Yang, Gene Luen.
Published 2016
Accelerated Reader® Level: 3.2 / 1.0 pts.

Can you see what I see? : out of this world
[Book] Call #: 793.73 WIC Wick, Walter, 1953-
Published 2013

Google Glass and robotics innovator Sebastian Thrun
[Book] Call #: 921 THR Ventura, Marne.
Series: STEM trailblazer bios
Published 2014
Accelerated Reader® Level: 4.9 / 0.5 pts.

Fly Guy vs. the flyswatter!
[Book] Call #: E ARN Arnold, Tedd.
Published 2011
Accelerated Reader® Level: 2.1 / 0.5 pts.

My robot
[Book] Call #: E BUN Bunting, Eve, 1928-
Series: Green Light readers. Level 2
Published 2006
Accelerated Reader® Level: 1.6 / 0.5 pts.

Space cat
[Book] Call #: E CUS Cushman, Doug.
Series: I can read book
Published 2004
Accelerated Reader® Level: 2.1 / 0.5 pts.

Robo-Pete
[Book] Call #: E DEA Dean, James, 1957-
Series: Pete the cat
Published 2015
Accelerated Reader® Level: 2.4 / 0.5 pts.

Smash trash!
[Book] Call #: E DRI Driscoll, Laura.
Series: Step into reading. Step 1
Published 2008
Accelerated Reader® Level: 1.3 / 0.5 pts.

Wall-E
[Book] Call #: E HAM Hammond, Katie.
Series: Step into reading. Step 1
Published 2009
Accelerated Reader® Level: 0.9 / 0.5 pts.

Love at first beep
[Book] Call #: E JOR Jordan, Apple.
Series: Step into reading. Step 2
Published 2008
Accelerated Reader® Level: 1.6 / 0.5 pts.

Star Wars, the Clone wars : battle at Teth
[Book] Call #: E MAY Mayer, Kirsten.
Published 2008
Accelerated Reader® Level: 3.5 / 0.5 pts.

Block party surprise
[Book] Call #: E NOL Nolen, Jerdine.
Series: Bradford Street buddies
Published 2015
Accelerated Reader® Level: 2.7 / 0.5 pts.

Ricky Ricotta's mighty robot vs. the uranium unicorns from Uranus
[Book] Call #: E PIL Pilkey, Dav, 1966-
Published 2015
Accelerated Reader® Level: 4.1 / 0.5 pts.

Frank Einstein and the antimatter motor
[Book] Call #: FIC SCI Scieszka, Jon.
Series: Frank Einstein ; 1
Published 2014
Accelerated Reader® Level: 4.7 / 3.0 pts.

Frank Einstein and the BrainTurbo
[Book] Call #: FIC SCI Scieszka, Jon.
Series: Frank Einstein ; 3
Published 2015
Accelerated Reader® Level: 4.3 / 2.0 pts.

Frank Einstein and the Electro-Finger
[Book] Call #: FIC SCI Scieszka, Jon.
Series: Frank Einstein ; 2
Published 2015
Accelerated Reader® Level: 4.4 / 2.0 pts.

My robot buddy
[Book] Call #: FIC Slo Slote, Alfred.
Published 1986
Accelerated Reader® Level: 3.6 / 1.0 pts.

Ben's robot
[Book] Call #: FIC STE Stevenson, Robin, 1968-
Series: Orca echoes
Published 2010
Accelerated Reader® Level: 3.0 / 1.0 pts.

Beware! Space junk!
[Book] Call #: FIC STI Stilton, Geronimo.
Series: Spacemice ; 7
Published 2016
Accelerated Reader® Level: 4.6 / 1.0 pts.

Robots
[Book] Call #: 629.8 STE Stewart, Melissa.
Series: National Geographic readers. Level 3
Published 2014
Accelerated Reader® Level: 5.0 / 0.5 pts.

Robots
[Book] Call #: 629.8 TUC Tuchman, Gail.
Series: Scholastic reader. Level 2
Published 2016
Accelerated Reader® Level: 4.2 / 0.5 pts.

Robots at home
[Book] Call #: 629.8 ZUC Zuchora-Walske, Christine.
Series: Lightning bolt books. Robots everywhere!
Published 2015
Accelerated Reader® Level: 3.5 / 0.5 pts.

Ricky Ricotta's mighty robot
[Book] Call #: FIC PIL Pilkey, Dav, 1966-
Published 2014
Accelerated Reader® Level: 2.9 / 0.5 pts.

Ricky Ricotta's mighty robot : an adventure novel
[Book] Call #: FIC PIL Pilkey, Dav, 1966-
Published 2000
Accelerated Reader® Level: 2.9 / 0.5 pts.

Ricky Ricotta's mighty robot vs. the Jurassic Jackrabbits from Jupiter : the fifth robot adventure novel
[Book] Call #: FIC PIL Pilkey, Dav, 1966-
Published 2002
Accelerated Reader® Level: 3.6 / 0.5 pts.

Ricky Ricotta's Mighty Robot vs. the Mecha-Monkeys from Mars : the fourth robot adventure novel
[Book] Call #: FIC PIL Pilkey, Dav, 1966-
Published 2002
Accelerated Reader® Level: 3.6 / 0.5 pts.
Fountas and Pinnell: L

Ricky Ricotta's mighty robot vs. the mutant mosquitoes from Mercury : the second robot adventure novel
[Book] Call #: FIC PIL Pilkey, Dav, 1966-
Published 2000
Accelerated Reader® Level: 3.5 / 0.5 pts.

Ricky Ricotta's mighty robot vs. the naughty nightcrawlers from Neptune
[Book] Call #: FIC PIL Pilkey, Dav, 1966-
Published 2016
Accelerated Reader® Level: 3.9 / 0.5 pts.

Ricky Ricotta's mighty robot vs. the stupid stinkbugs from Saturn
[Book] Call #: FIC PIL Pilkey, Dav, 1966-
Published 2015
Accelerated Reader® Level: 4.1 / 0.5 pts.

Ricky Ricotta's Mighty Robot vs. the Stupid Stinkbugs from Saturn : the sixth robot adventure novel
[Book] Call #: FIC PIL Pilkey, Dav, 1966-
Published 2003
Accelerated Reader® Level: 4.1 / 0.5 pts.

Ricky Ricotta's Mighty Robot vs. the Uranium unicorns from Uranus : the seventh robot adventure novel
[Book] Call #: FIC PIL Pilkey, Dav, 1966-
Published 2005
Accelerated Reader® Level: 4.1 / 0.5 pts.
Fountas and Pinnell: L

Ricky Ricotta's mighty robot vs. the voodoo vultures from Venus
[Book] Call #: FIC PIL Pilkey, Dav, 1966-
Published 2014
Accelerated Reader® Level: 3.8 / 0.5 pts.

A day at work with a software developer
[Book] Call #: 005.3023 MCK McKinney, Devon.
Series: Super STEM careers
Published 2016
Accelerated Reader® Level: 5.5 / 0.5 pts.

Discovering STEM at the museum
[Book] Call #: 069 HAY Hayes, Amy.
Series: STEM in the real world
Published 2016
Accelerated Reader® Level: 5.0 / 0.5 pts.

Discovering STEM at the airport
[Book] Call #: 387.7 ROB Roby, Cynthia.
Series: STEM in the real world
Published 2016
Accelerated Reader® Level: 4.8 / 0.5 pts.

A day at work with an astronomer
[Book] Call #: 520 LEE Lee, David, 1990-
Series: Super STEM careers
Published 2016
Accelerated Reader® Level: 5.7 / 0.5 pts.

A day at work with a chemist
[Book] Call #: 540 GAD Gaddi, Rosalie.
Series: Super STEM careers
Published 2016
Accelerated Reader® Level: 5.3 / 0.5 pts.

A day at work with a geologist
[Book] Call #: 550.23 LET Letts, Amelia.
Series: Super STEM careers
Published 2016
Accelerated Reader® Level: 5.6 / 0.5 pts.

A dandelion's life
[Book] Call #: 583 HIM Himmelman, John.
Series: Nature upclose
Published 1998
Accelerated Reader® Level: 2.3 / 0.5 pts.

Discovering STEM at the zoo
[Book] Call #: 590.73 SHE Shea, Therese.
Series: STEM in the real world
Published 2016
Accelerated Reader® Level: 4.6 / 0.5 pts.

A day at work with an electrical engineer
[Book] Call #: 621.3 LUZ Luz, Oscar.
Series: Super STEM careers
Published 2016
Accelerated Reader® Level: 5.4 / 0.5 pts.

Discovering STEM at the restaurant
[Book] Call #: 647.95 MAC Machajewski, Sarah.
Series: STEM in the real world
Published 2016
Accelerated Reader® Level: 4.7 / 0.5 pts.

Discovering STEM at the amusement park
[Book] Call #: 791.06 ROB Roby, Cynthia.
Series: STEM in the real world
Published 2016
Accelerated Reader® Level: 4.2 / 0.5 pts.

Discovering STEM at the baseball game
[Book] Call #: 796.357 NAG Nagelhout, Ryan.
Series: STEM in the real world
Published 2016
Accelerated Reader® Level: 4.7 / 0.5 pts.

Vaccine innovators Pearl Kendrick and Grace Eldering
[Book] Call #: 920 WOO Wood, Susan, 1965-
Series: STEM trailblazer bios
Published 2017
Accelerated Reader® Level: 5.2 / 0.5 pts.

YouTube founders Steve Chen, Chad Hurley, and Jawed Karim
[Book] Call #: 920 WOO Wooster, Patricia.
Series: STEM trailblazer bios
Published 2014
Accelerated Reader® Level: 4.9 / 0.5 pts.

Computer scientist Jean Bartik
[Book] Call #: 921 BAR Reed, Jennifer, 1967-
Series: STEM trailblazer bios
Published 2017
Accelerated Reader® Level: 5.9 / 0.5 pts.

Environmentalist Rachel Carson
[Book] Call #: 921 CAR Hustad, Douglas.
Series: STEM trailblazer bios
Published 2017
Accelerated Reader® Level: 5.8 / 0.5 pts.

Genius physicist Albert Einstein
[Book] Call #: 921 EIN Marsico, Katie, 1980-
Series: STEM trailblazer bios
Published 2018
Accelerated Reader® Level: 5.4 / 0.5 pts.

Aerospace engineer Aprille Ericsson
[Book] Call #: 921 ERI Waxman, Laura Hamilton.
Series: STEM trailblazer bios
Published 2015
Accelerated Reader® Level: 5.5 / 0.5 pts.

Flickr cofounder and web community creator Caterina Fake
[Book] Call #: 921 FAK Wooster, Patricia.
Series: STEM trailblazer bios
Published 2014
Accelerated Reader® Level: 5.0 / 0.5 pts.

Animal scientist and activist Jane Goodall
[Book] Call #: 921 GOO Hustad, Douglas.
Series: STEM trailblazer bios
Published 2017
Accelerated Reader® Level: 5.5 / 0.5 pts.

Theoretical physicist Brian Greene
[Book] Call #: 921 GRE Doeden, Matt.
Series: STEM trailblazer bios
Published 2015
Accelerated Reader® Level: 5.8 / 0.5 pts.

Space engineer and scientist Margaret Hamilton
[Book] Call #: 921 HAM Di Piazza, Domenica.
Series: STEM trailblazer bios
Published 2018
Accelerated Reader® Level: 5.0 / 0.5 pts.

Theoretical physicist Stephen Hawking
[Book] Call #: 921 HAW Cornell, Kari.
Series: STEM trailblazer bios
Published 2016
Accelerated Reader® Level: 6.1 / 0.5 pts.

Mathematician and computer scientist Grace Hopper
[Book] Call #: 921 HOP Pelleschi, Andrea, 1962-
Series: STEM trailblazer bios
Published 2017
Accelerated Reader® Level: 5.8 / 0.5 pts.

Astronaut Mae Jemison
[Book] Call #: 921 JEM Lassieur, Allison.
Series: STEM trailblazer bios
Published 2017
Accelerated Reader® Level: 5.3 / 0.5 pts.

NASA mathematician Katherine Johnson
[Book] Call #: 921 JOH Schwartz, Heather E.
Series: STEM trailblazer bios
Published 2017
Accelerated Reader® Level: 5.5 / 0.5 pts.

Super Soaker inventor Lonnie Johnson
[Book] Call #: 921 JOH Schwartz, Heather E.,
Series: STEM trailblazer bios
Published 2018
Accelerated Reader® Level: 5.1 / 0.5 pts.

Genetics expert Joanna L. Kelley
[Book] Call #: 921 KEL Waxman, Laura Hamilton.
Series: STEM trailblazer bios
Published 2015
Accelerated Reader® Level: 5.5 / 0.5 pts.

Urban biologist Danielle Lee
[Book] Call #: 921 LEE Cornell, Kari.
Series: STEM trailblazer bios
Published 2016
Accelerated Reader® Level: 4.9 / 0.5 pts.

Programming pioneer Ada Lovelace
[Book] Call #: 921 LOV Bodden, Valerie.
Series: STEM trailblazer bios
Published 2017
Accelerated Reader® Level: 5.9 / 0.5 pts.

Nintendo video game designer Shigeru Miyamoto
[Book] Call #: 921 MIY Cornell, Kari.
Series: STEM Trailblazer Bios
Published 2016
Accelerated Reader® Level: 5.4 / 0.5 pts.

SpaceX and Tesla Motors engineer Elon Musk
[Book] Call #: 921 MUS Doeden, Matt.
Series: STEM trailblazer bios
Published 2015
Accelerated Reader® Level: 5.0 / 0.5 pts.

Astronaut Ellen Ochoa
[Book] Call #: 921 OCH Schwartz, Heather E.
Series: STEM trailblazer bios
Published 2018
Accelerated Reader® Level: 5.5 / 0.5 pts.

Minecraft creator Markus "Notch" Persson
[Book] Call #: 921 PER Cornell, Kari.
Series: STEM trailblazer bios
Published 2016
Accelerated Reader® Level: 5.4 / 0.5 pts.

Computer engineer Ruchi Sanghvi
[Book] Call #: 921 SAN Waxman, Laura Hamilton.
Series: STEM trailblazer bios
Published 2015
Accelerated Reader® Level: 5.3 / 0.5 pts.

Google Glass and robotics innovator Sebastian Thrun
[Book] Call #: 921 THR Ventura, Marne.
Series: STEM trailblazer bios
Published 2014
Accelerated Reader® Level: 4.9 / 0.5 pts.

Mars science lab engineer Diana Trujillo
[Book] Call #: 921 TRU Cornell, Kari.
Series: STEM trailblazer bios
Published 2016
Accelerated Reader® Level: 5.4 / 0.5 pts.

Astrophysicist and space advocate Neil deGrasse Tyson
[Book] Call #: 921 TYS Ventura, Marne.
Series: STEM trailblazer bios
Published 2014
Accelerated Reader® Level: 4.9 / 0.5 pts.

GoPro inventor Nick Woodman
[Book] Call #: 921 WOO Doeden, Matt.
Series: STEM trailblazer bios
Published 2015
Accelerated Reader® Level: 4.7 / 0.5 pts.

Nuclear physicist Chien-Shiung Wu
[Book] Call #: 921 WU Bodden, Valerie.
Series: STEM trailblazer bios
Published 2017
Accelerated Reader® Level: 5.9 / 0.5 pts.

Facebook founder and Internet entrepreneur Mark Zuckerberg
[Book] Call #: 921 ZUC Cornell, Kari.
Series: STEM trailblazer bios
Published 2016
Accelerated Reader® Level: 6.1 / 0.5 pts.

Mechanimals
[Book] Call #: E TOU   Tougas, Chris.
Published 2007
Accelerated Reader® Level: 2.5 / 0.5 pts.

The invisible Fran
[Book] Call #: FIC Ben   Benton, Jim.
Series: Franny K. Stein, mad scientist ; #3
Published 2004
Accelerated Reader® Level: 5.2 / 1.0 pts.

The wild robot
[Book] Call #: FIC BRO   Brown, Peter, 1979-
Published 2016
Accelerated Reader® Level: 5.1 / 5.0 pts.

Robot rumble
[Book] Call #: FIC DIX   Dixon, Franklin W.
Series: Hardy boys secret files ; #11
Published 2013
Accelerated Reader® Level: 3.9 / 1.0 pts.

Robot rampage
[Book] Call #: FIC FAR   Farshtey, Greg.
Series: LEGO Hero factory. Secret mission ; #4
Published 2013
Accelerated Reader® Level: 5.6 / 3.0 pts.

In the bathroom
[Book] Call #: FIC Gre   Greenburg, J. C. (Judith C.)
Series: Andrew lost ; 2
Published 2002
Accelerated Reader® Level: 3.7 / 1.0 pts.

APPENDIX H

Stem Learning Center Videos and Games

Wednesday

Students used Chromebooks to view videos related to STEM subjects and careers or play online games designed to promote computational thinking skills. Students were provided with a variety of web-based activities from which to choose, including:

Career Videos - https://www.ignitemyfutureinschool.org/resources/career-vignettes#utm_source=discoveryeducation.com&utm_medium=email

Discovery Education Career Videos - http://www.discoveryeducation.com/

Flurbs - https://studio.code.org/s/course1/stage/1/puzzle/2

Angry Birds - https://studio.code.org/hoc/1

Minecraft - https://code.org/minecraft

Star Wars - https://code.org/starwars

Tinker - https://www.tynker.com/hour-of-code/

Kodable - https://game.kodable.com/play?hc=1&user=sgxptvk

Engineering Games - http://engineering-games.net/

Tangrams - http://www.abcya.com/tangrams.htm

BrainPop - Blockly Maze - https://www.brainpop.com/games/blocklymaze/

Lightbot - http://lightbot.com/flash.html

APPENDIX I

Career Interest Activity Data Collection Instrument

Counts were made for sections 1 and 2. Responses were collected for section 3.

<table>
<tr><th colspan="4">Pre-Test</th><th colspan="4">Post-Test</th></tr>
<tr><td colspan="8">1. Is this job traditionally viewed as STEM or Non-STEM?</td></tr>
<tr><td colspan="2">Non-STEM</td><td colspan="2">STEM</td><td colspan="2">Non-STEM</td><td colspan="2">STEM</td></tr>
<tr><td colspan="8">2. Student response to “Will you need to know STEM to do this job?”</td></tr>
<tr><td>Yes</td><td>No</td><td>Yes</td><td>No</td><td>Yes</td><td>No</td><td>Yes</td><td>No</td></tr>
<tr><td colspan="8">3. Student responses.</td></tr>
<tr><td colspan="2">Non-STEM Careers</td><td colspan="2">STEM Careers</td><td colspan="2">Non-STEM Careers</td><td colspan="2">STEM Careers</td></tr>
</table>

Figure I1. Data collection instrument used for career interest writing/drawing activity.

APPENDIX J

Artifact-Based Interview Questions

Part 1: STEM Subjects & Careers

1. How do you feel about STEM subjects and careers?
2. Can you tell me any jobs that require STEM training?
3. Do you think it's important to learn STEM in school? Why or why not?
4. Do you think STEM jobs are important? Why or why not?
5. You've said you want to be a _____________________. Is STEM important in this job? Why or why not? Why do you like this job?
6. What can you do or learn to prepare for this job?
7. How did you learn so much about STEM? Volunteers? Teachers? Partner? Learning Center books? Videos? UMC? Showcase?

Part 2: Computational Thinking

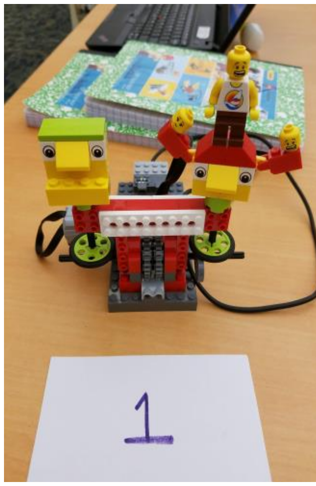
8. Explain your idea for your robot.
9. Which did you plan first? Your robot or your story?
10. How did you plan the way your robot would look?
11. Did you use, modify, or create the Lego design for your robot?
12. How did you make your robot move the way you wanted it to move?
13. Did you use, modify, or create code?
14. Can you explain what your code does?
15. Did you have any problems?
16. How did you solve them?
17. Did you test and improve your design or code?
18. What did you do when you got stuck and didn't know what to do?
19. What are you most proud of?
20. If you built another robot, what would you do differently?
21. Did you like creating your robot?
22. Have you worked with robots before? Please explain.
23. How did you learn so much about robots?

Part 3: Intervention

24. What did you think of your weekly Lego building sessions? Best? Hardest?
25. What did you think of the activities you did in your classroom STEM learning center? Best? Hardest?
26. What did you think of the showcase? Best? Hardest?
27. Is there anything else you would like to share about STEM or robotics?

APPENDIX K

Robotics Showcase Artifacts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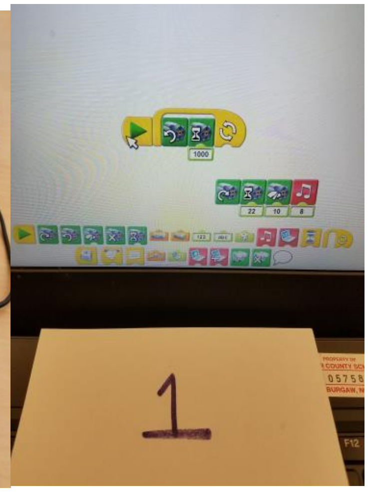
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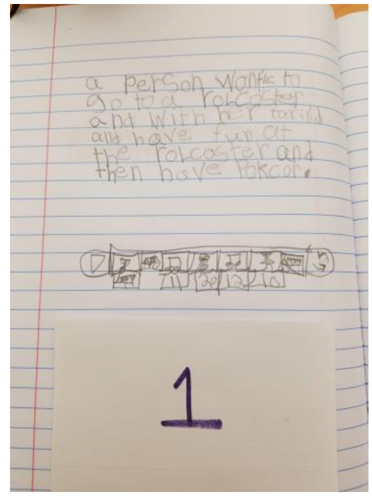
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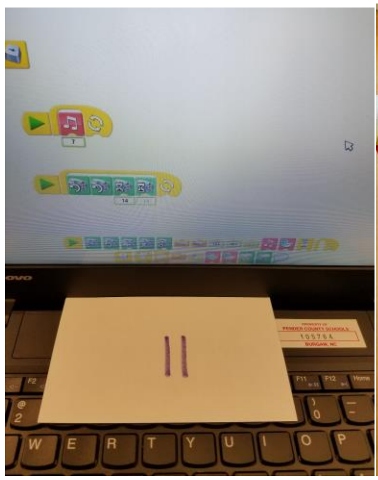
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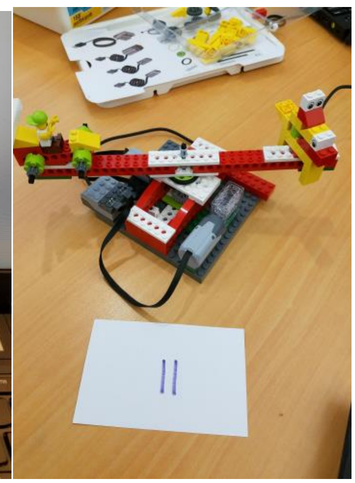
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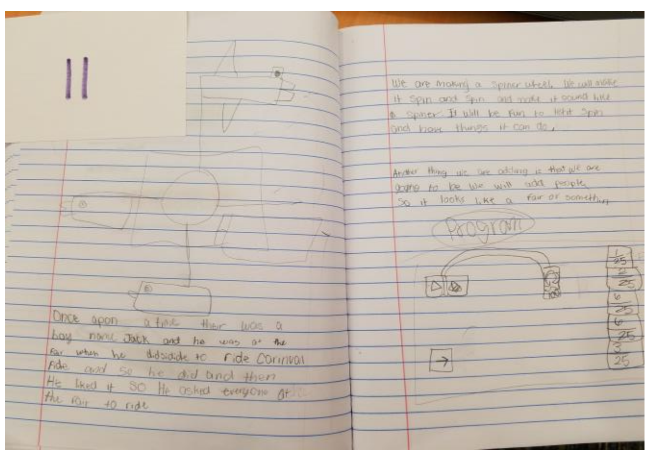
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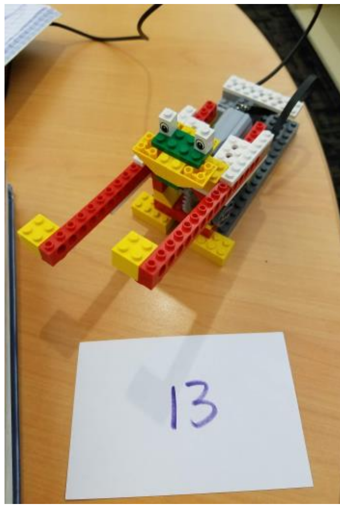
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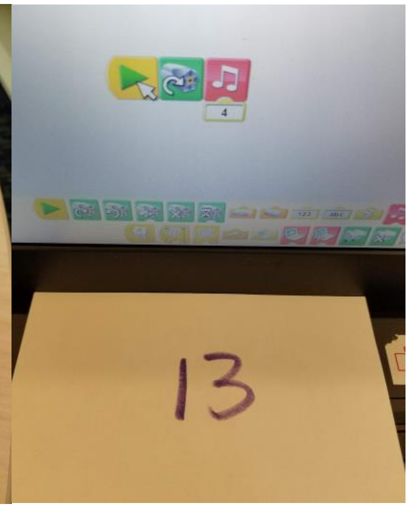
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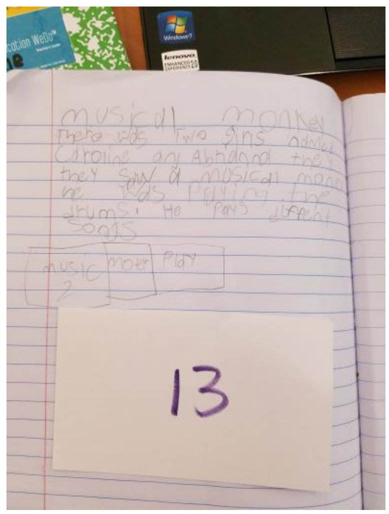
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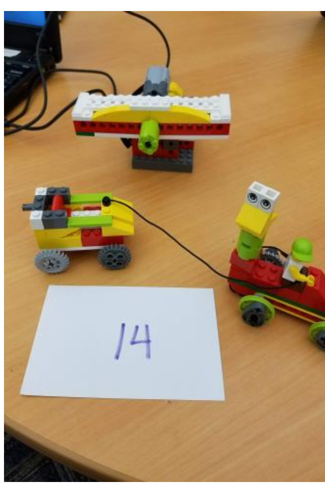
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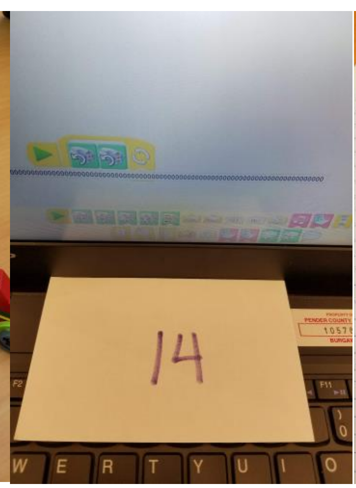
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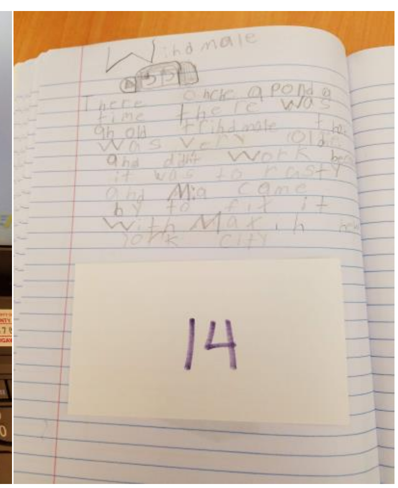
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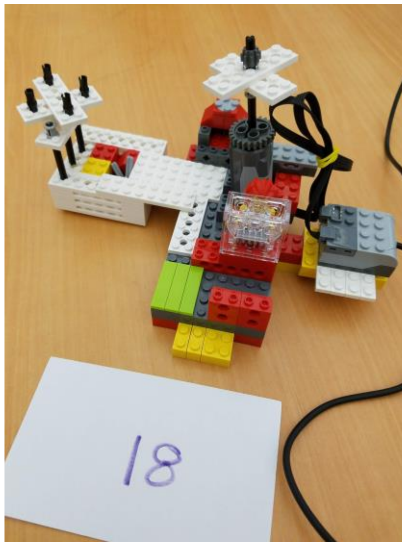
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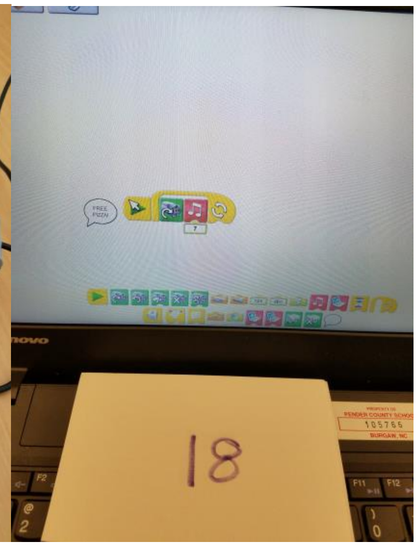
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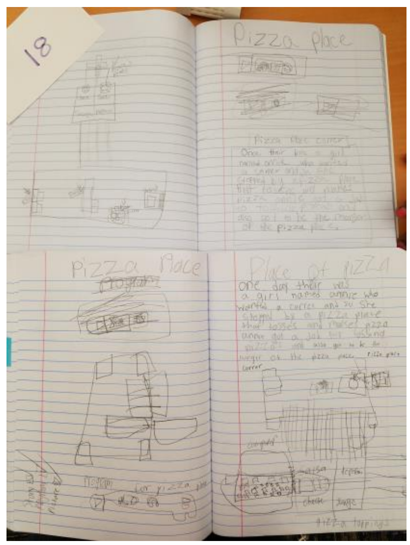
18
Pizza place
Pizza Place

APPENDIX L

Artifact-Base Interview Recording Sheet

Student Identifier____ Date of Interview ____________________ Interviewer ______________________________

Interview Questions	Indicators	Evaluation N= No Evidence S=Some Evidence E=Evident			Narrative Evidence
1. How do you feel about STEM subjects and careers?	1. Student has positive attitude toward STEM subjects and careers.	N	S	E	
2. Can you tell me any jobs that require STEM training?	2. Student can identify jobs that require STEM training.	N	S	E	
3. Do you think it's important to learn STEM in school? Why or why not?	3. Student demonstrates an understanding of the value of STEM subjects in school.	N	S	E	
4. Do you think STEM jobs are important? Why or why not?	4. Student demonstrates an understanding of the value of STEM jobs.	N	S	E	
5. You've said you want to be a __________________. Is STEM important in this job? Why or why not?	5. Student indicates interest in pursuing a STEM career or using STEM knowledge in a non-STEM career.	N	S	E	
6. What can you do or learn to prepare for this job?	6. Student demonstrates understanding of ways STEM subjects can prepare them for a job.	N	S	E	
7. How did you learn so much about STEM?	7. Thoughtful reflection is evident.	N	S	E	

8. Explain your idea for your robot.	8. Ability to think abstractly is evident in robot's description.	N	S	E	
9. Which did you plan first? Your robot or your story?	9. Ability to break down a problem into smaller parts is evident in planning.	N	S	E	
10. How did you plan the way your robot would look?	10. Ability to identify and focus on the most important information is evident in plan description.	N	S	E	
11. Did you use, modify, or create the Lego design for your robot?	11. Ability to make generalizations is evident in use of use-modify-create in design creation.	N	S	E	
12. How did you make your robot move the way you wanted it to?	12. Ability to UMC code which results in desired outcomes is evident.	N	S	E	

Figure L1. Page one of data collection instrument used during artifact-based student interviews.

13. Did you use, modify, or create your code? 14. Can you explain what your code does?	13. Ability to use, modify, and/or create code which results in desired outcomes is evident. 14. Ability to understand computer coding is evident.	N N	S S	E E	
15. Did you have any problems? 16. How did you solve them? 17. Did you test and improve your design or code? 18. What did you do when you got stuck and didn't know what to do? 19. What are you most proud of? 20. If you built another robot, what would you do differently?	15. Ability to identify problems is evident. 16. Ability to solve problems is evident. 17. Ability to identify and solve problems is evident. 18. Solution seeking behavior is evident. 19. Thoughtful reflection is evident. 20. Ability to thinking beyond current goal is evident.	N N N N N N	S S S S S S	E E E E E E	
21. Did you like creating your robot? 22. Have you worked with robots before? Please explain. 23. How did you learn so much about robots?	21. Positive Attitude is evident 22. Establish previous experience 23. Thoughtful reflection is evident	N N N	S S S	E E E	

24. What did you think of your weekly Lego building session? Best? Hardest? 25. What did you think of the activities you did in your classroom STEM center? Best? Hardest? 26. What did you think of the showcase? Best? Hardest?	24. Positive Attitude 25. Positive Attitude 26. Positive Attitude	N N N	S S S	E E E	

27. Is there anything else you'd like to share about STEM or robotics?	

Figure L2. Page two of data collection instrument used during artifact-based student interviews.