A multi-case study of student interactions with educational robots and impact on Science, Technology, Engineering, and Math (STEM) learning and attitudes

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A Multi-Case Study of Student Interactions with Educational Robots and Impact on Science, 
Technology, Engineering, and Math (STEM) Learning and Attitudes

by

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A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
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Keywords: Roamer, STEM, Educational Robots, Educational Robotic Applications (ERA), 
Assessment for Learning (AfL), Authentic Assessment

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DEDICATION

This dissertation is dedicated to my husband, Richard Terry Johnson. He has been my rock throughout this process. I couldn’t have asked to be married to a kinder, or more understanding man. Most of all he is my best friend and soul mate. I could have not completed this dissertation without his constant belief and support. He has been my knight in shining armor throughout this process.
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ABSTRACT

The demand for STEM trained workers continues to increase not only in the United States, but globally. Reports have indicated that the United States is not doing a good job encouraging students to pursue STEM oriented degrees. In particular, it has become increasingly important to emphasize STEM connections at an early level in order to encourage student career exploration as they continue their education. Educational robots represent a unique alternative to traditional methods, especially at the elementary level. Considering the use of educational robots have largely been ignored at this level, the purpose of this study was to describe the interactive process and outcomes using educational robots to facilitate elementary school students understanding of STEM concepts. A multi-case approach was used for the design as it is in line with the underlying conceptual framework for the study. Independent T-tests were utilized to determine student’s interaction with educational robots, impact of STEM understanding, as well as their impact regarding the understanding of STEM attitudes. The study was conducted as an extracurricular program involving fourth grade students at a rural elementary school in Florida. The sample size consisted of 20 randomly selected participants assigned to either the group working with robots, or the groups without the robots, for a total of 10 participants in each group. The associated activity utilized in this study was selected due to the high level of STEM integration. Data results indicated high levels of interactivity within both groups. The group working with the robot demonstrated a significant difference in the level of substantive talk. Considering the understanding of STEM concepts, both groups demonstrated a high level
regarding depth of knowledge as well as understanding. There were significant gains within groups regarding pre and post test STEM scores. When considering participants impact on STEM attitudes, the study suggested a practical significance in math attitudes for the group working with the robots. This study is significant as it yielded valuable information concerning the use of educational robots in the elementary environment. In particular, this study supports the idea that STEM concepts can be promoted utilizing authentic instructional strategies. This study suggests there is a potential impact regarding the use of educational robots in the elementary setting. This study also supported the use of authentic assessment strategies for this type of activity. Overall, both groups were actively involved and engaged, with the group working with the robot demonstrating a slightly higher depth of knowledge, substantive, conversation, as well as a slight boost in efficacy in math, science, and engineering and technology attitudes. The results of the study align with the underlying conceptual framework as well as the use of authentic assessment. This study aligns to the movement to promote STEM education at an elementary level. In addition, the type of activity associated with this study can potentially help students make sense of career oriented experiences, thus promoting career awareness within an interdisciplinary approach.
CHAPTER ONE: INTRODUCTION

In a survey of 11-13 year olds, it was reported that children “would rather clean their room, eat their vegetables, go to the dentist, or take out the garbage than do math” (Leong, 2005). How does this apparent lack of motivation to learn and master mathematics concepts impact test scores? Unfortunately, the lack of motivation appears to negatively affect student performance in mathematics, science, technology and engineering (STEM) subjects or fields; fields which are vital to the nation’s global competitiveness, innovation, economic growth, and productivity (Carnevale, et al., 2011). To this end, there is an increased demand for STEM-related education and training for workers from the technician to doctoral level. STEM education and training can yield an average earning potential of 26% more for workers. By 2019, it is estimated that 92% of traditional STEM jobs will require some form of post-secondary education including some level of specific industry-based certification (Carnevale, et al, 2011; DPE, 2012). Further, some reports have suggested that even workers in non-STEM jobs will need to possess some basic STEM competencies to remain globally competitive and survive in today’s technological society (BHEF, 2011).

While demand for STEM related talent is increasing, the education pipeline in the United States is not doing a good job encouraging students to pursue STEM oriented degrees. Only half of the students who enter college with intent to major in a STEM career graduate with a related degree. This rate is considerably lower for African-Americans, Hispanics, and Women (NSB, 2010). According to a number of reports, there are two issues associated with this problematic situation: The lack of student academic preparation and a heavy focus on interventions at the
upper end of the education pipeline. Kuenzi (2008) reported that K-12 students in the United States are not prepared to pursue careers in STEM oriented fields but that fourth grade students were found to rank slightly above the international average on the Trends in International Mathematics and Science Study (TIMSS). Similarly, scores on the Program for International Student Assessment (PISA), which measures scientific and mathematical literacy of students 15 years of age, found students in the U.S. ranking 23rd among 29 participating countries (NCES, 2010).

In the past, to increase participation in the STEM workforce, much of the emphasis of programs designed to boost related enrollment in the 1980s and 1990s, was aimed at supporting undergraduate and graduate education with the intention of recruiting and retaining students (Rockland, et al., 2010). However, over the past decade it has been recognized that emphasizing STEM in higher education may be too late to prepare and attract the new generation of STEM workers (Myers & Pavel, 2011). This realization has spearheaded recent calls for STEM initiatives to begin earlier in middle and high school. For example, mainstream academic education has resorted to magnet schools featuring STEM-related themes in public education and national initiatives such as a project seeking to prepare 10,000 high school teachers in mathematics and science (NAS, 2007). As recent efforts for earlier interventions at the middle and high school level begin to yield results, the lingering issue is that at the secondary education level even students who are interested in pursuing STEM fields lack an overall awareness of STEM applications (BHEF, 2011). The issue is that despite its growth in popularity, STEM education is not a fully realized concept; though mathematics and science are formally taught in K-12 settings, technology and engineering are outside the formal scope of the official curricula.
While technology is often treated implicitly as computer literacy; engineering is primarily found—if at all—in high school as part of technical education in pre-engineering programs such as Project Lead the Way (PLTW) on the periphery of mainstream education (ITEEA, 2012).

There is no coherent articulation for comprehensive STEM teaching and learning at the secondary level either. Thus, educators have suggested beginning much earlier than middle and high school to introduce students to STEM concepts and build related career awareness. The time, perhaps, to build the foundation for STEM education is when the student is in elementary school. While at the high school and middle school levels students move from class to class with a variety of teachers, creating a silo effect to education; in elementary school, students tend to stay with the same teacher with the exception of “specials” such as Physical Education, Music, and Art. In this context, teachers have greater opportunities to integrate mathematics, science, and technology during the school year. The challenge for the teacher is to create relevant, engaging, age-appropriate, and feasible applications to fit into an already tight curriculum (Carr, Bennett, & Strobel, 2012).

In response to the emerging call to emphasize STEM concepts in earlier grades, STEM labs have been introduced as a “special” at the elementary level in some districts. However, due to budget constraints, these labs have proven to be very difficult to maintain (Epstein & Miller, 2011). Project-based learning has been offered as an alternative as well, but so much is left to the elementary classroom teacher who has to deal with learning blocks to teach core academic areas, that student engagement in projects requiring flexible scheduling is prevented (DeJarnette, 2012). Appropriate preparation for engaging students in project-based work and competing demands for content coverage often interfere with the effective implementation of project-based learning (Epstein & Miller, 2011). Given these limitations, it is not surprising that teachers often
resort to canned curricula and rote applications void of contextual relevance and student engagement. Rockland, et al. (2010) emphasized the need to bridge the gap between standard curriculum, the scientific nature of STEM-related concepts, and the use of engaging teaching and learning approaches.

**Educational Robotics: A Promising Alternative**

At the elementary level, it has been argued that STEM education should be exploratory and offer students the opportunity to experience relevant applications they can relate to thus serving as a springboard for awareness of related fields they may later decide to explore or pursue. The question is, how can educators encourage students to pursue careers in fields that require strong math, science, and technology skills? Educational robotics offers a unique alternative to traditional “drill and grill” teaching methods while incorporating STEM-based applications. Educational robotics is an instructional strategy that relies on the use of robots for teaching purposes (Catlin, 2012). Most robotics in education can be found in the middle and high school level and their use has grown in popularity as demonstrated by the proliferation of national and international robotics competitions, such as VEX Robotics (VEX), FIRST Robotics Competition (FIRST), Boosting Engineering, Science, and Technology (BEST), and First LEGO League (FLL). Typically, many of the robotics courses offered in schools today are geared towards these student competitions (Rusk, et al., 2008).

Interest in the use of robotics with elementary school-aged students began in the early to mid-1980s using software programs building upon the technology available at that time. The interest in this new teaching medium remained untapped for a while due to limited access to related technology, cost, lack of research, and an increased focus on high-stakes testing preventing the extensive use of robots for teaching purposes (Barker & Ansorge, 2007). Times
have changed. Over the past decade, with the advent of dramatic technological innovations, students are now fully acculturated to technology use via iPods, iPads, the Internet, and virtual worlds created in the video games they play. Students are motivated to use these devices, which have the potential to add a new dimension to classroom teaching. Hands-on robotic devices have evolved on this wave of technological innovation and represent a promising method of providing students with exposure to STEM concepts (Swift & Watkins, 2004).

Educational robotics provide students with the opportunity to collaborate in STEM oriented activities to promote, for example, computational thinking (Bers, 2010). Unfortunately, robots in the elementary classroom have been thought of as an added activity; something for teachers to bring out when there is time and to liven up the routine of daily instruction (Rogers & Portsmove, 2004). In very few cases have the robots been used systematically to teach key academic concepts. In this regard, the Roamer Too robots represent a promising development that has emerged in recent years as they were specifically designed for instructional purposes. The Roamer Too was originally developed based on the concept of the Valiant Turtle, which was designed as a way of bringing the computer MicroWorlds turtle to “life” (Valiant, 1983). MicroWorlds is a program that builds upon the Logo programming language and uses a turtle as an object that can be manipulated to respond to commands (Papert, 1980). Based on this concept, the first generation of Roamers was sold to schools in 1988 to help teachers teach math, science and language arts (Valiant UK, 2012). The Roamer enabled teachers to utilize a constructivist approach to actively engage students in their own learning of core academic concepts. For example, the Roamer was used to help students solve mathematical equations by programming the Roamer to move forward or backward, and requiring student journal entries to record progress and to encourage both technical and creative writing (Catlin & Balmires, 2010).
The second generation of the Roamer is the “Roamer Too”, which was released in 2012. The Roamer Too is smaller than the original Roamer and therefore easier for younger students to handle. Its teardrop shape allows the student to designate the robots front and back. Another major difference is that it utilizes four different keypads that can be interchanged depending on the grade level and ability of the student. The Roamer Too also allows the teachers to create their own theme-based keypads. This new version of the Roamer also speaks to the students to remind them to turn it off, or to let them know that there is a problem with their program, making the Roamer Too much more realistic. This scaffold application of visual, auditory, and hands-on learning provides a promising interface of technology and engineering suitable for teaching interdisciplinary STEM concepts for all grade levels.

Given its versatility and fantasy element, the Roamer is designed to motivate students and to fit into cross-curricular purposes. As such, the Roamer is designed to be culturally diverse and to be used with students of all skill levels from at-risk to gifted. The Roamer is appealing because it is considerably less expensive than other educational robotic products available and it was developed using a constructivist approach which allows students to explore and design solutions to interdisciplinary problems (Catlin, 2012).

Research Problem

The use of educational robotics in elementary education is relatively limited and there is a lack of consistent use by teachers at this level. Perhaps this is why there has been very little research done on how students learn with robots at this level. While Barker and Ansorge (2007) reported that users of robots in the classroom have noted positive learning results, there is a large void in research, particularly in the area of STEM education. Current research has demonstrated that educational robotics promotes the scaffolding of knowledge as a method of enhancing
learning and problem-solving (Chambers, Carbonaro, & Rex, 2007). However, Barker and Ansorage (2007) pointed out that most research studies have been conducted at the high school or college level. In addition, they noted a lingering limitation of available research; where the focus is on teacher or student perceptions rather than on quantitative measures of learning or descriptive studies of how students learn. In this regard, given the growing potential of educational robotics for teaching STEM concepts, there is a need to study how students interact and learn with robots in elementary education. To this end, Liu (2010) suggested that students tend to look at robots as playthings first, as a way of learning high technology next, and finally as a source of employment.

At an elementary level, use of toys is an excepted method of teaching key concepts, and educational robots can be used that way to promote student engagement and learning of STEM concepts (LaBarbera, La Paglia, & Rizzo (2011); VanHorn, 2005). The use of educational robotics to help students learn and apply STEM concepts in the context of problem-solving by creating, testing, running, and verifying programs to accomplish assigned tasks represent important instructional applications. However, the problem is that we don’t know much about how elementary school students interact and learn with robots under self-paced conditions required by problem-based approaches. Further, there has been virtually no research conducted on the interface of student learning with robots and interdisciplinary STEM concepts. As such, research on the use of robots in elementary education focusing on applied STEM concepts is warranted to better understand related use, the impact on student learning, and understanding of STEM applications.

One of the areas to be examined in this study is improving student attitudes towards STEM education. According to Greenspan (2000), a recent survey on high school seniors’
attitudes towards math demonstrated that fewer than half stated they liked mathematics. This was the same proportion who felt they were good at it. Greenspan further states that these proportions are lower than when the survey was conducted in the 1990’s. He attributes much of the negative attitude to math anxiety, which decreases student confidence in their mathematical abilities. This lack of confidence decreases self-esteem and motivation in students.

Further, it has been well-documented that an important problem in attracting students to STEM-related pathways, is the attitudinal perceptions about related subjects. For example, engineering has been perceived as heavy on manual labor, while mathematics-based occupations are only for students who are well-prepared in that subject (Bowen, 2007). Perceptions and attitudes like these cause students to opt for unrelated degrees and career paths. An intervening factor for these attitudes may be the fact that STEM applications are not visible and engaging earlier in school, beginning in elementary school. Unfortunately, there is not much research about the attitudes toward STEM at the elementary level, especially in connection to discrete interventions requiring the application of STEM concepts.

**Purpose and Research Questions**

The purpose of this study is to describe the interactive process of using educational robotics to facilitate elementary school students’ understanding of and attitudes towards Science, Technology, Engineering, and Math (STEM) concepts. In this context, fourth-grade students at an elementary school located in a rural county in the state of Florida will represent the target population. Educational robotics will be defined as the application of robots as a pedagogical tool (Riberio, et al., 2008). Specifically, the Roamer Too will be used in the study due to its promising use based on its instructional design and relatively affordable cost. The use of robots will require participants to implement program instructions and build a design involving the
completion of sequential tasks. An interdisciplinary unit will be used to address the following STEM concepts: (a) forces and motion, and structures for science, (b) programming and use of robots for technology, (c) design, make, present, and implement solutions for engineering, and (d) vectors, distance, measurement, budget, and metric units of measurement for mathematics. The interactive process will be defined by the way participants work with the Roamer Too to accomplish STEM unit goals in comparison to participants receiving instruction without robots. Student outcomes will be operationally defined as scores on a test at the end of the unit, evaluation of student work, and attitudes toward STEM. The following research questions will be used to guide the study:

1. How do elementary school students interact with an educational robot to design and test problems?
2. Does interacting with an educational robot impact the understanding of STEM concepts?
3. Does interacting with an educational robot impact attitudes towards STEM?

The results of this study should contribute to the shared understanding of how educational robotics may be incorporated into the traditional elementary classroom or after-school programs to teach STEM concepts.

**Conceptual Framework**

The underlying framework of this study is based on cognitivist, constructivism, and constructionist principles. The basic premise of Piaget’s cognitivist theory is that we learn from our experiences and that we make choices based on these experiences. For example, within a classroom, the teachers facilitate learning based on students’ previous experiences as opposed to imparting information. In turn, constructivism is based on the belief that the learner must actively
build knowledge and skills (Huitt, 2003). In the case of constructivism, it is the learner’s processing of stimuli that produce the adaptive behavior. Thus, where constructivism focuses on mental real-world models, constructionism follows the belief that learning is most effective when students are immersed in a hands-on approach to learning real-world situations (Papert, 1980). Under these premises, there is not necessarily one right or wrong way to accomplish a task and students are encouraged to draw their own conclusions.

Educational robotics is based on the concept of a microworld designed on a constructivist approach to learning, which evolved from cognitive design. It is based on the principles of invention, play, and discovery (Rieber, 1996) and according to Papert (1980), means a tiny world inside which a student can explore alternatives, test hypotheses, and discover facts that are true about that world. The microworld concept is designed to create a simplified reality and more natural mode of learning. It builds on the belief that we create our own interpretations of the world and that learning is natural (Clements, 1989). In this context, educational robotics can be used for learning that is cognitively appropriate to different ages following constructionist and constructivist instructional principles.

Drawing from this conceptual framework, it will be posited in this study that elementary school students interacting with an educational robot will be more engaged in their own learning and knowledge production, compared to students receiving only instruction. Students will create their own “world” as they use this framework to solve the problems. The use of Roamer Too as an educational tool will encourage students to use their experience, and build on prior knowledge to support and increase their understanding of STEM related academic concepts.
Significance of the Study

Most schools in the United States are faced with the dilemma of how to improve student test scores and interest in STEM careers. The schools themselves are “graded” on how well their students perform on standardized tests. School districts need to find a way to improve test scores and encourage student pursuits in STEM oriented careers. Students benefit from higher test scores. Those with higher achievement scores, especially in STEM, will have more opportunities and career choices than those that score below expectations. However, successful STEM-oriented cost-effective delivery has proven to be elusive.

Teacher training within the constructivist environment is also a significant factor regarding success in a classroom (Tzur, 1999). When working within an educational robotics environment at the elementary level, the teachers take on the role of mentor or facilitator. Papert and Harel (1991) believe that learning “will not come from finding better ways for the teacher to instruct but from giving the learner better opportunities to construct.” This requires many teachers to go beyond their comfort level. A traditional classroom teacher tends to take a reactive approach to learning. For example, they may present a mathematical concept such as fractions as a classroom lecture and then have students open their math books and work on related problems. Except as enrichment within a computer lab or single classroom station, there is very little technology implemented.

Elementary education tends to lend itself to the concept of STEM education, whereas middle and high school programs tend to be tougher to incorporate due to the curriculum “silo” approach. Largely due to the very structured approach taken to increase test scores, elementary schools have not embraced an educational robotics STEM approach to education. Embracing educational robots would require a paradigm shift in how teachers teach involving the promotion
of a hands-on approach to science, mathematics and technological literacy in the early grades (Swift and Watkins, 2004). To this effect, the “drill and grill” approach may not be the key to unlocking student interest and motivation in STEM-oriented careers. While teachers continue to rely on textbooks and science kits to teach math and science concepts, it is the hands-on nature of the “E” or engineering within STEM that has sparked interest and student excitement in education (Swift & Watkins, 2004).

Another factor making elementary robotics difficult to evaluate is that as previously discussed, not all elementary STEM robotic environments are created equal. There has been very little research performed concerning the actual use of robotics at an elementary level. Many teachers are not clear about student outcomes within this environment (Hatfield, 1985). Perhaps this is why evaluation has been so problematic (Hoyles, Noss, & Adamson. 2002). In addition, there is no standardized STEM curriculum focusing on educational robotics a teacher can consult. A successful STEM program is an integration of the areas of Science, Technology, Engineering, and Math. It would be difficult if not impossible to follow a single context for delivery.

Given the many issues associated with the use of educational robots, this study will address an underlying question as a means for generating evidence about the value of education robots: Does an educational robotics approach to learning support learning of STEM concepts? Research must be performed to promote or discount the use of these techniques within the current educational environment (Rieber, 2005). Thus, an exploration of the potential use of robotics could play a significant role in expanding the repertoire of STEM education. It is anticipated that the results of this study will yield valuable information on the use of educational
robots at the elementary school level and contribute to our understanding of how to best use them in the classroom.

The study will be designed for an easy adaptation into a traditional classroom setting and will explore the role that educational robotics could play in the quest to improve STEM education. It is also expected that this study will contribute to the understanding of the use of educational robots by stimulating learning and hands-on problem-solving using robotic mobile technology. It is expected that students using the Roamer Too will demonstrate significant gains in the targeted areas.

**Scope and Limitations of the Study**

This is a comparative case study that will investigate the use of the Roamer Too in an extracurricular program for fourth grade students at an elementary school located in a rural county in the state of Florida. A small sample of 10 students each will be randomly selected for participation for one of two conditions: 1) use of robots in instruction and 2) use of traditional instruction with no robots involved. Since these students will be drawn from the general population of the cooperative school, the sample, although small, should be representative of a typical classroom. The study will be restricted to a particular STEM unit created by Valiant for the use with Roamer Too. The unit will take five meetings to complete which will occur over the course of five days. Each session will between one to two hours in length.

As with any research study, there are limitations that may affect the ability of the researcher to draw conclusions and generalize to other elementary school populations. Initial differences in skill levels and exposure to robotics will be a minor factor in the study as it is expected that no students will have had exposure to the Roamer Too or the activities.
Other factors that could affect the outcome may be that: 1) One or more students may have disabilities that will make building or programming difficult. An adult assistant will be provided if necessary. 2) There may be talented or gifted students with previous programming knowledge. A high percentage of either of these groups could skew the results of the study one way or the other. Average percentages of these students are typically low and, therefore, their impact on the results is expected to be minimal.

Definition of Selected Key Terms

**Constructionism** - Term coined by Seymour Papert, it builds on constructivism but stresses use of tangible hands-on applications.

**Constructivism** - Learning theory based on the idea that knowledge is constructed based on the understanding of the world.

**Educational Robotics** - The use of robots to expand knowledge in a variety of educational areas.

**LOGO** - Computer language popular in elementary education and specifically utilized to teach mathematical concepts.

**Microworlds** – This term was used by Seymour Papert and means a tiny world inside which a student can explore alternatives, test hypotheses, and discover facts that are true about the world. Commonly used when programming the Roamer.

**Robotics Education** - The field of teaching robotics applications specifically within an engineering framework.

**Turtle** - Term used to describe either an on-screen or hands-on robot. Commonly applied to Turtle Math or Turtle LOGO educational programs on the computer. A drawing implement is usually attached to the actual robot to duplicate the design created on screen by the computer-based robot.
CHAPTER TWO: LITERATURE REVIEW

The purpose of this study is to describe the interactive process and outcomes of using educational robots to facilitate elementary students understanding and attitudes toward science, technology, engineering, and mathematics (STEM) focused curricula with elementary school students. Thus, the review of literature begins with an overview of the STEM movement, followed by a description of how educational robotics can be used as an instructional tool for teaching STEM content. Next, the use of educational robotics in elementary school context is reviewed, with particular emphasis on a popular educational robot called the Roamer Too. Further, the review of literature describes research and evaluation findings on the use of educational robotics, and concludes with a description of the conceptual framework informing the study.

The STEM Education Movement

The push for boosting participation in STEM education can be traced to the publication of A Nation At Risk in 1983, which resulted in the development of the American Competitive Initiative calling for a better prepared workforce in STEM-related fields (ACI, 2006). More recently, the National Academy of Sciences (NAP, 2007) further reinforced the need for STEM focus in the education pipeline as a springboard for a globally competitive workforce. This movement has translated into specific incentives in the form of federal grants to promote STEM education in schools (Richardson, Berns, & Marco, 2010). What follows is a broad description of
the STEM movement, the challenges for teaching and learning in schools, and the issues and opportunities for teaching STEM content in elementary education.

**The STEM movement.** STEM is an acronym for science, technology, engineering, and math. As noted above, earlier concerns about the nation’s productivity and workforce competitiveness discussed in the A Nation at Risk publication (NCEE, 1983), pointed to the roots of the problem associated with stagnant academic performance in mathematics and science (NCEE, 1983). This resulted in calls for education reform in the mid 1990s leading to the standards movement and increased assessment as a means to boost performance in core academic subjects (Kuenzi, 2008). Concurrently, due to dramatic changes in technology innovations and the growth of the global economy, new skills demands emerged in the workplace requiring enhanced preparation drawing from technology and engineering. The consensus that emerged at that time was that STEM skills were necessary in virtually every occupation as the workplace had transitioned from routine manual tasks to non-routine, technology and information-driven interactive skilled tasks (OECD, 2007). STEM competencies have been deemed as required for STEM-focused occupations as well as for an increasing number of careers traditionally categorized as “non-STEM” (Carnevale, Smith, & Melton, 2011). Some reports suggested that without STEM literacy, students would not be equipped to succeed in the jobs of the future (Kesidou & Koppal, 2004). Thus, the STEM movement as we know it began to take shape as perceived shortages of high-skilled workers in related areas continued to be reported (SETDA, 2008).

Over the past decade, the STEM movement has gathered further momentum with additional reports essentially reproducing the same storyline of the 1990s pointing to low levels of achievement in math and science test scores and the need to prepare for and increase
participation in STEM-related workforce fields (Kuenzi, 2008). For example, in 2008, it was reported that K-12 students were not prepared to pursue careers in STEM-oriented fields noting trends in academic performance (NSB, 2008). It was reported that fourth grade students in the United States were found to rank slightly above the international average on the Trends in International Mathematics and Science Study (TIMSS), with the United Kingdom, Singapore, Russian Federation, Netherlands, Lithuania, Latvia, Japan, Hungary, Hong Kong SAR, Chinese Taipei, Belgium-Flemish scoring higher, particularly in mathematics. Reports like this fueled the STEM movement and prompted federal and state governments to get involved in promoting ways to emphasize initiatives for an enhanced focus on STEM preparation in schools (Kurnzi, 2008). Today, virtually every state and school district has some form of STEM initiative designed to boost related preparation in K-12.

**Teaching and learning challenges.** One of the problems with the STEM movement has been the loose designation of what STEM signifies because it is often treated as a discrete set of disciplines. The issue is that the STEM designation represents a very diverse set of broad fields and each includes many overlapping disciplines and occupations (NGA, 2012). Despite this loose definition, federal and state STEM initiatives often refer to STEM as a set of well-defined, identifiable subjects that can be addressed in schools. The problem is that aside from science and mathematics, technology and engineering are not core subjects taught in the school curricula. This, in turn, presents a series of teaching and learning challenges for K-12 teachers. Part of the problem is that there are no adopted standards for developing these skills.. While the United States is moving towards Core Standards to cover science and mathematics, technology and engineering education still is not well-defined and is not integrated into school curricula (Car, Bennett, and Strobel, 2012). Car, et. al., study found that while examining engineering studies in
all 50 states, only 41 states had engineering skills standards and of these only one had engineering integrated into their math standard.

To be sure, thanks to standards and benchmarks, science and math curricula are established and understood in schools, while technology and engineering preparation have proven to be more difficult to conceptualize and implement. For example, The International Technology and Engineering Educators Association (ITEEA) has published standards for technological literacy since the 1990’s (Rose, 2007). Yet, even though these standards are geared towards engineering technology education programs, many educators involved in STEM education still confuse technological literacy with computer literacy (Rose, 2007; NGA, 2012). ITEEA even changed its name from the International Technology Educators Association (ITEA) to the International Technology and Engineering Educators Association (ITEEA) to include engineering as a way to facilitate an understanding of related interconnections within STEM education (ITEEA, 2012). Rose (2007) noted that the three key academic areas of science, math, and technology have their own version of STEM literacy which usually leans toward their particular academic concentration, with science and math taking on predominant roles and with technology education taking on more of a supporting role. As such, the fundamental problem is that without formal curricular treatment in the schools it is difficult for teachers to address technology and engineering in coherent and sustained ways across the curriculum.

Teaching STEM in elementary education. While the primary focus of the STEM movement in the United States has been on secondary and post-secondary education, it is becoming increasingly evident that it is important to emphasize STEM connections in elementary schools (Epstein and Miller, 2011; NRC, 2012). For example, in 2010, a federal report spearheaded a national initiative for K-12 recommending the creation of 1,000 STEM-
focused schools by 2020, with 800 in elementary and middle schools (President’s Council of Advisors on Science and Technology, 2010). The importance of earlier interventions in middle and elementary schools has been supported by reports suggesting that a strong STEM background at an early age will encourage continued STEM participation as the student proceeds through middle, high school, and on to post-secondary education (DeJarnette, 2012). This push has led many elementary schools to call themselves STEM schools without documentation of the nature and extent of student engagement in related activities (Epstein & Miller, 2011; NRC, 2012).

The problem with teaching STEM in elementary schools involves a combination of curriculum, instruction, and training. At the curricular level, aside from the issue noted above about the lack of formal emphasis on engineering and technology, initiatives at the elementary level have mainly focused on engineering as a means of reinforcing science, technology and math concepts (Rogers & Portsmore, 2004). Many of these initiatives are packaged programs that are considered “stand alone” and not integrated within the curriculum. Examples include Project Lead the Way (PLTW) (PLTW, 2013), Engineering is Elementary (EiE) (Brenner, 2009), and Engineering by Design (EbD) (ITEEA, 2013). The problem is that these programs are typically offered for a small segment of the student population, either for the gifted and talented, or for students who are predisposed to related vocations (Meyrick, 2011). Given the rigid structure of the curriculum in elementary schools which is typically compartmentalized in the core academic subjects of mathematics, science, language arts, and social studies, there is little room for enhanced emphasis on technology and engineering which targets all students (Epstein & Miller, 2011).
From an instructional perspective, another related issue is that at the K-12 level teachers do not have a strong understanding of how to integrate and modify their curriculum (Rockland et al, 2010). Specifically, integrating the “E” or engineering component has proven problematic. Many elementary teachers feel that engineering is too confusing to be taught at those grade levels (Swift & Watkins, 2004). This has made the adoption of any type of STEM curriculum with an engineering focus difficult. Successful STEM integration at any educational level requires more time than currently allotted both for teacher preparation and for conducting related instruction (NRC, 2012). For instance, integrated STEM activities require hands-on activities and usually require more time for students to discover and learn key concepts (Brenner, 2009; Epstein & Miller, 2011; Kisidou & Koppal, 2006). Thus, when done well, engineering taught in the elementary environment is something students tend to enjoy due to the hands-on nature of the activities (Rogers & Portsmore, 2004).

Although the organization of the elementary school curricula—whereby students spend more time with a single teacher—lends itself to integrated instruction, as the same teacher usually teaches math, and science education, elementary school teachers are ill-prepared to teach STEM courses where these concepts are taught utilizing an integrated approach. They lack the appropriate background to successfully teach STEM-oriented curricula in an integrated fashion (NGA, 2012; Tucker, 2012; Swift & Watkins, 2004). According to Brenner (2009), the mix of lack of training and time constraints in the classroom tend to prevent teachers from trying integrated instructional activities. In addition to pedagogical knowledge, training, and time constraints contributing to the implementation of integrated instruction, another issue is the limited content knowledge in the areas of science, math, technology, and engineering for appropriate applications in the classroom (Epstein & Miller, 2011).
Even though there is no consensus on the best way to teach STEM content in the classroom, there is broad agreement that an integrated approach to activities and projects may provide more promising results (Meyrick, 2011). There is consensus about the quest to design and implement STEM education for all students, especially those who have been largely underrepresented in STEM careers, with particular emphasis on early interventions at the middle and elementary school level (Myers & Pavel, 2011; Robelen, 2011). The problem is that there is very little research examining learning gains mediated by integrated learning approaches (Mahoney, 2010). To be sure, there is research on the integration of specific subjects into the curriculum, but there is limited literature on the interdisciplinary integration of STEM concepts at the elementary school level (Stohlmann, et al, 2012).

**Educational Robotics: Implications for STEM Teaching**

In the context of the broader issues for STEM teaching and learning, and the opportunities and limitations for related applications in elementary education, educational robotics has emerged in recent decades as a promising instructional tool (Ribeire, et. al., 2008). This concept has been extensively used in secondary education, albeit as peripheral projects, but related use has been limited in elementary education. In this section, the concept of educational robotics is documented along with the evolution of the concept and applications for STEM teaching and learning.

**Educational robotics and robotics education.** Educational robotics, or pedagogical robotics is the term used when teaching with robots (Thomaz, et. al., 2009). This is not to be confused with the term robotics education, which concentrates on learning robotics (Catlin, 2012). That is, educational robotics utilizes robots to educate and deliver curriculum, while
robotics education is learning about robots (Catlin, 2012). To make this distinction more explicit, European educators refers to these terms as *teaching robotics and teaching with robots* (TRTWR). The ideas can be represented in two ways as illustrated on Figure 2.1.

![Figure 2.1. TR and TWR: Two Representations of Teaching with Robots (Source: Catlin, 2012).](image)

On Figure 2.1, the illustration on the left shows a representation of what is typically thought of LEGO, as primarily teaching robotics (TR); while another robot called the Roamer is primarily used to teaching with robots (TWR). However, in both cases, there is a bit of an overlap. In turn, on the right side of Figure 2.1, the diagram shows that TR can be another subject within TWR. In any case, educational robots lend themselves to establishing an environment that promotes creative problem-solving and contextual learning. The use of robots
allows teachers to deviate from a scripted instructional approach and encourage a constructionist approach. Constructionism is an approach to learning which requires students to consider potential solutions to a problem by taking on the role of inventor to engage in meaningful activities, while teachers take on the role of facilitators of learning rather than lecturers (Thomaz et al., 2009).

As reported by Maxinez, et al., (2012), educational robots generally fall into one of the following categories:

- Android: Robot with human appearance (Head).
- Zoomorphic: Robot with animal appearance.
- Mobile: Platform based on wheels or with the capacity of displacement.
- Poliarticulated: Robot capable of movement in limbs to pick-up or move and object.
- Hybrid: Robot with a mixture of the previous morphologies.

Maxinez, et. al (2012) evaluated the educational robots listed above in a constructivist environment. They determined that teaching with robots can raise students’ interest where experiential learning is conducted in a social environment where students work in teams or groups and can be an important factor in the acquisition of knowledge. In another study reported by Thomaz et al. (2009), the use of educational robots as an educational tool to teach key interdisciplinary subjects to elementary school children is further supported. Thomaz and Associates reported that while they did not observe any gains in the area of History, gains were observed in Science, Geography, Portuguese (the study was conducted in Brazil), Math, Art, and English. The study also resulted in learning gains in the areas of decision-making, logical reasoning, computing skills, and robotics.
The evolution of educational robotics. The concept of early robotics in the classroom can be credited to Seymour Papert who developed the MicroWorlds software and Logo computer language (Rieber, 1992). At the core of robotics is the idea of a *microworld* based on Jean Piaget’s constructivist approach to learning, which evolved from cognitive design (Papert, 1980). The idea of a *microworld* is essentially defined as small world through which students can navigate and explore to test courses of action and facts about it. Unlike simulations, students are encouraged to view a microworld as a real world defined by its own set of facts and constraints (Rieber, 1996; Rieber, 2005). While working with Piaget in the 1960s, Papert became interested in how children think and learn using constructivist strategies (Papert, 1980). Constructivism calls for students developing their own understandings of the world around them and create their own knowledge (Martin-Stanley, & Martin-Stanley, 2007). Papert took constructivism a step further with the development of the theoretical framework of constructionism which requires students to convert their understanding into concrete designs and construction of a project mediated by technology (Papert & Harel, 1991, Bers, et. al, 2002). The design process of this approach requires the implicit application of engineering concepts as the means for constructing solutions to a problem. Under a constructionist approach students are required to address a problem or situation they can relate to. To solve the problem students need to design and plan a potential solution, and manipulate objects (e.g., robots) to test their solutions (Papert, & Harel, 1991). The manipulation and testing of solutions as well as the development of models are the basis for knowledge construction and production as students develop an understanding of their findings (Jonassen & Strobel, 2006).

Along with a group of colleagues, Papert developed the Logo programming language originally to encourage science, math, and art ideas via a computer and eventually to allow the
manipulation of robots and the testing of solutions to problems (Rieber, 2005). The Logo computer language is loosely based on a set of computer programming languages identified as LISP, which stands for locator/identifier separation protocol. Building upon work in artificial intelligences, the Logo language was created in 1967 to control a turtle robot on a computer and make it to move forward, back, right, and left. To illustrate, the following example of the very basic Logo commands below draws a square of 100 units long:

```
FORWARD 100
LEFT 90
FORWARD 100
LEFT 90
FORWARD 100
LEFT 90
FORWARD 100
LEFT 90
```

Today, there are over 160 dialects of Logo that have been developed in the past 40 years. For the most part they are incompatible with each other; each dialect serves a unique purpose and presents a problem for universal use (Gates, 2007). Nevertheless, there are many versions of Logo that are used in classrooms throughout the world on computers running either the Macintosh or Windows operating system. Some of the more popular versions include: RoamerWorld, LEGO Logo, MicroWorlds (LCSI), LogoWriter, Turtle Tracks, Elica, MIT StarLogo, and NETLogo. Logo users can create their own unique microworlds in the areas of mathematics to work on projects involving fractals, measurement, and geometry; as well as Robotics (Rieber, 2005)
Another important component of an educational robot reflects how students seem to relate better to a robot depicting a specific object. In the 1950s, Grey Walter tested this concept by building a small robot he called a “turtle” because it resembled the shell of a turtle (Papert, 1980). Building upon these ideas and robotics developments, Papert (1980) utilized this concept of a robot turtle and created his own Logo-based turtle. The physical recognition of a turtle enabled students to understand mathematical concepts that were usually considered too difficult as they followed the movements of an animal they could relate to (Rieber, 2005).

Robotics was first introduced on a fairly large scale into the classroom environment in the early 1980s when LEGO TC Logo emerged. The kits were based on the use of the Logo programming language and the concept of a “turtle” robot to elicit movement and the creation of shapes in response to commands (Resnick & Ocko, 1991). The LEGO TC Logo kit combined the easy to learn programming language of LOGO and the hands-on LEGO manipulatives. Students had to learn to program in LOGO and were required to type every word of code into the program. Instead of being limited by the computer screen, the turtle was now a hands-on object made of LEGO’s (Resnick & Ocko, 1991).

In the 1980s computers were just being introduced in educational environments and teachers as well as students had to overcome a huge learning curve just to learn to operate the Apple IIIE’s, the first computers to be introduced into classrooms on a grand scale (Rieber, 2005). This was before the development of the Graphic User Interface (GUI) so students had no other choice but to learn the programming language to create their microworld or to operate their turtle. The robots were wired and connected to the computer making them limited in travel.

In the late 1980s, the Roamer robot was introduced as a part of a three-tiered building concept consisting of the basic Roamer (Catlin, 2013), Tronix (electronics that could be added to the
Roamer), and Inventa (building materials for the Roamer). This modular approach to learning with educational robots allowed students to create their own designs using a variety of materials in addition to the ability of the robot to operate autonomously via a computer program (Valiant, 2012). By the 1990s, there were hundreds of versions of the Logo software produced by a variety of companies and programs such as Turtle Math by LCSI and LEGO Logo used as enrichment to formal instruction (Resnick, 1993; LCSI, 2013).

Since then and with the advent of dramatic innovation in computer technology, there have been many updated generations of robots used in education internationally (Rusk, et. al., 2008). At the elementary school level most versions have migrated from writing code in favor of the “click and drag” approach to programming, while some robots still follow LOGO programming, or have moved to versions of C+, or Java software language (Sklar, Parsons, & Azhar, 2006). Today, most robots allow elementary school students to program on the robot as well as download from a computer program to the robot. Since 1998 LEGO has used the “Smart Brick”, a keypad attached to the design project which serves as the brains of the robot (LEGO, 2013). In the case of the Roamer robot, the programming keypad is a part of the Roamer’s body (Valiant, 2012).

Given the increasing availability, ease of use, and decreasing cost, educational robotics are being used more prominently in middle and high schools, while in elementary education the use of robots has been thought of as an added activity. Teachers use robots when there is time, focus more on robotics education than educational robotics, and in very few cases have the robots been used to teach key academic concepts (Catlin, 2012). Due to the increase in popularity of robotics competitions, interest in competition at the elementary level is growing and taking cues from competitions at the middle and high school level. However, the increased
interest in robotics competitions does not necessarily equate to an increased use of robotics at the elementary school level for educational purposes (Catlin, 2012).

**Educational robotics applications in STEM context.** The constructivist and constructionist use of educational robotics suggests engagement in learning activities mediated by technology requiring the engineering (i.e., design and construction) of solutions to problems involving applications of mathematics and science concepts. Thus, the underlying premises of educational robotics point to promising applications for STEM teaching and learning (Catlin, 2012). To this end, Catlin and Balmires (2010) have proposed a framework of *Educational Robotic Application (ERA) Principles* to assist in the evaluation of activities taught with robots. ERA is based on the building blocks of constructivism and constructionism established by Piaget and Papert.

**Table 2.1.** Educational Robotics Applications Principles (Catlin, 2012).

<table>
<thead>
<tr>
<th>Technology</th>
<th>Intelligenc</th>
<th>Educational robots can have a range of intelligent behaviors that enables them to participate effectively in educational activities.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>Interaction</td>
<td>Students are active learners whose multimodal interactions with educational robots take place via a variety of appropriate semiotic systems.</td>
</tr>
<tr>
<td>Student</td>
<td>Embodiment</td>
<td>Students learn by intentional and meaningful interactions with educational robots situated in the same time and space.</td>
</tr>
<tr>
<td>Student</td>
<td>Engagement</td>
<td>Educational robots can foster affirmative emotional states and social relationships that promote the creation of positive learning attitudes and environments which improves the quality and depth of a student's learning experience.</td>
</tr>
<tr>
<td>Student</td>
<td>Sustainable Learning</td>
<td>Educational robots can enhance learning in the longer term through the development of metacognition, life skills and learner self-knowledge.</td>
</tr>
<tr>
<td>Student</td>
<td>Personalization</td>
<td>Educational robots personalize the learning experience to suit the individual needs of students across a range of subjects.</td>
</tr>
<tr>
<td>Teacher</td>
<td>Pedagogy</td>
<td>The science of learning underpins a wide range of methods available for using with appropriately designed educational robots to create effective learning scenarios.</td>
</tr>
<tr>
<td>Teacher</td>
<td>Curriculum and Assessment</td>
<td>Educational robots can facilitate teaching, learning, and assessment in traditional curriculum areas by supporting good teaching practice.</td>
</tr>
<tr>
<td>Teacher</td>
<td>Equity</td>
<td>Educational robots support principles of equity of age, gender, ability, race, ethnicity, culture, social class, lifestyle, and political status.</td>
</tr>
<tr>
<td>Teacher</td>
<td>Practical</td>
<td>Educational robots must meet the practical issues involved in organizing and delivering education in both formal and informal learning situations.</td>
</tr>
</tbody>
</table>
There are ten principles associated with this framework grouped into factors and conditions associated with technology, students, and teachers as noted in Table 2.1. The principles associated with the use of technology point to the role of robotics as mediators of learning rather than as the focus of learning. The role of robots is to promote active learning through meaningful interactions with students. Likewise, the principles associated with students are sustained engagement in learning through manipulation of robotics variables and integrated learning. In turn, the principles associated with teachers suggest a role of facilitators of learning, rather than dispensers of information (Catlin & Blamires, 2007).

Taken as a whole, the principles for educational robotics suggest a fluid interaction among robot, student, and teacher as illustrated in Figure 2.2. Teachers may facilitate access to robots and mediate related interactions with students, while robots need to be suitable for manipulations appropriate to the learning tasks and to the age of students. Students are expected to engage in flexible, active, and integrated learning allowing them to explore and test designs and solutions.

Educational robotics can be an effective tool for teaching a STEM-oriented curricula (Alemdar, & Rosen, 2011). Students become engaged while developing new skills in a variety of academic areas by applying Papert’s constructionist approach to learning (Catlin, 2012). This spans across all the STEM-specific disciplines as well as art and literacy (Mosley & Kline, 2006). STEM is interdisciplinary by nature and using the building blocks of various academic subjects within engineering and educational robotics, the teacher has the tools to improve confidence in a variety of academic fields (Rogers & Portsmore, 2004).
Educational Robotics in Elementary Education

Much of the literature and applications of educational robotics has been in the context of secondary education, and with very limited emphasis on STEM. However, with recent developments in educational robotics there are promising opportunities for enhanced use at the elementary school level. The Roamer Too, in particular, has been singled out as a promising instructional tool for its versatility, affordability, and suitable use in elementary education and STEM applications. Thus, in this section the use of educational robotics in elementary education is first discussed followed by a description of the Roamer Too as an instructional tool. A description of educational robotics applications using the Roamer Too in STEM context is also provided.
**Use of educational robotics in elementary education.** Until recently educational robotics at the elementary level has been largely ignored (DeJarnette, 2012). However, school districts have begun to target elementary programs in an effort to increase performance and interest in STEM once students enter middle school (NRC, 2012). The problem is that there is limited time available for teachers to work on projects requiring multiple periods and open-ended solutions given the organization of the elementary school curricula and pressure for content coverage (NRC, 2012). There is the issue of appropriate teacher training in the use of educational robotics to design and implement projects appropriate to elementary school students (Epstein & Miller, 2011). The cost of robotics kits often prevents schools from promoting robotics in the classroom or, in other cases, create unequal opportunities for access in schools (Catlin, 2012). Assuming that educational robotics kits are available for use in elementary schools, and teachers are prepared to use them, two important questions have been posited for effective use: What elementary school curricular content can be taught using robotics-based activities? What types of skills are best promoted through robotics activities in elementary school education?

According to Catlin (2012), robotics-based activities can be used to address various disciplinary content and skills, as related instructional strategies can draw from the following features:

- **Self-Expression:** Educational robots are tools that allow students to explore ideas and express their understanding in personal creative ways

- **Flexible Use:** Robots are adaptable to the needs of the teaching situation and the needs of the individual student.


- **Differentiation**: Robot activities find a natural level of difficulty. They support the constructionist principles and recognize that students build their own understandings in their own ways. They support struggling learners and challenge gifted students.

- **Learning Styles**: Robots engage in multiple modal experiences including: Kinesthetic, visual, spatial, auditory and tactile.

  For example, a typical educational robotic activity such as the Roamer Robotics “Performing Arts Project” (Valiant, 2012) is an approach to STEM via cooperation and not competition. Students replaced the use of puppets with the Roamer in this activity. Grade level appropriate math and science skills were used to create the puppets as well as the performance. Then the activity was videotaped to create a movie-short. These applications represent the range of possibilities in addressing disciplinary content and skills.

  **The Roamer Too: A promising development.** Based on Seymour Papert’s concept of the “turtle,” David Catlin designed the Valiant Turtle in 1983 (Valiant, 2012). The Valiant Turtle was developed as a way of bringing the computer microworld turtle to “life” using the Logo computer language (Valiant, 2012). With the advancement in technology Papert’s original computer screen turtle eventually became a “floor turtle” powered by a robot (Resnick & Ocko, 1991). In cooperation with Papert, Catlin developed the Valiant Turtle, their first educational robot (see Figure 2.3). It even looked like a turtle and was designed to enforce math concepts similar to the logo computer turtle. Students could hold the turtle they were programming as opposed to viewing on a computer screen; students actually programmed the turtle and watched the turtle make a right turn, left turn, or a square on the floor. They could insert a pen into the
turtle to document the figure the turtle was drawing. Also, students could program the turtle to take “turtle steps” (Resnick, 1991), simulating the use of a number line. This remains a key activity within the Valiant Curriculum (Valiant, 2012).

![Figure 2.3. The Valiant Turtle (Source: Valiant-technology.com (2012).)](image)

Valiant’s next educational robot was called the Roamer (now known and referred to as the Classic Roamer). Launched in 1989, the Classic Roamer (Figure 2.4) was a technological leap from the previous turtle. It was sold to schools in 27 countries to teach subjects such as math, science, and language arts (Valiant, 2012). In addition to computer programming it could also be programmed directly on the body of the robot with a built-in keypad. This allowed students, of all ages without access to computers the opportunity to program and create their own robot personalities. As with the Valiant Turtle the pen pack stayed on the robot so students could graphically record the path of the robot. The difference between this and other educational robots, such as the kit sold by LEGO, is that the Classic Roamer concentrated on educational robotics as opposed to robotics education, and LEGO went away from the concept of the turtle and concentrated on the building aspect of robotics. While there is overlap, the primary purpose
is not on the building of the robot as with other kits, but on using the robot as a tool to teach educational learning objectives (Valiant, 2012).

![Image of Roamer](valiant-technology.com)

**Figure 2.4.** The Roamer (Source: Valiant-technology.com (2012)).

The Classic Roamer has proven to be particularly popular within the special needs educational community because it is designed to be culturally diverse and is used with both at-risk and gifted students and all those in between (Valiant, 2012). Another key to its international popularity is that Roamer is considerably less expensive than other available educational robotics products. In addition, the Roamer was specifically developed to allow students to explore and design solutions to problems using an interdisciplinary constructionist approach.

Further, students tend to associate robots with fictional characters within industrial environments, which are typically gender-neutral (Bumby & Dautenhahn, 1999). In this case students can dress robots to depict different characters as illustrated in Figure 2.5. Robots fascinate children and the fantasy element of the Roamer is designed motivate students and to fit into a cross-curricular curriculum (Valiant UK, 2012). For example, as depicted in Figure 6, after reading about Cleopatra, the students are encouraged to create a map of the area and simulate her travels in the Nile. A Roamer dressed as Sherlock Homes can be programmed to go to specific
locations to gather clues to solve a mystery, or a numbers Roamers can form a football team and play against each other.

![Cleopatra (History) Sherlock Homes (Fiction/Literature) American Footballer (Sports)](image)

**Figure 2.5.** Examples of Curriculum-Related Roamer Robot Design (Source: Valiant, 2012).

The second generation of the Roamer is the “Roamer Too” (Figure 2.6), it was released in United States in 2012. The Roamer Too is smaller than the original Roamer and allows the student to easily use it on the floor or table. It is considerably more advanced and communicates with the student to advise of programming problems, or just to remind them to turn it off.

![Roamer Too](image)

**Figure 2.6.** Roamer Too (Source: Valiant, 2012).

The Roamer Too is designed to be student and facilitator friendly and requires a minimum amount of training (Hudson, 2012). For example, the Roamer will talk and remind the user to turn it off, or will politely tell the user that it has made a programming mistake (Valiant, 2012). In addition, the Roamer Too utilizes hands on control technology to enhance auditory, visual, and kinesthetic learning (Drage, 2012). The Roamer Too is versatile enough to be used in
early as well as primary education and in a variety of classroom settings from at-risk to gifted. The robot has a variety of keypad overlays that can be utilized and customized for the appropriate grade level and to a specific activity.

As with the previous Valiant turtle robots, the Roamer Too follows Papert’s principles of Constructionism by allowing for meaningful play (Catlin, 2012). According to Catlin (2013), the Roamer:

1. Prepares students for what you are going to tell them. (activities done before you teach them something)
2. Allow students to think about what you have told them and explore how it works. (activities just after you have taught them something)
3. Help students see the value of what you tell them by using it to solve problems. (activities testing the maturity of their knowledge, trying to reinforce it, trying to extend it and transfer it to other situations)

Simply put, the Roamer Too provides experiences to help students make sense of their experiences.

**Using the Roamer Too to teach STEM concepts in elementary education.** As suggested above, the Roamer Too can be used for instructional purposes targeting different subjects and interdisciplinary concepts. For example, the Roamer Too has the potential to provide math enrichment and synthesis of mathematics and science concepts, something that “drill and grill” techniques are lacking. Using the Roamer Too, student activities are designed to interact using mathematical concepts in a manner that mimics real-world applications appropriate to different age levels (Catlin, 2012). Further, the Roamer Too allows the student to work individually or in groups and can serve as the vehicle to integrate STEM concepts into the
standard classroom curriculum through an integrated technological approach to learning (Hudson, 2012). In general, Catlin (2013) has reported that the Roamer Too allows:

1. Engagement of students in doing things in a way that gives the teacher time to observe what is going on. The teacher can observe the student's thinking and evaluate what they have understood and misunderstood.

2. The teacher to create a situation where students are working through problems with their peers.

3. Guided participation that can be practiced.

4. Emotional engagement of students in a positive manner with STEM concepts. It is about getting students to realize how natural mathematics and science is and what natural mathematicians and scientists they are.

5. A scaffolded approach to learning that supports the child’s acquisition of STEM. Also, the fact that Roamer is the world’s first talking educational robot adds an excitement to the learning.

6. Students to bridge the gap between the abstract and the concrete. It brings STEM alive, making it authentic and connecting with the child’s experience of the world.

Based on these premises, the Roamer Too is a tool that can introduce students to STEM activities targeting disciplinary or interdisciplinary concepts. Regarding the potential use of the Roamer Too in teaching integrated STEM concepts, the following are examples of applications in the classroom taken from Classic Roamer activities that can be easily utilized with the Roamer Too:
• Journeys is an activity that covers numerous subjects including Art, Citizenship, Geography, History, Literacy, Math, Music and Science for example. In this activity, students utilize the Roamer to create context by creating their choice of a journey within a purpose, literature, fun, or history (Valiant, 2012).

• Roamer, Turtle, and Measurement (Units 1-3) where students focus on the theory and practice of measurement. In these activities, students program progressively more advanced shapes utilizing the concept of the Turtle to draw their geometry (Valiant, 2012).

Research and Evaluation of Educational Robotics

While there is a large amount of information on robotics education in the classroom, there is limited research on the use of educational robotics in teaching STEM concepts in elementary schools. On this issue, Carbonaro, Rex, and Chambers (2004) stressed that there must be a shift in education between the learning from technology towards learning with technology. Thus it is important to review related literature to assess the value and impact of using educational robotics as an instructional tool, for teaching STEM, and related applications in elementary school settings.

Evaluation of educational robotics as an instructional tool. How do we know if educational robots work as an instructional tool? That is, what is the impact on and nature of student learning? In this regard, Catlin (2012), noted that it is important to first differentiate between Assessment of Learning (AoL) and Assessment for Learning (AfL). As defined by Catlin, Assessment of Learning (AoL) is what we traditionally think of when evaluating and reporting student progress. This takes on the form of standardized testing through the use of
national standards and grading scales used for report cards. Catlin’s focus is on Assessment for Learning (AfL) where diagnostics and feedback plays and role in student success and focuses on best teaching practices (Catlin, 2012). AfL methods consist of clear learning intentions and success criteria from a students’ perspective, as well as feedback and quality interactions from both the teacher and peers.

Catlin (2012) also demonstrated how ERA Principles can be implemented with Assessment for Learning (AfL) within an educational robotics context to implement and assess STEM based activities with the Roamer. For example, during one project, students noticed that various other teams had expertise needed within their group. They worked together to share this expertise with all of the groups creating a successful completion of the project for all. Also, this freed up the teacher to step back and provide quality feedback on all of the interactions, with feedback being provided in terms of comments as opposed to grades.

Along these lines, in a study of educational robotics Riberio, et al, (2008) asked whether robotics was an appropriate tool to allow elementary students to acquire skills important to their instructional level. Ribeiro and his colleagues were also interested in finding out whether robotics activities motivate elementary school students to learn, and whether the use of robotics kits allow the construction and programming of robots at the elementary school level. The resulting study observed the use of robotics as an instructional tool with elementary school students in a robotics club and involving the completion of a project over a 5-week period. The results of the study confirmed that the use of robotics was adequate for elementary school students, appeared to impact motivation to learn, and allowed students to learn basic programming of robots. The researchers also recognized the limitations of the study and concluded that further research is needed in this area (Ribeiro et al., 2008).
**Evaluation of educational robotics in elementary education.** What do we know about the use and impact of educational robots in elementary education context? In general, there is limited research examining applications of educational robotics at the elementary school level. One study performed on early adolescents on students’ perceptions concluded that most students considered Educational Robots as a plaything. The study also noted that some students considered robotics as a way to learning high-technology (Liu, 2010).

Another study demonstrated that robots can be used to increase the metacognitive skills of student in mathematics (LaPagila, Rizzo, & LaBarbera, 2011). The study noted when students are problem-solving within the context of educational robotics, they utilize contextual learning to apply sequencing and problem-solving to create, test, run, and verify programs to accomplish the assigned task.

There is little research in the area of STEM and elementary robotics, specifically that address the use of robotics as a serious alternative or addition to the traditional classroom due to the relative newness of the concept (Barker & Ansorage, 2007). Much of the existing research is based on LEGO robotics and is focused on robotics education, which is not the focus of this study.

**Evaluation of educational robotics in STEM context.** What do we know about the use of robots and impact on teaching and learning of STEM concepts in elementary education? Mathematics is the language of science and is used to describe many of the basic scientific concepts. The mathematics that students need today differs from the math that their grandparents needed to learn (Kirkpatrick, et al, 2001). Students need to learn to think mathematically to gain an integral understanding of the topics, and rote memorization no longer fills their needs (Kirkpatrick, et al, 2001). Thus, to learn math effectively students need to gain conceptual

Microworlds and the Logo computer language are the first steps to understanding educational robotics (Catlin, 2013). They are synonymous with each other. One of the advantages of the Logo computer language is that it is child-friendly (Gillespie, 2004). Logo utilizing microworlds and robotics may be introduced in early childhood education allowing students to become comfortable with technology while learning important math concepts within a constructivist and constructionist environment. Logo, microworlds, and robots can also be used as an integrated approach to learning. For example, Vincent (2002) suggests that the writing skills of elementary students can be improved utilizing a microworlds environment as a result of his research on brain hemisphere integration. Microworlds present a realistic “real-time” learning environment for student exploration (Rieber, 1992). It allows students to test their hypothesis and to receive immediate feedback. This type of feedback is critical in a STEM classroom particularly with the use of robotics.

**Conceptual Framework**

Given the nature of educational robotics and the connections to teaching and learning, the conceptual framework underlying this study is rooted in cognitivist, constructivist, and constructionist principles. The premises of the conceptual framework are summarized in this section.
Cognitivism. Cognitivist theory is based on the internal mental thought process behind desired behaviors (Mergel, 1998). Cognitivism was developed by Jean Piaget and takes behaviorism a step further. Behaviorism in the classroom focuses on behaviors that can be measured using quantitative methods (Mergel, 1998). Patterns of practice and/or reinforcement are repeated until desired responses become automatic. Pavlov, Thorndike, and Skinner used this type of conditioning in many of their experiments. In education, for example, multiplication tables are frequently recited orally in class and repeated until responses are automatic. This type of learning theory may enforce immediate results, but may diminish as the stimulus fades (Mergel, 1998). In contrast, cognitivist theory is based on the internal mental thought process behind the behavior (Piaget, 1983). Cognitivism did not begin to take hold as an educational theory of learning until the 1960s. Behaviorism and cognitivism both present an objective view of the nature of knowledge, with both theories emphasizing that learning tasks are broken down into similar steps (Mergel, 1998). This step-by-step design has been implemented in computer-aided instruction and is seen in many vocationally oriented curricula (Nanjappa & Grant, 2003).

Piaget believed that children did not learn linearly and suggested that there are certain points where their minds “take off” to different areas (Altherton, 2011). To this end, Piaget (1983) proposed four stages of cognitive development for children from birth to 11 years and older as presented in Table 2.2. Cognitivism is interpreted as operational stages of instruction that are appropriate to the age of participants in this study. Specifically, the exploration of how students think the sequential logic of events as well as the classification of objects in series, will inform the design and implementation of a project involving the use of educational robotics in the study.
<table>
<thead>
<tr>
<th>Stage</th>
<th>Characterized by</th>
</tr>
</thead>
</table>
| **Sensori-motor**           | - Differentiates self from objects  
- Recognizes self as agent of action and begins to act intentionally: e.g. pulls a string to set mobile in motion or shakes a rattle to make a noise  
- Achieves object permanence: realizes that things continue to exist even when no longer present to the sense (pace Bishop Berkeley)                                                                                                                                                                                                                                                                                                           |
| (Birth-2 years)              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| **Pre-operational**         | - Learns to use language and to represent objects by images and words  
- Thinking is still egocentric: has difficulty taking the viewpoint of others  
- Classifies objects by a single feature: e.g. groups together all the red blocks regardless of shape or all the square blocks regardless of color                                                                                                                                                                                                                                                                                              |
| (2-7 years)                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| **Concrete operational**    | - Can think logically about objects and events  
- Achieves conservation of number (age 6), mass (age 7), and weight (age 9)  
- Classifies objects according to several features and can order them in series along a single dimension such as size.                                                                                                                                                                                                                                                                                                                   |
| (7-11 years)                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| **Formal operational**      | - Can think logically about abstract propositions and test hypotheses systematically  
- Becomes concerned with the hypothetical, the future, and ideological problems                                                                                                                                                                                                                                                                                                                                                                           |
| (11 years and up)            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |

**Constructivism.** Constructivism is based on the belief that the learner must actively build knowledge and skills (Huitt, 2003). It is the learners’ processing of stimuli that produce the adaptive behavior in this paradigm. As such, constructivism seeks to promote a learner-centered classroom and to that end, according to Jonassen, Marra, and Palmer (2004), constructivist learning environments should: (a) provide multiple representations of reality to avoid oversimplification and represent the complexity of the real world, (b) emphasize knowledge construction instead of knowledge reproduction, (c) emphasize authentic tasks in a meaningful context rather than abstract instruction out of context, (d) provide learning environments such as real-world settings or case-based learning instead of predetermined sequences of instruction, (e) encourage thoughtful reflection on experience, (f) enable context- and content-dependent knowledge construction, and (g) support collaborative construction of
knowledge through social negotiation, not competition among learners for recognition. A comparison of constructivist and traditional classrooms is presented in Table 2.3 as compiled by Brooks and Brooks (1993).

Based on the comparative analysis of constructivist and traditional classrooms, constructivist instructional activities are well-suited for teaching with technology where the teacher takes the primary role of facilitator (Nanjappa & Grant, 2003). Educational robotics enable ponder, explore, and test alternative solutions to problems and help them arrive at their own understandings as a stepping-stone to producing their own knowledge (Hoyles, Noss, & Adamson, 2002; Nanjappa & Grant, 2003).

**Table 2.3.** The Constructivist Classroom vs. The Traditional Classroom (Source: Martin-Stanley, & Martin-Stanley, 2007).

<table>
<thead>
<tr>
<th>Constructivist Classroom</th>
<th>Traditional Classroom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students collaborate of tasks.</td>
<td>Students primarily work alone.</td>
</tr>
<tr>
<td>Student input is highly valued in the teaching-learning</td>
<td>Adherence to the established curriculum is highly valued.</td>
</tr>
<tr>
<td>process.</td>
<td></td>
</tr>
<tr>
<td>Students are treated as thinkers with the ability to</td>
<td>Students are treated as empty vessels into which</td>
</tr>
<tr>
<td>construct new knowledge.</td>
<td>information is poured by the teacher.</td>
</tr>
<tr>
<td>Teachers partner with students in the classroom.</td>
<td>Teachers are the experts, disseminating information to</td>
</tr>
<tr>
<td></td>
<td>students.</td>
</tr>
<tr>
<td>Teachers seek students’ feedback in order to better</td>
<td>Teachers seek the “correct” answer to validate student</td>
</tr>
<tr>
<td>understand student learning.</td>
<td>learning.</td>
</tr>
<tr>
<td>Assessment of student learning is integral to the</td>
<td>Assessment of student learning is separate from teaching.</td>
</tr>
<tr>
<td>teaching-learning process.</td>
<td></td>
</tr>
</tbody>
</table>

**Constructionist principles.** Constructionism is an approach to learning developed by Seymour Papert representing both a learning theory and a strategy for education based on Piaget’s theory of constructivism (Papert & Harel, 1991). Papert’s notion of constructionism included everything associated with Piaget's constructivism, but went beyond it to assert that constructivist learning works especially well when people are engaged in constructing something to create their own knowledge (Papert & Harel, 1991; Han & Bhattacharya, 2001). In his works, Papert explains that the “v” in constructivism is the theory that knowledge is built not by the
teacher, but by the learner. In constructionism, he argued, the “n” is an expression of an idea when the learner is engaged with something that is constructed and shareable (Papert & Harel, 1991).

Given the fact that students engage in a design and construction process, constructionism allows for immediate and ongoing feedback, and encourages collaboration and sharing (Chambers, Carbonaro, & Rex, 2007). In learning how to program in LOGO, for example, an apprenticeship approach can be very successful (Oakley & McDougall, 1997). In this case, students more experienced in a particular programming situation help teach other students to program in LOGO so they may solve their design problem. Learning in this contextual environment allows students to immediately apply what they are learning as opposed to individual students learning programming just as an academic exercise. Therefore, transfer occurs between students, as the student becomes the teacher, and the teacher becomes the facilitator. Learning is social, active and ongoing, or contextual. Facts are not learned in isolation, but in relationship to what students know and believe leading to the creation of their knowledge (Hein, 1991).

**Integration of the conceptual framework.** The conceptual framework for this study integrates the theoretical roots of cognitivism, constructivism, and constructionism in the context of using educational robotics to teach STEM concepts in elementary education as illustrated on Figure 2.7. Based on this conceptual framework, it will be posited that elementary school students interacting with an educational robot will be more engaged in their own learning and knowledge production, experience greater motivation as a result of interacting with an educational robot, compared to students receiving instruction without robots. Students will create their own “world” as they use this framework to solve the problems. The use of Roamer
Too as an educational tool will encourage students to use their experience to build on prior knowledge in support of and increase in their understanding of STEM-related academic concepts.

**Figure 2.7.** Conceptual Framework Bridging Cognitivism, Constructionism, and Constructivism Principles.

**Summary**

The literature review revealed a shift in thinking of an integrated STEM approach. The relative loose definition of the initiative as well as undefined implementation concerning STEM-oriented literacy has proven to be problematic. Although research is limited, educational robotics shows a promising enhancement as a means of teaching utilizing STEM concepts. Educational robotics shows relevance within the elementary environment. Utilization of ERA principles which has its building blocks based on cognitivism, constructivism, and constructionism, show a promising alternative to the implementation of educational robotics within a STEM environment.

This approach highlights the need to understand concepts rather than just recite them. Recent trends support teaching STEM-oriented integrated concepts rather than as completely separate ideals. This new view of mathematics is more in alignment with the use of robotics than the “drill and grill” methods. New views in ideology support robotics, either in addition to
traditional classroom methods, or as a replacement. However, there are still the traditional ways of thinking that continue to support older ideologies and methods. This will be difficult to overcome without similar research studies to this one. Although the theory and concepts behind teaching math support the use of robotics in the elementary classroom, there is a demonstrable lack of academic research to support its use. This was one of the key gaps found through the literature review and a key reason for the need of this study.

New principles such as ERA are now being developed to assist the educational community in the development of assessment within a STEM, and particularly a robotic STEM environment. The literature demonstrates that there will need to be considerable training to educate the teacher so they can successfully teach Educational Robotics concepts and principles such as ERA. This will require a paradigm shift to enable the teacher, student, and robot to work within an integrated ERA format utilizing AfL assessment principles. There will need to be a clear understanding between the differences between Educational Robotics (TWR) and Robotics Education (TR) within the educational environment.

Current ideas regarding what constitutes learning have changed. It now encompasses more than stand-alone test scores. Yet the system surrounding the educational environment continues to support methods that do not promote this type of contextual learning. Using the Roamer Too in a contextual learning method incorporating ERA principles is more in line with new perspectives on what children will need to address in the world in which they will live. Contextual learning has been virtually replaced by other learning processes. The literature found sufficient support that suggests contextual learning should once again be integrated into the classroom setting. Teachers expressed concerns that the material being presented may not meet the curriculum requirements. This is a valid concern and one of the key gaps between the
potential benefits of robots and the necessity of addressing standard benchmark and curriculum standards.
CHAPTER THREE: METHODOLOGY

The purpose of this study was to describe the interactive process and outcomes of working with educational robotics to facilitate fourth-grade elementary school students’ understanding of Science, Technology, Engineering, and Math (STEM) concepts. The study was driven by the following research questions:

1. How do elementary school students interact with an educational robot to design and test problems?
2. Does interacting with an educational robot impact the understanding of STEM concepts?
3. Does interacting with an educational robot impact attitudes towards STEM?

This chapter provides a description of methodological considerations and procedures to address the purpose and research questions driving the study. The chapter begins with the rationale for the research design followed by a description of the study setting and participants; types of data, data sources, and instrumentation; and data collection procedures. Finally, the analytical plan is also described.

Research Design

A multi-case study approach to research was used to meet the study purpose and research questions. The multi-case study method was best suited for the proposed study because it requires an in-depth examination of the context and conditions underlying the cases of interest. In this regard, case study research is about developing a holistic and contextual understanding of a phenomenon of interest based on multiple sources of evidence, rather than a study of specific
variables relying on single data sources (Yin, 2009). This is in line with constructivist, constructionist, and ERA principles serving as a basis for this study.

Further, case studies allow for a heuristic approach allowing for the explanation of what happened and why which increases applicability (Merriam, 1998). Under this premise, the case study method is best suited for the proposed study because it is driven by descriptive research questions seeking to understand how participants interact with an educational robot and the impact on different outcomes. The use of a multi-case study approach yielded rich descriptions and multiple sources of data that helped explain the nature of participant interactions with an educational robot and the impact on nature of student work, understanding of STEM concepts, and attitudes toward STEM.

Another reason the case study method was best-suited for the proposed study is because it requires data collection in natural settings (e.g., classrooms) involving a small group of participants; the goal was to describe what happened and under what conditions. In addition, the case study method was also used for evaluation purposes allowing the use of multiple cases for comparative purposes (Yin, 2009). Multi-case studies allow for the evaluation of each case on its own as well as across cases to observe whether participants behave differently in a different setting or when conditions have changed for specific tasks (Bloomberg & Volpe, 2012; Stake, 2006). To this end, for comparative purposes, two cases represented the unit of analysis in the study: One case was a group of fourth graders receiving instruction mediated with Roamer Too robots, while the other case was another group of participants receiving instruction without the use of robots. The common denominator was a design activity featuring STEM concepts developed by Valiant (2012). Both groups were given the same problem to solve, but only one group used the Roamer Too. Thus, the multi-case study approach allowed for documentation of
how participants interacted and used an educational robot to learn STEM concepts and the extent to which interacting with an educational robot, compared to instruction-only, impacted the nature of the participants work, understanding of target STEM concepts, and attitudes toward STEM.

Case Study Context: Setting and Participants

The setting for the study was an extracurricular program for fourth grade students at an elementary school located in a rural county in the state of Florida. The school district is academically ranked 64th out of 67 counties in Florida, and has three elementary, one middle, and one high school (fldoe.org, 2013). The elementary school—referred to hereafter as the “Cooperative Elementary School” to protect its identity—agreeing to participate in the study is typical of the other elementary schools in the district and is ranked in the bottom 100 elementary schools academically in the state. The school has 652 students with 92% on free or reduced lunch (fldoe.org, 2013). The school district superintendent endorsed this study and agreed for the Cooperative Elementary School to offer the one-week program featuring the target STEM activity for the proposed study. This site was chosen as students in this district and particularly at the elementary school have had limited exposure to STEM, robotics, or other related activities.

Typically, a total of 100 students enroll in fourth grade with a relatively balanced participation by gender (56 male, 44 female), and with predominantly White (n = 42) and Hispanic (n = 45) backgrounds. Students of Black (n = 6) and multi-racial backgrounds enroll at lower rates. All students enrolled in the fourth grade at the Cooperative Elementary School were eligible to participate in the study. The target sample will consist of 20 participants who were randomly assigned to one of two groups (Group 1 = Working with robots and Group 2 = Working without robots) for a total of 10 participants in each group. To address ethical considerations for participation, students in the “working without robots” group as well as all
students in the class not selected for participation in the study had the opportunity to repeat the learning activity or participate in a similar one using the Roamer Too once the study was completed. Upon completion of the study, the robots and additional educational robotics STEM curriculum were given to the school for continued use. This allowed all students within the school to have use of the Roamer for future activities. None of the participants will had prior experience with either the Roamer or Roamer Too, and limited to no experience with other robotics sets.

STEM Activity and Use of Robots

The STEM learning activity used in the study was implemented with both groups but only one group used an educational robot. What follows is a description of the activity, the educational robot, and the procedures for conducting the activity.

The learning activity: A design problem. The activity “Space Craft Rescue” was selected due to the embedded integration of STEM concepts appropriate for students in grades third to fifth. The Space Craft Rescue (See Appendix A) is a learning activity involving hands-on STEM oriented activities grounded on a design problem. The design problem requires participants to complete a rescue “mission” to be presented as follows:

Our spaceship has crash-landed in a ravine. First reports suggest that the damage is not severe. The bulk of the spaceship is intact and can be rescued. It has a valuable cargo and you must get to it quickly before the Jawas (Jawas are technology scavengers native to Luke Skywalker's home planet of Totooine) find and loot it. You will need to build a special structure to lift the spaceship onto the rescue vehicle and safely bring it back to the repair base. You can only land your team on salt flats about 20 km from the ravine. It
is treacherous terrain and you have to find a quick and safe route to the crash site and back. Unfortunately the company is trying to cut costs so you must perform the rescue within strict economic restraints. This means submitting you structural design and travel route to the chief accountant for approval, before you set off on the rescue journey.

The basic STEM concepts covered included: (a) forces and motion, and structures for science, (b) programming and use of robots for technology, (c) design, make, present, and implement solutions for engineering, and (d) vectors, distance, measurement, budget, and metric units of measurement for mathematics. Essentially, the primary objectives of the design problem were to help students:

1. Experience how they can use the same mathematical processes to solve different types of engineering problems.
2. Use graphical methods of vector analysis to calculate forces acting on structures.
3. Use vectors to plan the movement of a robot.
4. Understand how engineers use mathematics to predict solutions to problems.
5. Understand that engineering problems involve more than finding the best technical solution.

Additionally, secondary objectives of the design problem were to promote working as a team and help students develop problem-solving skills (Valiant, 2013).

The fourth grade level was chosen due to its close alignment with the adopted Common Core State Standards Curriculum for Mathematics, Sunshine State Standards for Science, and ITEEA (International Technology and Engineering Educators Association) Standards for Technological Literacy. For an overview of the fourth grade relevant standards see Appendix D.
The educational robot. The educational robot used in the study is the Roamer Too. The Roamer Too is a flexible and modular robot, which allows students to easily modify it to meet the needs of a learning activity. As shown in Figure 9, the base of the Roamer Too (on the left) is a standard platform that can support interchanging a variety of age-appropriate keypads. The keypads are designed to build upon each other as students progress in their use, with each level representing an increase in programming options. To match the target level in the study and purpose of the learning activity, the Junior level Roamer keypad used. This keypad contains all programming features available needed to complete the target learning activity, and can be easily learned by study participants.

Figure 3.1. Roamer Too Standard Platform with Interchangeable Keypads (Reprinted with permission from Valiant Technology, 2013).

The Roamer Too comes with a single control pod, which will allow input and output for sensors and motors. However, the control pod will not be utilized as the use of sensors and motors are not central to the activity. Although the Roamer Too affords the use of other features,
for the purpose of the target STEM learning activity, only the features involving the Junior Roamer Keypad shown in Figure 3.2 were used in the study.

Figure 3.2. The Junior Roamer Keypad (Source: Valiant (2013))

Conducting the learning activity. The learning activity was completed in five one- to two-hour consecutive school day sessions. Sessions one and five were extended to two hours to complete the pre/post tests, surveys, as well as other necessary paperwork, as noted in Table 3.1. The same room was used for both groups. The initial session began with a preliminary survey (Appendix B) to document prior attitudes toward STEM, the pre-test to identify prior knowledge of STEM concepts related to the activity (Appendix C), and direct instruction was provided to both groups as stated in Table 3.1. The shared instruction involved a debriefing of the design problem underlying the learning activity and expected outcomes, and direct instruction of
foundational STEM concepts needed for understanding and completing the design the problem.

At this point, participants were introduced to the design problem, and expected outcomes.

**Table 3.1. Plan for Learning Activity Using Robots and Traditional Teaching.**

<table>
<thead>
<tr>
<th>Session</th>
<th>Student Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Teaching with Robots(WR)</td>
</tr>
<tr>
<td>1</td>
<td>Preliminary survey to determine prior attitudes toward STEM</td>
</tr>
<tr>
<td></td>
<td>Mission briefing: Introduction of the design problem</td>
</tr>
<tr>
<td></td>
<td>Direct instruction: Focus on basic STEM concepts including forces and motion, structures, beams, struts and columns, loads, and metric measurement</td>
</tr>
<tr>
<td>2</td>
<td>Programming the Roamer Too, and rescue design</td>
</tr>
<tr>
<td>3</td>
<td>Material cost calculation, building, and programming</td>
</tr>
<tr>
<td>4</td>
<td>Building and testing</td>
</tr>
<tr>
<td>5</td>
<td>Project completion and administration of post-survey of STEM attitudes</td>
</tr>
</tbody>
</table>

Both groups were given the same design problem. The difference was in the use of the Roamer Too. The “teaching without robots” (NR) participants were asked to rescue the spacecraft using the hands-on building materials provided. They were instructed to follow the same obstacle route for the rescue as the experimental group. The “teaching with robots group” (WR) had the Roamer Too as well as the hands-on building materials, as a means of rescuing and guiding the spacecraft through the obstacles to safety. These differences were introduced in session two when each group is separated. Groups were separated from Session 2 on, but came together for the Post STEM exam as well as the STEM Survey. One group participated in the activity first, which was immediately followed by the next group. Session times alternated between groups each day. For example, the “teaching with robots” (WR) group met first for sessions 2 and 4, but second for sessions 1 and 5, and vice versa for the “teaching without robots” (NR) group. This was to avoid any unintentional effects associated with participant’s response as related to the time of day, and to also avoid taking participants out of their classroom the same time of day, possible missing the same academic class.
To minimize the possibility of Hawthorne’s effect, the two groups were drawn randomly from different classrooms utilizing the parental permission slips authorizing participation. Participants in the “robots” (WR) group were drawn from classes A and B, and participants in the “without robots” (NR) group were drawn from classes C and D. All of these classes were considered to have a typically consistent academic range of students represented in each class. This method allowed for the same facilitator to work with both groups and thus ensuring that the only variation in the learning activity was the use of robots. The facilitator was an elementary classroom teacher at the school with four years of teaching experience. The facilitator had no specific prior training and was trained by the researcher on the activity as well as in the use and programming of the Roamer Too. The facilitator had very little previous experience implementing a hands-on STEM oriented activity. Roamer robots, obstacle course, and building materials to complete the design problem were provided to the participants by the researcher. Examples of building materials consisted of pipe cleaners, popsicle sticks, foil, string, tape, etc. A complete list is available within the Space Craft Rescue Student Worksheets (Appendix A). All materials were given to the school for future use.

The week prior to the start of the study, Parental permission slips were sent out via each classroom teacher and given to each student to deliver to their parent. All permissions that were returned, were received the next day with a few coming in the second day. Of the 100 parental permission slips that were distributed, 47 were returned. 46 of these forms gave permission for their child to participate, one declined. Five student’s names were initially drawn at random from each class using these forms. Potential participants were then called in individually and asked, via the student assent process, by the facilitator with the researcher present if they were willing to participate in the study. During these interviews, two students declined to participate.
Two more names were drawn from the parental permission slips in their respective classes. Therefore there were 5 students from each of the 4th grade classes selected to participate. The treatment group (WR) consisted of 5 Males and 5 Females (& Hispanic, 2 Caucasians, and 1 African American (n=10). The control group (NR) had 4 Males and 6 Females (5 Hispanic, and 5 White (n=10). A total of 20 (n=20) students participated in the study. No participants dropped out during the course of the study. All permission forms, exams, surveys, as well as audio and video tapes were secured in a locked cabinet at the end of each day.

During session 1, both groups were together. This session was two hours in length. The session began with the facilitator giving a brief introduction of the activity. Participants were informed that they would be video and audio taped, and would have pictures taken. There was initial concern among the participants that the STEM test and survey administered would be considered a part of their grade. The facilitator assured all participants that this was not part of their grade, but that is was important that they complete everything to the best of their ability.

The pre STEM Exam as well at the STEM Survey took participants approximately a half hour to complete. An administrator from the curriculum department in the school district was sent to proctor. The same person proctored the post exam and survey on the final day. Direct instruction on the STEM terms necessary for the study were then introduced by the facilitator to both groups. Journals with the Space Craft Rescue (Appendix A) document as well as pencil’s, were distributed to all participants. The sheet with the roamer programming information was distributed to the TR group the following day. These materials were collected at the end of each session. To teach these concepts, the facilitator utilized a variety of hands-on activities, such as two participants holding hands and pulling away from each other to illustrate stress. Participants were encouraged to respond, as well as ask questions during the session.
During sessions 2 and 3 of the learning activity, the participants were divided into teams of two. The group assigned to the “teaching with robots” (WR) group learned how to program the Roamer Too using basic commands to go forward, backward, left turn, right, turn, and so forth. Participants programmed directly on the Roamer Too to practice. Once participants were familiar with programming commands and general use of the Roamer Too, they then explored units of movement associated with direction and turning. Then the participants performed some simple activities to demonstrate their ability to program so they will be able to utilize the robot to solve design problems appropriate to their level including calculation of materials cost. In turn, during sessions 2 and 3, participants in the “teaching without robots” group used paper and pencil and other didactical materials typically used in traditional teaching to plan the design of their project and estimate the cost of materials including a post-survey of attitudes toward STEM as well as the post-test. Participants were encouraged to write their list of required items before going to the materials table. They were told once they removed it from the table they “bought” that item whether they used it or not. If the “purchased” an item they realized they did not need, they were encouraged to “Barter” or “exchange” with other teams. Roamers were placed out of site in a closet when this group was in the room.

For both groups, session 4 concentrated on building and testing. The facilitator placed an emphasis on the calculation of the cost of their build. Calculations seemed to take up the most time during this session. Also, many projects were refined during this session. Secrecy on design became important between teams and many teams became concerned that other teams were copying their design. The group working with the robots had the added process of utilizing the robot for the rescue. All of the participants remembered how to program the Roamer which had been introduced in session 2.
The first hour for each group in Session 5 was focused on the testing of each team's design. Both groups were excited to test on the actual mock-up. All participants within the group watched each of the teams. Teams were required to discuss the cost of their design. During the rescue, both teams were required to verbally describe the vectoring used to get in and out of the Ravine in order to rescue the spacecraft. The facilitator conducted an overall review of the activity with both groups once the testing was complete. While still in their individual groups, participants completed their project and final reports. Both groups were brought together after lunch to complete the STEM Exam and STEM Survey.

Data and Instrumentation

As participants completed the learning activity, the documentation of the case studies focused on the interactive process with the learning activity, as well as the impact on participant understanding of target concepts and attitudes toward STEM.

Interactive process in learning activity. To address the first research question, the interactive process was defined by the way participants worked with the Roamer Too to accomplish STEM unit goals in comparison to participants receiving instruction without robots. Three indicators identified from related literature were used to document the interactive process (Catlin 2012; Liu, et al., 2013; Newmann & Wehlage, 1995; Mosley, 2006). The three indicators are: (a) engagement, (b) substantive conversation, and (c) knowledge production. Specifically, building upon the work of Newmann & Wehlage (1995), a rubric was used to document the indicators of the interactive process based on a 5-point scale with 1 and 5 representing low and high levels, respectively (see Appendix E).
**Student engagement.** Engagement was defined by the extent to which participants stayed on task demonstrating a high level of motivation to learn (Catlin, 2012; Newmann & Whelage, 1995). The contrasting elements of the corresponding 5-point scale for low and high engagement were identified as follows:

- **Low.** Participants stay on task for a very short period of time during the session losing focus after getting started. Participants appear to be bored and unmotivated to learn during the entire session.

- **High.** Participants stay on task during the learning session showing obvious engagement in the instructional activity by remaining focus on related work. Participants appear to be excited and motivated to learn during the entire session.

**Substantive conversation.** This indicator refers to the level of substantive conversation resulting from participation in a learning activity (Newmann, & Whelage, 1995). Substantive conversation is characterized by frequent interactions to share ideas reflecting higher-order thinking and participants’ own thinking, and a recurrent dialogue during an activity. The contrasting elements of the corresponding 5-point scale for low and high level of substantive conversation will be identified as follows:

- **Low.** Verbal interactions, sharing of ideas, and dialogue are practically absent during the session. There are virtually no examples of any coherent exchanges with participants or teacher.

- **High.** There are considerable instances of substantive conversation featuring interactions, sharing, and dialogue. That is, more than one episode of at least three consecutive exchanges are observed, and with many participants and facilitator engaged.
Knowledge production. This indicator is defined by the extent to which participants manipulate information and ideas to solve the design problem and make their own conclusions (Newmann & Whelage, 1995).

Low. Participants primarily follow instructions during the session. Participants have essentially no opportunities to manipulate information and/or materials to test ideas and solutions to problems.

High. Participants spend the time during the session manipulating information and/or materials to test ideas and solutions to problems. In the process, during the session participants combine facts and ideas to synthesize, generalize, explain, hypothesize, or arrive at some conclusion or interpretation.

Understanding of STEM concepts. To address the second research question, the inquiry focused on the understanding of STEM concepts covered in the activity. Understanding of target concepts are necessary for the successful completion of the activity by participants in both groups. The documentation of participant understanding drew from three sources of data including scores on a test at the beginning and end of the activity, evaluation of participant reports, and scores on a complementary indicator of participant understanding.

Activity test scores. The first indicator of participant understanding of the specific STEM concepts introduced within the activity were test scores on the Space Craft Rescue Exam reported in Appendix C. The exam features 10 items requiring participants to provide open-ended explanations, examples, graphical representations, contrasting, and justification statements. The exam focused on questions that are grade-level appropriate and aligned to the coverage of the standards described in Appendix D. Here are two examples:
• What is a force? Can you give an example?
• Which is a stronger structure, a triangle or a square?

**Student reports.** Participant reports provided another source to evaluate their understanding of STEM concepts. “Space Craft Rescue” worksheets (Appendix A) developed by Valiant in 1998 were given to each participant in a binder for use throughout the project. The worksheets for both groups were the same with the exception of the section on “Navigation Vectors” where the picture of the Roamer Key pad will be covered for the group not working with robots. The appropriate document was given to each group on the second day of the activity. The worksheets begin with a description of the project and then move on to review basic building and programming concepts associated with the activity. The facilitator led the participants through this section with a variety of hands-on activities. The next section consists of participants designing their method of rescue and calculating the cost of their design. The final section of the document contains the final project report to be completed by each participant.

The final report yielded a self-assessment of what participants learned during the activity. The first section of the final report required participants to first agree/disagree with three 5-point Likert scaled statements summarizing final outcomes of the activity. Next, participants were asked to provide open-ended responses about things that worked and did not work, and identify ways in which performance could have improved. In the second section of the final report, participants were asked to agree/disagree with three statements about whether the project was enjoyable, working as a team, and extent of learning. This was followed by a request for open-ended responses to elaborate on responses to previous statements.
**Indicator of understanding: Depth of knowledge.** An indicator identified from the work of Newmann and Wehlage (1995) on authentic assessment, depth of knowledge, was used to complement the documentation of participant understanding: Depth of knowledge is defined as the level of understanding demonstrated by the participant as they grapple with the STEM concepts underlying the design problem in the learning activity. A rubric was used to document the indicator on a 5-point scale with 1 and 5 representing “shallow” and “deep” levels, of knowledge respectively.

*Knowledge is shallow* was characterized when superficial participant understanding of STEM concepts was evident across their conversations, approaches to the problem design, and reporting of final results.

*Knowledge is deep* was characterized when it was evident that participants were able to make clear distinctions, develop arguments, solve problems, and construct explanations during the design activity.

**Attitudes toward STEM.** To document the third research question seeking to determine whether interacting with educational robots impact attitudes towards STEM, the Participant Attitudes towards STEM Survey (S-Survey) used. The survey was developed by the Friday Institute (2012) and is intended to measure changes in participant confidence and efficacy within STEM subjects of fourth and fifth grade students. It is the second phase of a survey originally developed by the Institute to measure STEM attitudes of students in grades 4-5th. To increase validity and reliability, the instruments went through two rounds of revisions. During the revision process the test was administered to 900 fourth and fifth graders. Experts in engineering education, subject matter experts, and grade level teachers were utilized to rate each question (Friday Institute for Education, 2012). The survey reflects participant interest in STEM careers
as skill based learning within the following constructs (including construct reliability levels using Cronbach Alpha): Math (8 questions, 0.860), science (9 questions, 0.838), engineering and technology (9 questions, 0.838), and Your Future (12 questions, 0.864). The survey was administered and scored by a proctor who works for the school district in the department of curriculum and instruction who was not directly involved with the study.

Data Collection Procedures

Access to and cooperation of the participating district and school was secured following the University Institutional Review Board’s (IRB) procedures with formal consent granted by the participating stakeholders. To ensure student participation, with the assistance of the Cooperative Elementary School program staff, parental/guardian consent forms (Appendix G), including permission to videotape the sessions, were sent out prior to the implementation of the study. Parents were informed that any videotaping will only be used by the investigators and will not be released for any other purposes. Parents were also informed of other standards assurances for participation in a research study including nature of the study, duration, anonymity, voluntary participation, and benefits. Prior to the introduction of the learning of activity, participants were given the opportunity to individually and away from others provide verbal assent to the facilitator and researcher to participate. This was scripted (Appendix H) and delivered by the facilitator. The researcher was present to answer any specific questions. In preparation for conducting the learning activity, the researcher trained the school facilitator in charge of teaching both groups. This training occurred the week prior to the exam and took about two hours. All materials and a Roamer Too were left with the facilitator to prepare for the survey. There was initial hesitation on the part of the facilitator to participate in the study due to a lack of confidence in conducting this type of activity. The facilitator was encouraged to participate, but
was informed that she could “opt out” with no professional consequences. Of primary concern were that the videotapes would be used for overall teacher evaluation. Again, the facilitator was assured no one from the district would view the videotapes. Once the facilitator had the opportunity to go over the materials and practice programming, she became excited, although nervous to assist with the study.

**Data collection on interactive process.** To document the interactive process, the extent and nature of engagement, knowledge production, and substantive conversation was recorded by noting the frequency and nature of questions, type of guidance and coaching needed, approaches to troubleshooting, design strategies, manipulation of materials, and sharing and expressing ideas during interactions. The documentation of these interactions was based on field notes of classroom observations, which were compiled at the end of each session in a detailed journal. With permission from participating stakeholders, each session were videotaped for analysis of interactions during the design activity. Audio tapes were used to record various conversations between teams. At the beginning of the first session, the facilitator introduced the researcher as an observer and reminded participants that sessions will be videotaped with consent from their parents. This allowed the researcher to take extensive field notes during the sessions to document the participant interactions and nature of work in progress. The completion of corresponding rubrics for engagement, knowledge production, and substantive conversation was based on field notes and review of video recordings for triangulation purposes.

At the end of each day’s activities, the researcher organized, summarized, and coded field notes in a reflective journal. The coding of notes was triangulated with reviews of video recordings and transcription of each session.
Data collection on student understanding. The documentation of participant understanding relied on data collected on activity test scores, review of participant reports, and scores on depth of knowledge. Regarding activity test scores, prior to the commencement of the activity, the activity test was administered to determine baseline knowledge of target STEM concepts. The same designated proctor not directly involved in the study administered the test. After administration, the facilitator will proceeded to conduct the learning activity as outlined in Table 3.1.

Data collection on both activity test scores and participant reports occurred at the end of the entire activity. At the end of the five-day period, participants were asked by the facilitator to complete a self-evaluation of the completed activity (the project report) and take a post-test focusing on their understanding of relevant STEM concepts. The post-test was the same as the pre-test administered during session one and was be administered by the same proctor. Participants took between 45-60 minutes following session 5 to complete the self-evaluation, pre/post exam and survey.

Data collection on the complementary indicator of participant understanding—depth of knowledge—followed the procedures noted for the documentation of the interactive process. To document depth of knowledge related behaviors were recorded during the completion of the design activity relying on field notes of classroom observations. Again, at the end of each day’s activities, the researcher organized, summarized, and coded field notes in a reflective journal. The coding of notes was triangulated with reviews of video recordings and transcription of each session. The resulting data was used to complete the rubric for depth of knowledge.

Attitudes toward STEM. Prior to the commencement of the activity, the Attitudes Toward STEM Survey was administered to all participants. The same proctor not directly
involved in the study will administered the instruments. After administration, the facilitator began conducting the activity following the outline in Table 3.1. Upon completion of the design activity after five sessions, participants were asked by the facilitator to complete the Attitudes Toward STEM Survey a second time to document post-activity responses. The survey was the same as the pre-test administered during session one and was again administered by the same proctor.

Finally, the researcher collected all data including activity test scores, survey results, learning activity reports, videotapes, and field notes for safekeeping and analysis.

Data Analysis

The analysis followed descriptive analytical techniques typical of multi-case studies. The goal was to characterize the nature of interactions and outcomes of participation in the design activity, and any differences in each team, within groups, and between groups.

Interactive process. The analysis of the interactive process focused on three indicators of interactions including engagement, substantive conversation, and knowledge production. The analysis of participant interactions was based on the frequency and nature of behaviors characterizing each indicator using the corresponding criteria on a 5-point scale with contrasting low (1) and high (5) elements. Frequency and nature of relevant behaviors was identified and quantified based on field notes and review of video recordings and session transcripts. For example, how many episodes of exchanges were recorded for a team during a session? What kind of questions did participants ask? How long did teams stay on task? For this purpose, coding ID’s was assigned to each participant to track participation and tag data collection. The
approach to the characterization of each indicator was to establish frequency and nature of interactions for participants in each team, as a group, and through a comparison between groups.

**Student understanding.** The analysis of participant understanding focused on three sources of data including activity test scores, participant reports, and an indicator of depth of knowledge.

For the *analysis of activity test scores*, descriptive statistics was used to determine understanding of STEM concepts. The emphasis of the analysis was on determining the average number of correct responses prior and upon completion of the activity to estimate how each individual, team, and group performed, trends in understanding of concepts based on correct/incorrect responses, and differences between groups. The exam consisted of 10 questions with each worth a total of 10 points for an exam total of 100 points. Since many of the questions require 2-part answers, partial credit may be given for an individual answer. A T-Test was used to analyze average gain scores between groups. A p-value of 0.05 between samples indicated that there is a statistically significant difference between two groups.

The *analysis of participant reports* provided complementary evidence of participant understanding. Scores on the agree/disagree statements on the final report were converted into a single composite score for each section to represent, on the average, whether in the participants’ self-assessment they believed: (a) the spacecraft was successfully rescued on budget and on time, and (b) it was enjoyable working on the project as a team while learning a lot. For comparison purposes, an independent T-Test for each of the Likert section of the worksheets was conducted for the analysis of group means to check for differences between participants in the “with robot” (WR) and “without robot” (NR) instruction. Open ended-responses were used to characterize and explain scores. Scores and complementary participant self-evaluation
perspectives of their work further triangulated with data from notes recorded during the completion of the activity.

The *analysis of depth of knowledge* further assisted in characterizing participant understanding of STEM concepts. The analysis of this indicator was based on the frequency and nature of related behaviors using the corresponding criteria on a 5-point scale with contrasting elements: Shallow knowledge (1) and deep knowledge (5). Frequency and nature of relevant behaviors were identified and quantified based on field notes, review of video recordings and session transcripts, and review of participant reports. For example, how often were participants able to clearly explain or justify a procedure during the design activity? Was the nature of design approaches based on logical reasoning? For this purpose, coding ID’s were assigned to each participant to track participation and tag data collection. The approach to the analysis was to characterize the depth of knowledge for participants in each team, as a group, and through a comparison between groups.

**Attitudes toward STEM.** The analysis of the pre- and post STEM attitude survey data relating to question three also relied on a descriptive summary of average gain scores for individual groups and determination of differences between, individuals, teams, groups, and between groups. Three sections of the survey (Math, science, and engineering and technology) was assigned a point with “Strongly Disagree” given 1 point and “Strongly Agree” given 5 points, and no response given 0 points. Therefore the range for the Math portion (8 questions) is 0-40, science (9 questions) is 0-45, and Engineering and Technology (9 questions) 0-45. Therefore, the overall possible range for this portion of the survey was 0-130. In addition, the section of the survey titled “Your Future” was administered at the same time. This test is focused on highlighting the STEM career focused interest of the participants. Due to the focus
of the activity, was expected that there will be movement within the responses covering mathematics and engineering. There were a total of 12 questions to this section. 4 Points were assigned for: “Very Interested” with no response given 0 points. An Independent T-Test will be used to form analysis within teams, within groups and between groups. After initial examination, it was deemed appropriate that a Mann-Whitney test should be conducted to verify results (McCrum-Gardner, 2007)
CHAPTER FOUR: RESULTS

The purpose of this research was to investigate the interactive process and outcomes of working with educational robotics to facilitate fourth-grade elementary school participants understanding of Science, Technology, Engineering, and Math (STEM) concepts. In this chapter, the results of the study are presented for each research question underlying the inquiry. The chapter begins with a description of results of the participant’s interaction process in the context of completing a STEM design activity. This is followed by a report of results on the extent of the understanding of STEM concepts and depth of knowledge as a result of completing the design activity. The final section of this chapter features the results on the question about the impact of participation in the design activity on STEM attitudes.

The Interactive Process

Research question one was concerned with the characterization of the participants interactive process in the context of using an educational robot to complete a STEM design activity. The “interactive process” was defined as the way in which participants stayed on task during the activity, how they communicated with each other and the instructor, and the nature of manipulation of mediating instruments and materials (e.g., robot). To characterize the interactive process, three indicators were used: (a) engagement, (b) substantive conversation, and (c) knowledge production (Newmann & Wehlage, 1995). The indicator of participant’s engagement references the extent to which participants demonstrate a high level of motivation by staying on task. In turn, substantive conversation captured the participant’s frequency of interactions and
dialogue during the activity. Knowledge production was an indicator of the extent participant’s manipulated information and materials (e.g., robot) to solve problems and create their own learning.

To recap, two groups of participants were presented with a STEM design activity and were asked to solve it after receiving related instruction. One group used a robot as part of related instruction and the design activity, while the control group did not use a robot in instruction or as part of the design activity. The question here was whether the use of the robot made a difference in the way participants stayed on task (engagement), communicated in the process (substantive conversation), and the nature of knowledge applications (knowledge production). Building upon the work of Newmann & Wehlage (1995), a rubric for each indicator was used to characterize the interactive process involving a five-point scale with one representing a “low” level and five a “high” level. The coding for each indicator was validated using two independent raters and verification through video reviews, field notes, facilitator comments, and participant’s journals. The interactive process was then characterized within and between groups as reported on Table 4.1.

**Table 4.1.** Ratings for Indicators of Process Defined by Participant’s Engagement, Substantive Conversation, and Knowledge Production.

<table>
<thead>
<tr>
<th>Working with Robots (WR)</th>
<th>Working Without Robots (NR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants (n=10)</td>
<td>Participants (n=10)</td>
</tr>
<tr>
<td>Engagement</td>
<td>Engagement</td>
</tr>
<tr>
<td>Substantive Talk</td>
<td>Substantive Talk</td>
</tr>
<tr>
<td>Knowledge Production</td>
<td>Knowledge Production</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
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<td>2</td>
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<td>10</td>
<td>10</td>
</tr>
<tr>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>SD</td>
<td>SD</td>
</tr>
<tr>
<td>4.8</td>
<td>4.3</td>
</tr>
<tr>
<td>0.42</td>
<td>0.67</td>
</tr>
<tr>
<td>4.5</td>
<td>3.6</td>
</tr>
<tr>
<td>0.71</td>
<td>1.07</td>
</tr>
<tr>
<td>4.1</td>
<td>3.6</td>
</tr>
<tr>
<td>0.88</td>
<td>0.84</td>
</tr>
</tbody>
</table>
**Interactive process within groups.** As can be gleaned on Table 4.1, the “working with robots” (WR) group showed a high level of interactivity demonstrated by high ratings for each indicator ranging from 4.1 for knowledge production to 4.8 for level of engagement. That is, on the average, participants stayed on task working in the design activity, engaged in substantive episodes of verbal interactions, and had the opportunity to manipulate the robot and design materials. Of the three indicators, the level of engagement was highly consistent within the “working with robots” (WR) group (4.8 mean rating) with all the participants engaged at either a relatively high (4.0) or high (5.0) level. Participants who stayed on task and remained focused and motivated while working with their partner represented an example equivalent to a “high” rating description. Overall, during the activity participants were primarily focused on their design and were not distracted by what other teams were building. That is, they remained “engaged” on the design task.

Engagement in substantive conversation about the design activity was also consistent and high (4.5 mean rating) with the majority of participants (n=9) showing relatively high (4.0) or high (5.0) level of on-topic conversations. In this case, a high rating was given when a participant’s conversation consisted of at least three consecutive verbal interactions relating to the activity with the participants as well as the facilitator. For example, an in depth participants discussion concerning the use of a particular building material between participants and between participants and instructor would be considered a high level of substantive conversation.

Knowledge production was relatively consistent within the “working with robots” group at a moderately high level with a mean rating of 4.1. On this indicator, seven of the participants were observed interacting at a relatively high (4.0) or (5.) level regarding knowledge production, while the rest engaged at a 3.0 level. A high rating would be earned if, participants were able to
explain in detail both verbally and utilizing their written journal entries how they arrived at their design, including similar reflection on what worked and what didn’t. In other words, a team going page by page through their journal entries and sketches showing the redesign process and explaining both verbally and in writing how they came up with their final design would earn a 5.0 rating. On the average for this group, participants demonstrated the ability to synthesize ideas, and were able to arrive at a reasonable conclusion. For example, participants were able to discuss their design ideas with their teammate, but might not have been able to translate these same ideas as a team clearly on to paper or in their actual model.

In the “working without robots” (NR) group, albeit a slightly lower level, participants also showed a relatively high level of consistent interactivity demonstrated by mean ratings of 4.3 for engagement, and 3.6 for substantive conversation and knowledge production. That is, on the average, participants also stayed primarily on task working in the design activity, had frequent episodes of verbal interactions, and also engaged in the manipulation of design materials. Of the three indicators, participant’s engagement was highly consistent within the “working without robots” group (4.3 mean rating). In this case, the majority of the participants (n = 9) engaged at either a relatively high (4.0) or high level (5.0), with only one showing moderate (3.0) engagement. On the average, participants remained focused on the activity, with distractions noted while at the materials table, with a tendency to “touch” the available items. For example, participants wanted to pick up the craft sticks and pipe cleaners. However, in most cases, they picked up these items to determine if they could be used within their design.

Engagement in substantive conversation about the design activity was relatively consistent clustering around a mean rating of 3.6. For this indicator, half of the participants were given a rating of 3.0, while the rest (n = 4) was rated at higher levels (4.0-5.0) and one rated at a
lower level (2.0). On the average, participants engaged in discussions requiring frequent
guidance from the facilitator, but not as much communication with each other.

Similarly, knowledge production was relatively consistent within the “working without
robots” group with a mean rating of 3.6 and the majority (n = 6) rated as being engaged at a 3.0
level. The rest (n = 4) of the participants scored at either a 4.0 or 5.0 level of knowledge
production activity. That is, on the average, rating of 3.6 would be earned if, participants were
able to explain to some extent but not completely, both verbally and utilizing their written
journal entries how they arrived at their design and with similar reflection on what worked and
what didn’t. In other words, a team may be able to explain their design process, but there are
some inconsistencies when referring to their drawings.

Comparison of interactive process between groups. As reported on Table 4.1, the
group working with the robot (WR) obtained slightly higher scores—compared to the group
receiving instruction without robots—on indicators of participant’s engagement, substantive
conversation, and knowledge production. The question at this point was whether the observed
discrepancies between the groups were significantly different.

Regarding participants engagement, the group working with the robot (WR) obtained
slightly higher scores \((M=4.8, SD = 0.42)\), than the group without the robot (NR) \((M=4.3, SD =
0.67)\). To assess whether the means were significantly different, an independent Two-Tailed T-
Test was performed as the two samples were independent and the scale of measurement was on
an interval scale. The results of the Two-Tailed T-Test test indicated that there was no significant
difference, \(t(15)=1.99, p=0.06\) for participants’ engagement between the two groups\( (d=0.89)\).
About substantive conversation, the group working with the robots (WR) again obtained slightly
higher scores \((M=4.5, SD=0.71)\) than the group without the robots (NR) \((M=3.6, SD = 1.07)\). In
this case, the results of the T-Test $t(15)=2.21$, $p=0.04$, indicated slightly significant differences between the two groups ($d=0.99$). Similarly, for knowledge production, the WR group obtained slightly higher scores ($M=4.1$, $SD = 0.88$) as compared to the NR group ($M=3.6$, $SD = 0.84$). The Two-tailed T-Test, $t(17)=1.3$, $p=0.21$ resulted in no significant difference between the two groups ($d=0.58$).

These results were verified through the review of field notes and instructor feedback. It was specifically noted by the instructor, who was familiar with the participants, that it was significant to her how well the participants stayed on task (i.e., engaged) with no discipline problems at all in either of the groups. Discipline issues were a concern of hers prior to the beginning of the activity due to the fact that all participants had little to no exposure to hands-on instruction before. The instructor initially worried that discipline issues would emerge during independent work.

Although only slight differences were observed between the groups regarding substantive conversation, practical differences were observed and further supported by the instructor. The group with robots (WR) actually communicated with each other a bit more when discussing the programming of the robot, while the group with no robot did not have as much discussion when designing their solution. In general, the instructor noted that some of the participants, who were normally very quiet and shy, worked well with their teammates and had no hesitation communicating with their partner in the WR group. The instructor cited one particular case to support her assessment. She reported that “Participant 7” in the WR group had a personal loss in the family in the prior year. From this loss the participant had become introverted, barely spoke and had lost interest in school. This participant said nothing the first day of the activity. The next day, the participant asked a question, and by the third day he had begun conversing with
partners, facilitator, and other participants. By the last day, this participant was able to verbally explain the teams’ solution to the problem presented within the activity and discuss the programming of the robot. A smile, the first they had seen from this participant since the personal loss, was noted upon completion of the testing portion on the final day.

Further, it was also noted that the nature of the hands-on design activity, which provided participants the opportunity to manipulate materials and test their solutions in both groups, might have minimized group differences regarding the level of knowledge production. To wit, at the beginning of the building portion of the activity, all participants were encouraged to utilize their journals to sketch designs before building. Participants wanted to go quickly through this and start building. The instructor let them do this, and by the second day of building, participants were using paper and pencil to sketch designs and modifications as necessary as they realized that as a team, they needed to have clear understanding of the proposed solution. Also, by the second day of building, teams became more secretive about their designs. Concern grew that other teams may copy their ideas. Some teams moved from the tables to corners and nooks in the room and hid themselves from the other teams. This occurred consistently with both the WR and NR groups. This type of participant’s reaction is an example of authentic and interactive tasks where participants are highly engaged in solving relevant problems.

**Understanding of STEM Concepts**

Research question two focused on participants understanding of STEM concepts underlying the design activity. The understanding of STEM concepts was documented using three sources of data: evaluation of participant reports, activity test scores, and ratings on depth of knowledge. In this instance, the goal was to determine whether the use of the robot made a
difference in the participants understanding of STEM concepts related to: work, stress, force, vectors, push and pull, structures, simple machines, and load.

**Evaluation of participant reports.** At the culmination of the activity, participants were asked to self-assess their perceived success completing the project as well as the satisfaction they experienced during the activity. The focus of these responses were to determine the participants’ own assessment of their performance as proxy of conceptual understanding. Using a 5-point Likert scale ranging from “strongly disagree” with a score of 1 point to a “strongly agree” with a score of 5 points, participants reported whether the design activity had been successfully completed, on budget, on time; and whether they had enjoyed the activity, working as a team, and learned a lot. Thus, an average score of 2.5 would indicate the participant only marginally experienced success in the activity, while a score of 5.0 would indicate the participant experienced a satisfactory result as well as enjoyment with the activity. For the analysis, participant responses were averaged and composite scores for participants are reported in Table 4.2.

Examination of the composite report, showed participants within the group working with robots (WR) consistently (n=10) scored themselves at either a relatively high (4.0) or high (5.0) level of agreement with project completion statements, which resulted in an average agreement of 4.5 ($SD=0.47$). That is, on the average, participants either “agreed” or “strongly agreed” that they enjoyed working on the project, that they worked well with their partner, and that they learned a lot. Concurrently, the composite report for the group without robots (NR) showed all participants within this group (n=10) scoring themselves slightly higher ($M=4.67$, $SD=0.30$) on the project completion statements when compared to the group working with robots.
When comparing the means of the two groups related to project completion statements, no statistically significant difference was observed between the two groups $t(15)= 1.19, p=0.25$. Thus, it was concluded that both groups felt they had been successful completing the project and were satisfied with their performance ($d=0.53$).

Table 4.2. Ratings for Indicators of Understanding STEM as Defined by Participant’s Likert Project and Final Report Responses.

<table>
<thead>
<tr>
<th>Working With Robots (WR)</th>
<th>Working without Robots (NR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants (n=10)</td>
<td>Participant Response</td>
</tr>
<tr>
<td>1</td>
<td>5.0</td>
</tr>
<tr>
<td>2</td>
<td>4.0</td>
</tr>
<tr>
<td>3</td>
<td>4.0</td>
</tr>
<tr>
<td>4</td>
<td>4.2</td>
</tr>
<tr>
<td>5</td>
<td>5.0</td>
</tr>
<tr>
<td>6</td>
<td>5.0</td>
</tr>
<tr>
<td>7</td>
<td>4.2</td>
</tr>
<tr>
<td>8</td>
<td>5.0</td>
</tr>
<tr>
<td>9</td>
<td>4.0</td>
</tr>
<tr>
<td>10</td>
<td>4.2</td>
</tr>
<tr>
<td>M</td>
<td>4.46</td>
</tr>
<tr>
<td>SD</td>
<td>0.47</td>
</tr>
</tbody>
</table>

Activity test scores. The Space Craft Rescue Exam was administered by an independent proctor prior to and after the design activity was completed. Participants in both groups took the exam at the same time. The exam featured 10 items, each worth 10 points, with the highest possible score of 100. The test required participants to provide open-ended explanations, examples, graphical representations, and justification for responses. The items covered the STEM concepts underlying the design activity. The results are reported on Table 4.3.

Overall pre-test scores for both groups were relatively close. Initially, since there had been little to no exposure of these concepts, the raw pre-test scores of both groups ranged from 0 to 20 for the WR group and from 0-15 for the NR group. With one exception, most of the participants in both groups who scored a 5 or higher ($n=17$) answered the first question “What is
force and can you give an example?” at least partially correct. The concept of force had very recently been introduced to these participants through their classroom science instruction.

Overall, for the pre-test, the group that worked with robots (WR), had slightly higher score ($M=7.5$, $SD=5.89$), than the group without the robots (NR) ($M=6.5$, $SD=4.74$). The result of the independent T-test indicated that there was not a significant difference between the two groups $t(17)=0.42$, $p=0.68$ ($d=0.19$).

**Table 4.3. STEM Exam Pre/Post Test Scores.**

<table>
<thead>
<tr>
<th>Participants (n=10)</th>
<th>Working with Robots (WR)</th>
<th>Working Without Robots (NR)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>STEM Exam Pre-Test Score</td>
<td>STEM Exam Post-Test Score</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>75</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>90</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>65</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>35</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>45</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
<td>70</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>65</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>70</td>
</tr>
<tr>
<td>9</td>
<td>15</td>
<td>75</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>65</td>
</tr>
<tr>
<td>$M$</td>
<td>7.5</td>
<td>65.5</td>
</tr>
<tr>
<td>$SD$</td>
<td>5.89</td>
<td>15.53</td>
</tr>
</tbody>
</table>

In comparison, upon completion of the design activity, post-test scores indicated a slightly higher level of concept of understanding by the WR group with a range of 35 to 90 points. On the other hand, the NR group showed a level of understanding ranging from 20 to 80 points. Thus, the WR group had a higher overall post-test score ($M=65.5$, $SD=15.53$), than the group without robots (NR) ($M=53.0$, $SD=17.19$). Albeit the 12-point difference between the means, there was not a significant difference between the groups, $t(17)=1.70$, $p=0.11$ ($d=0.76$).

However, when comparing the gains within each group, there was a statistical significance based on the pre and post-test scores for the WR group, $t(11)=11.04$, $p<0.00001$ ($d=0.03$), as well as for the NR group $t(10)=8.25$, $p<0.00001$ ($d=3.7$). Both groups scored
consistent gains on the science, mathematics, as well as the vectoring and programming questions. For example, one of the concepts reflecting an increase in understanding was related to the definition of a vector. For that concept, the pre-test score on Q6 for both groups (n=20) was at zero level of understanding, compared to post-test scores showing the majority of participants in the WR (n=8) and NR (n = 6) groups scoring a 10.

**Depth of knowledge.** Upon determining how participants viewed their performance as a result of completing the design activity, and whether the use of a robot made a difference on understanding (based on activity scores), it was also important to characterize the depth of knowledge. Depth of knowledge was defined as the level of concept understanding using a 5-point rubric with 1 representing “shallow” level of knowledge and 5 a “deep” level (Newmann & Wehlage, 1995). To determine participants’ depth of knowledge, the results from the assessment of the journaling portion of the project reports, final reports, as well as review of session transcripts were used as evidence to produce ratings on this indicator. The results are reported on Table 4.4.

Overall, the group with the robots (WR) exhibited a higher than average depth of knowledge ($M=3.9, \text{SD}=0.39$) with five participants scoring in the 4.0 to 5.0 range. An example of depth of knowledge around the mean score of 3.9 would be a participant exhibiting a clear understanding of the STEM concepts underlying the activity by written elaboration, using STEM terminology (use of 2-3 terms) appropriately, describing how the problem was solved, and detailing how difficulties were overcome. For example, in response to why a team decided on a particular design, they responded “We decided to use pulleys made with string to pick-up the
load of the spacecraft because when we tried foil, it ripped. We needed something stronger to bring the spacecraft over the ravine and a pulley seems to work, and we can use it again without having to rebuild anything.”

By comparison, the group without the robots scored slightly lower (M=3.4, SD=0.22) with none of the participants scoring higher than 3.8. An example representing the mean rating of 3.4 for depth of knowledge would be minimal written use of STEM terminology (2 terms), and limited written explanation as to how the problems were solved. For example, “We used a pulley to pull it up, we tried other things like the pipe cleaners, but they didn’t work.”

**Table 4.4. Ratings for Depth of Knowledge Indicator.**

<table>
<thead>
<tr>
<th>Participants (n=10)</th>
<th>Working With Robots (WR)</th>
<th>Participants (n=10)</th>
<th>Working without Robots (NR)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Depth of Knowledge</td>
<td></td>
<td>Depth of Knowledge</td>
</tr>
<tr>
<td>1</td>
<td>4.5</td>
<td>1</td>
<td>3.5</td>
</tr>
<tr>
<td>2</td>
<td>3.9</td>
<td>2</td>
<td>3.8</td>
</tr>
<tr>
<td>3</td>
<td>3.6</td>
<td>3</td>
<td>3.6</td>
</tr>
<tr>
<td>4</td>
<td>3.1</td>
<td>4</td>
<td>3.5</td>
</tr>
<tr>
<td>5</td>
<td>4.1</td>
<td>5</td>
<td>3.4</td>
</tr>
<tr>
<td>6</td>
<td>4.1</td>
<td>6</td>
<td>3.6</td>
</tr>
<tr>
<td>7</td>
<td>3.7</td>
<td>7</td>
<td>3.1</td>
</tr>
<tr>
<td>8</td>
<td>4.1</td>
<td>8</td>
<td>3.2</td>
</tr>
<tr>
<td>9</td>
<td>4.0</td>
<td>9</td>
<td>3.4</td>
</tr>
<tr>
<td>10</td>
<td>3.5</td>
<td>10</td>
<td>3.2</td>
</tr>
<tr>
<td>M</td>
<td>3.9</td>
<td></td>
<td>3.4</td>
</tr>
<tr>
<td>SD</td>
<td>0.39</td>
<td></td>
<td>0.22</td>
</tr>
</tbody>
</table>

Albeit the slight difference in mean ratings, when comparing the two groups, there was a significant difference, $t(13)=3.02$, $p=0.01$ between the means for depth of knowledge ($d=1.58$). That is, the WR group appeared to have had a little edge providing fuller explanations of the work in writing, using appropriate STEM terminology, and elaborating on the details of their design solutions.
Impact on STEM Attitudes

Research question three examined participants’ attitudes towards STEM as well as their interest in pursuing careers in related fields. The Student Attitudes Towards STEM Survey (S-Survey) developed by the Friday Institute (2012) was used to determine impact of participation on the design activity on attitudes toward STEM. The survey features two components. STEM interest and Your Future. The STEM component focuses on participant perceived self-efficacy in science, technology and engineering, mathematics (STEM); and Your Future refers to interest related to STEM careers. Both groups took the pre- and post-surveys in the same room at the same time. An outside proctor administered both surveys.

Pre/post survey data were analyzed first using an Independent T-Test. Since the two distributions had a similar shape it was determined that a Mann-Whitney test was better suited to compare the medians of the dependent variable for the two groups on the independent variable. This was performed for each question for both the pre- and post-activity survey responses. A T-test for two-dependent means was then performed to compare the scores pre- and post-survey scores between groups.

As reported on Table 4.5, with the exception of technology and engineering, both groups began their participation with almost identical perceptions of self-efficacy on science, mathematics, and future aspirations. Regarding technology and engineering, the “with robots” group showed a slightly higher mean ($M = 4.3, SD = 0.39$) on this indicator compared to the “without robots” group ($M = 3.6, SD = 0.61$). Thus, when comparing the pre-survey results between groups, there were no statistical differences on the math, science, or your future portion of the survey. There was only a slight statistical difference in the pre-survey on the engineering and technology portion, $t(17) = 2.20, p = 0.04$ ($d=1.03$). For example, on question 18, the
majority of the participants (n=8) in the WR group “strongly agreed” that they “liked to imagine making new products” signaling a slightly higher level of self-efficacy associated with engineering and technology grounds.

Table 4.5. Ratings for Indicators of STEM Attitudes as Defined by Participant’s STEM Attitudes Survey - PRE.

<table>
<thead>
<tr>
<th>Working with Robots (WR)</th>
<th>Working Without Robots (NR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants (n=10)</td>
<td>Math</td>
</tr>
<tr>
<td>1</td>
<td>3.4</td>
</tr>
<tr>
<td>2</td>
<td>3.0</td>
</tr>
<tr>
<td>3</td>
<td>3.4</td>
</tr>
<tr>
<td>4</td>
<td>3.3</td>
</tr>
<tr>
<td>5</td>
<td>3.8</td>
</tr>
<tr>
<td>6</td>
<td>3.3</td>
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<tr>
<td>7</td>
<td>3.1</td>
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<tr>
<td>8</td>
<td>3.0</td>
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<tr>
<td>9</td>
<td>3.4</td>
</tr>
<tr>
<td>10</td>
<td>3.1</td>
</tr>
</tbody>
</table>

Note: Responses for the Math, Science, and Technology section were recorded on a 5-point Likert Scale, Your Future was based on a 4-point Likert Scale.

Upon completion of the design activity, the “with robots” group reported slightly higher levels of self-efficacy on math, science, technology and engineering, and related future aspirations (Table 4.6) compared to pre-survey results. Although the pre- and post-survey mean differences were modest, the results were statistically significant for the math portion of the survey, \( t(16) = 2.22, p = 0.04 \) \((d=0.96)\). However, there was no significant difference on the science, \( t(17) = 1.55, p = 0.14 \) \((d=0.59)\), engineering and technology, \( t(13) = 1.62, p = 0.13 \) \((d=0.68)\), or on the “Your Future” section of the survey \( t(17) = 0.78, p = 0.44 \) when comparing pre- and post-survey results \( (d=0.62)\). Therefore, even though this group demonstrated a higher level of self-confidence in math, their overall confidence or interest in STEM careers did not change.
In contrast, based on an examination of pre- and post-survey scores, the “without robots” (NR) group showed a modest decrease in efficacy in the math, science, and engineering and technology components of the survey as reported in Table 4.6. The slight mean differences in the post-survey for math, \( t(12) = 1, p = 0.36\) (\(d=0.47\)), science, \( t(12= 0.90, p = 0.38\) (\(d=0.53\)), and engineering and technology, \( t(13) = 0.75, p = 0.46\) (\(d=0.31\)), resulted in no significant differences. The post-survey scores on the career aspirations component (Your Future) remained unchanged and thus not significantly different (\(d=0.00\)).

**Table 4.6.** Ratings for Indicators of STEM Attitudes as Defined by Participant’s STEM Attitudes Survey - POST.

<table>
<thead>
<tr>
<th>Working with Robots (WR)</th>
<th>Working Without Robots (NR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants (n=10)</td>
<td>Math</td>
</tr>
<tr>
<td>1</td>
<td>3.8</td>
</tr>
<tr>
<td>2</td>
<td>3.6</td>
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<tr>
<td>3</td>
<td>3.5</td>
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<td>4</td>
<td>3.5</td>
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<td>3.5</td>
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<td>7</td>
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<td>3.4</td>
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<td>9</td>
<td>3.5</td>
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<tr>
<td>10</td>
<td>3.5</td>
</tr>
<tr>
<td>(M)</td>
<td>3.5</td>
</tr>
<tr>
<td>(SD)</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Note: Responses for the Math, Science, and Technology section were recorded on a 5-point Likert Scale, Your Future was based on a 4-point Likert Scale.

In turn, when comparing post-survey results between groups, the only statistically significant difference between the groups was noted on the engineering and technology portion of the survey, \( t(10) = 3.5, p = 0.002\) (\(d=1.56\)). The post-test mean for the “with robots” group on the engineering and technology section was 4.7 (\(SD = 0.39\)), while the mean for the “without robots” group was 3.3 (\(SD = 1.21\)).

In general, it appeared there was a slight boost in self-efficacy in math, science, and engineering and technology associated with the use of robots in instruction. The use of robots, in
particular, resulted in a slightly significant difference on engineering and technology self-efficacy when compared to the mean score on the same indicator for the group not using a robot. Upon completion of the design activity, almost all participants (n = 9) in the “with robots” group rated their self-efficacy with either a 4.0 or 5.0 rating. In contrast, participants in the group “without robots” rated their self-efficacy ranging from 1.0 to 5.0 with an average of 3.3.
CHAPTER FIVE: CONCLUSIONS, DISCUSSIONS, AND IMPLICATIONS

In this chapter the results of the study are summarized, followed by a discussion of major findings, and implications for practice and further research.

Conclusions

The primary purpose of this study was to determine whether the use of educational robots has an impact on Science, Technology, Engineering, and Math learning and attitudes in the context of elementary education. To address this purpose, three research questions drove the study. The first question addressed the interactive process. For instance, to what extent were participants engaged in authentic and active learning? The second research question was set to characterize the understanding of STEM concepts underlying the design activity. That is, did participants demonstrate their knowledge of these concepts? Also, how did participants apply STEM concepts to complete the design activity? Finally, the third research question focused on whether the participation in the design activity had an impact on participants’ attitudes towards STEM as well as on related careers.

The interactive process. How do elementary school students interact with an educational robot to design and test problems? This was the underlying research question in the context of a design activity and in comparison to a group of participants not using a robot. In this regard, while the results were slightly higher for the group working with robots (WR), both
groups showed a relatively high level of involvement within the interactive process defined by extent of engagement, substantive conversation and knowledge production.

On the first day, all participants sat together for the introduction of the activity. Questions were asked by individual participants only; they had not been put into teams. By the second day, participants began working with their teammate, which were selected at random. Overall, all teams within both groups were very quiet and it was hard to hear their conversations with the exception of the WR group who quickly came together as a team to learn to program the roamer. This activity seemed to help the WR group develop a team approach faster than the group without the robot (NR). By day three, all teams in both groups were well on their way to coming up with a design they felt would work. Both groups tended to move away from other teams at this point so as one participant put it “no one would copy them.” As focus on the process increased, it became important for them to hide their built design from others. Confidence regarding their design began to grow and on day four, the teams were ready to begin testing. Since they were not allowed to test at the actual “rescue site”, many teams in both groups built a model of the site for testing within the areas they had created. Conversation within teams became extremely focused on interpretation and explanation of results to re-design their model as participants put it to “get it to work” or “make it better.”

When finally day five came, all teams were excited to test their designs. Participants showed high levels of interest in all of the designs, asked questions constructively, used appropriate STEM terminology, speculated on what and why a particular design worked or didn’t work. All in all, with the exception of the indicator on substantive conversation, there were no differences on level of engagement and knowledge production characterizing the nature and extent of the interactive process.
Specifically, regarding student engagement, the analysis of results revealed a high level of focus throughout the activity for both groups. Cohen’s effect size value \( (d=0.89) \) suggested a large practical significance. Even though participants actively moved around the room, and there was considerable use of manipulatives, no disciplinary problems were noted in either group. Documented through field notes and instructor’s feedback, participants were excited to come to the activity and did not want to leave when the session was over. In the activity, participants remained focused and on task and worked well within teams, even though they may not have known their teammate prior to the study since teams had been randomly formed with participants that may or may not have been in the same classroom. Regardless of the gender matching in teams (same or mixed gender), all teams worked well together and remained eager to participate in the activity. For example, participants often expressed concern regarding the date and time of subsequent sessions, to make sure they would not miss any sessions.

About knowledge production, participants within and between groups showed similar interactions associated this indicator. Cohen’s effect size value \( (d=0.58) \) suggested a moderate effect size. Initially, there was concern that the participants working with the robots would just want to “play” with the Roamer robot and their attention to the task would get diverted since each team had a robot available to them in their work area. In this case, even though there was a tendency to decorate or “dress” the robot, once the initial “novelty” of the programming wore off, the participants utilized experimentation with the robot strictly to solve the task at hand (e.g., knowledge production/application). In other words, they saw the robot as a tool to assist them in completing the activity successfully, with no apparent gender differences regarding preferences for robot decoration. To this end, teams were prone to give the robot a personality that related in some way to the method of the rescue. For example, an “alien rescue” created an alien robot. A
more traditional type of rescue had the roamer decorated more like a tow truck driver. However, if participants determined that the decoration was getting in the way of the rescue, they removed it. This demonstrated that participants with the robot were able to reason that even though the decoration was “nice”; solving the task was the primary goal. This finding was verified by many journal entries in both groups showing knowledge production and application emphasizing the need to overcome load issues, which were solved by reducing amount of materials (e.g., decorations). To wit, when a team was asked why the flags on the team’s “trailer” had been removed, one of the team members replied, “because they got in the way of our pulley and they weren’t important anyway.” In short, it was noted during the activity that participants in both groups were able to use the information they researched on their own or had available in their journals, and/or manipulate materials to find a solution to the design problem.

The only differences noted between groups were on the extent of substantive conversation. The effect size for this analysis ($d=0.99$) was found to exceed Cohen’s convention for a large effect ($d=0.80$). Although a review of video recordings and field notes indicated a considerable amount of substantive conversation within teams in both groups, the level of conversation was one level higher in the WR group. In general, almost all conversations were about how to design and build something that would successfully rescue the spacecraft and stay within budget calculations. Throughout the activity, as participants increased their knowledge production, they also enhanced their use of appropriate terminology in their conversations. In this regard, it was also noted—as reported by homeroom teachers—that participants even carried related conversations back to their traditional classrooms after activity sessions. Albeit, the generally high level of conversation in each group, participants in the WR group showed a higher
level of substantive conversation perhaps added by the novelty and programming requirements of the robot, as compared to participants in the NR group.

**Understanding of STEM concepts.** *Does interacting with an educational robot impact the understanding of STEM concepts?* Regarding this question, the results indicated that both groups showed a comparable high level of self-efficacy completing the project and related learning as well as on understanding and knowledge of STEM concepts, and slight differences in depth of knowledge.

To assess their own assessment of success and learning efficacy, participants reported their perceptions of success and satisfaction completing the project. In this regard, a comparison of the mean composite level of agreement with project completion statements demonstrated no significant difference between the groups. In fact, the WR group had a slightly lower degree of perceived performance on the activity. Cohen’s effect size ($d=0.53$) suggested a moderate significance. The lower self-assessment score for the WR group may be due to the added difficulty level associated with learning to program the robot. The differences were minimal though and, in general, both groups reported a high level of satisfaction with both their performance as well as their satisfaction completing the activity. Given these results, it was concluded that both groups felt they had been successful completing the project and were satisfied with their performance. These results align with research on authentic instruction by Newman, Secada, and Wehlage (1995), as well as the *ERA principles* as outlined by Catlin (2012). That is, when participants are engaged in relevant and active learning, they are most likely to enjoy instructional tasks and report high levels of self-efficacy.

Next, to determine actual level of STEM concept understanding, the analysis of STEM exam scores showed the participants in the WR with a slightly higher post-test mean score ($M =$
65.5) compared to that of the NR group (M = 53.0). Despite the 12-point difference, the discrepancy was not statistically different. However, Cohen’s effect size (d=0.76) suggested a moderately high significance. That is, the nature of the design activity with or without the use of an educational robot was similarly interesting and relevant for participants, and resulted in comparable results on learning measures.

To further characterize the nature of conceptual understanding, participants’ project was further analyzed to assess depth of knowledge. On this indicator, which provides an idea of participants’ ability to elaborate and explain what they are learning, there was a significant difference between the two groups. Cohen’s effect size value (d=1.58) suggested a large practical significance. Although the difference was small, the WR group was found to utilize STEM terms more frequently that the NR group. This might be due to the increased use of technology associated with the robot. To solve the design problem, participants in the WR group were more apt to discuss utilizing STEM terminology and the details of programming the robot. This result also aligns with the principles of educational robotics (Catlin & Balamires, 2007) suggesting that the use of robots fosters multimodal interactions within a semiotic system.

Overall, as Alemdar and Rosen (2011) contends, this method of integrated learning of skills, knowledge, and curriculum shows potential as an effective STEM teaching tool.

In summary, regarding conceptual understanding, there were no differences in self-evaluations of project performance or in the mean scores on the activity test. Nevertheless, the depth of knowledge demonstrated by participants in the WR group resulted in significant difference although the gap was small.

Impact on attitudes toward STEM. Does interacting with an educational robot impact attitudes towards STEM? The results addressing this question indicated that overall, there was
no significant difference between the teaching with robots group (WR) and the teaching without robots (NR) group when examining attitudes toward mathematics, science, and future aspirations, with moderate effect sizes in these areas. There was a significant difference though, between groups regarding attitudes toward engineering and technology in pre-test scores, which carried forward to post-test scores. The effect size for this analysis ($d=1.56$) was found to exceed Cohen’s convention for a large effect. When examining results within groups, the WR group showed significant differences in pre- and post-test scores in attitudes toward mathematics, but no differences in science, engineering and technology sections, and related career aspirations. Cohen’s effect size value ($d=0.96$) suggested a large practical significance with the math portion of the survey. By comparison, the NR group showed no differences in attitudes toward STEM disciplines or interest in related careers. Differences in attitudes toward engineering and technology between the groups may be due to the use of the robot within the WR group. Overall, both groups had a higher than average interest in STEM and related careers based on pre- and post-tests.

**Discussion of Results**

Given the small sample size and short duration of the study, the results are not generalizable. However, the results tend to confirm the value of authentic instructional strategies and showed promising evidence about the use of educational robotics in elementary education, and impact on STEM attitudes and related career aspirations.

**Role and value of authentic instructional strategies.** Based on the premises of the framework underlying the study, STEM learning and attitudes in elementary education can be boosted through instructional strategies allowing participants to logically sequence learning tasks
(cognitive principle), engage in active and relevant learning (constructivist principle), and produce their own knowledge through hands-on activities (constructionist principle) (Piaget, 1983, Huitt, 2003, & Papert & Harel, 1991). In 1995, Newmann and Wehlage released a landmark report on indicators of school success promoting student learning, capturing the premises of the conceptual framework under the rubric of authentic instruction and learning. Newmann and Wehlage (1995) suggested that when students are engaged in authentic learning focusing on construction of knowledge, disciplined inquiry, and value beyond school, they are able to exhibit active engagement along with the transfer of knowledge. As alluded to by Newman, Secada, and Wehlage (1995), instructional tasks that are engaging and relevant promote higher order thinking and problem solving, and boost student motivation to remain engaged in their own learning.

Overall, the results of this study align with the research on authentic instruction based on cognitivist, constructivist, and constructionist premises. In this study, the results were comparable for both groups suggesting that in the context of a well-designed instructional activity, the use of a robot has only marginal impact. That is, in the context of “good” instruction, materials and equipment needed for the completion of a design task may become incidental mediating tools. What matters is that the instructional tasks involve opportunities for student engagement in relevant learning such as the completion of a design problem (Newmann & Wehlage, 1995; Newmann et al., 1995).

Under these premises, the results of this study also support the notion that STEM concepts can be promoted through authentic instructional activities in elementary education context. To wit, participants were presented with a problematic situation (i.e., design activity) requiring the production of their own knowledge, applications of problem solving skills, and
substantive conversation to interact and share what they knew in the process of arriving at a solution. The nature of the design activity provided the conditions for student motivation to remain engaged, to ask good questions, provide explanations, and test their ideas in the context of STEM concepts.

Albeit the group working with the robots did not exhibit significantly different results when compared to the groups without robots, it should be noted that the challenge of learning rudimentary programming skills was an added challenge and benefit to this group. Regardless of their group assignment though, participants experienced a high level of satisfaction with the activity and clearly demonstrated their understanding of the STEM concepts underlying the design problem. The design task gave participants the opportunity to sequentially test their solution utilizing the technology available to them and obtain immediate feedback to inform their knowledge production. As noted in the literature, this type of learning environment is a key aspect to a successful STEM oriented classroom (Riberio, et. al., 2008).

**Promising evidence on the use of educational robotics.** While the results between the two groups were generally similar, there were promising tidbits of evidence suggesting the potential impact and benefits of using educational robotics in elementary education. In this case, participants in the WR group demonstrated a higher level of substantive conversation and a slightly higher level of depth of knowledge. It can only be speculated that, perhaps, an activity of longer duration may have resulted in more defined differences. Nevertheless, it was the group working with the robots (WR) that had higher gains in the understanding of STEM concepts. Further, participants were also exposed to programming skills that may have not been otherwise introduced in regular classroom instruction. In addition, it was observed that the additional programming task provided increased interest and relevance when using the robot and clearly
boosted participants to personalize the use of technology (e.g., decorating the robots). Handling interactive technology (i.e., the robot) provided a bridge between the abstract and concrete and created an authentic activity connecting the classroom experience to the real world.

Indeed, both the facilitator and the researcher noted that through the use of the educational robot, participants were more apt to create their own world (e.g., using decorations and modeling sites to test their programming solutions). This was an expected outcome that directly correlates to the literature (Papert, 1980) regarding how students relate and apply that relationship to educational robots. This approach to learning also addresses the three areas within the conceptual framework. Again, construction and building of knowledge was demonstrated by the decoration of the robot into activity specific characters. This is in line with the underlying framework of this study positing that educational robots provide emotional engagement leading to positive engagement as students work on STEM-based design problems (Catlin, 2013).

The promising use of robotics in context of elementary education identified in this study aligns with the Educational Robotic Application (ERA) Principles set forth by Catlin and Balmiris (2010), which views the use of a robot as a mediator to learning through a fluid interaction between the robot, participant, and facilitator. In this study, for example, participant had to work with each other as well as with the facilitator to learn to program the robot. Once the technology associated with the programming skills for the activity was mastered, the robot became a tool to solve the problem at hand and provided the grounds for substantive related conversation. For example, the following is a typical conversation between participants in a team working with a robot:
Participant 1: “Hey, do you remember how to turn the robot.”

Participant 2: “I think so, how far do you want it to turn?

Participant 1: “Umm, 90 degrees, I think.”

Participant 2: “Which way?”

Participant 1: “To the right, after I vector forward 3 units.”

Participant 2: “OK, let’s try this….”

Participant 1: “OK, don’t forget to clear the memory first, I will write it down as you program.”

This type of interaction represents evidence of productive student engagement, and sustainable learning, as well as substantive conversation. Thus, the use of the robot appeared to have added benefits in metacognitive skills required to accomplish their task as noted in the related literature (LaPagila, Rizzo, & LaBarbera, 2011).

**Impact on STEM attitudes and related career aspirations.** In general, there were no differences between the two groups on attitudes toward mathematics, science, and future aspirations. However, there were differences on attitudes toward engineering and technology with the WR group showing a higher level on attitudes and related career interest. Further, while the NR group showed no differences in pre- and post-attitudes and career interests, the WR group showed enhanced attitudes toward STEM upon completion of their project. Interest in related careers remained the same for the WR group though. These results suggest support for the potential impact of robotics on attitudes toward STEM.

In elementary school, the use of educational robots may represent the first time students are exposed to this type of technology. This early exposure is aligned with the importance placed by Carbonaro, Rex, and Chambers (2004) on the shift from learning from technology towards
learning with technology. It also aligns with the movement to promote STEM education earlier in schools, especially in elementary education.

As noted by the American Competitive Initiative (ACI, 2003), the skills required to succeed in the world of work will require STEM knowledge and skills, as well as strong critical thinking skills. With an ever changing global and technological world, students will need to make sense of these new experiences and apply it to their own environment. In this regard, the use of educational robotics has the potential to create a seamless connection to STEM. For example, the use of robotics could be applied more broadly in mathematics and science instruction. The Roamer Too can be used to help students applying math in the form of estimation and measurement, not for the sake of getting a problem correct, but to accomplish an interdisciplinary task. In other words, the robot can be used to help students understand applications in the context of problems that may be posed in the context of STEM occupations to promote related career awareness as well. This notion is supported by the work of Papert (1980), suggesting that this type of applications will help students realize how natural math is and how they are natural mathematicians.

The use of robots as a technology application is an approach that also falls in line with the new skill sets demanded in the modern workforce. On the job, employees are required to successfully integrate a variety of skills. While traditional academics has been taught utilizing a silo approach, STEM education focuses on interdisciplinary applications in relevant contexts and the application of problem solving skills needed of the current and future workforce. This is true even for careers that have been categorized as “non-STEM” (Carnevale, Smith, & Melton, 2011).
On this note, the high level of self-efficacy with the group working with the robots in the area of attitudes in engineering and technology should be noted. As Ribeiro, et al. (2008) indicated, the use of robots in design activities encourages further exploration of related fields. This is particularly relevant for students who may have had little to no exposure to these fields, as with the participants in this study. As such, at the elementary school level, using robotics in design activities should promote their awareness about engineering and technology and related careers (NAP, 2007).

**Implications for Practice and Further Research**

Based on the results, and taking into consideration the limitations of the study, some important implications for practice and further research were identified.

**Limitations.** To put implications for practice and further research in proper context, it is critical to identify key limitations in this study. First, the study was conducted in a single school with a small sample size of 10 (n=10) participants in each of the two groups for a total of 20 participants (n=20). While a small sample was required for access to participants, and allowed the researcher closer observations of interactions, a larger sample size (e.g., whole classrooms) may have yielded more robust data to gauge more accurately differences within and between groups and enhance the generalizability of results.

Another limitation was that, even with a small sample size, the nature of the activity made it difficult to record and take field notes on participants’ interactions (e.g., conversations). Since participants spread out all over the room, the only way to document a conversation was to go directly over to the team. This may have inhibited participant discussion. An audiotape machine was placed inconspicuously near the materials table to record discussions at this spot,
which were concerned with the design process and math calculations, but it was limited to that particular spot. Also, the facilitator found herself in this area throughout the activity to answer specific questions associated with the materials, which in some cases prevented active and/or accurate note taking.

Further, participants’ academic scores (i.e., state standardized test scores) along with gender or socio-economic variables were not included as part of the analysis in the study. The exclusion of related data was at the request of the school district. In addition, the short duration of the activity may have also contributed to the observed differences within and between groups. As previously described in the literature review, it has been reported that it is difficult to assess learning gains when using educational robotics in the context of constructivism and constructionism strategies (Papert and Harel, 1991). This may be particularly true for short instructional activities preventing the expression of larger differences on learning and especially on STEM attitudes requiring longer stimuli.

Finally, in both groups, the participants’ reaction to paper and pencil evaluations were unenthusiastic. Although participants were told that their responses were important but that they would not factor into their school grades, they expressed reluctance to taking the STEM Survey again at the end of the activity. Even though this survey was purposely designed to this grade level, participants stated that the survey was too long and there were “a lot” of words, and “boring”. Participants may have simply just filled in the blanks to get through with the survey. Also, this was the final written assessment of the day. Participants had already completed the STEM exam, their project and final reports, as well as their journals. This may have been too much assessment for the participants in one day and thus influenced the fidelity of responses.
Implications for practice and further research. Based on the results of the study and the limitations noted above, several implications for practice and further research are noted. Regarding practical implications, given the promising nature of constructivist and constructionist instructional activities, the results of the study suggest that teachers may benefit from related training to carry on design activities in the classroom. As demonstrated in this study, with related basic training, it is possible to deliver authentic instructional activities even without the use of educational robots. In support of related implications for practice, the facilitator—who is employed as a teacher at the school—stated that in the four years she had been there, nothing close to this type of authentic activity had ever been conducted at the school. In fact, she stressed, that the majority of the teachers had no related training on authentic instruction view related activities as involving too much work. This view clearly suggests an opportunity for professional development on authentic instruction.

Regarding the use of educational robots in the elementary classroom, the results of this study suggest that it may be feasible to integrate related technology in elementary education. As observed in the study, discipline was not an issue. As a matter of fact, the facilitator viewed participant engagement as remarkable. Further, given the relatively low cost of new robots (e.g., Roamer Too), educational robots can be shared among classrooms in all grades making them a an affordable method of technology oriented content delivery, while introducing STEM concepts at the elementary level.

Regarding implications for further research, based on the results and limitations of the study, the following recommendations are suggested. One suggestion is to repeat this study utilizing a larger sample size such as whole classrooms in one or multiple school sites. Further, If possible, it is also recommended to account for background variables such as gender,
socioeconomics, as well as prior academic achievement. In turn, qualitative analysis of participant interactions with educational robots focusing on specific tasks may yield more granular understanding of the interactive process. Along these lines, it may also prove fruitful to research authentic instructional strategies in integrated context involving teams of teachers (e.g., mathematics, science, and reading teachers) to characterize how students transfer and applied STEM concepts across disciplines. By the same token, further research is warranted in the context of longer instructional activities involving educational robots such as unit or capstone projects, or in the context of entire programs (e.g., career academies) in comparison to control groups. Other recommendations for further research include the study of attitudes toward STEM and related careers comparing the use of robots in technical education as well as in traditional lecture based academic programs.
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Appendix A: Spacecraft Rescue Student Worksheets
Spacecraft Rescue

Our spaceship has crash landed in a ravine. First reports suggest that the damage is not severe. The bulk of the spaceship is in tact and can be rescued. It has a valuable cargo and you must get to it quickly before the Jawas’ find and loot it. You will need to build a special structure to lift the spaceship onto the rescue robots and safely bring it back to the repair base. You can only land your team on salt flats about 20 km from the ravine. It is treacherous terrain and you have to find a quick and safe route to the crash site and back.

Unfortunately the company is trying to cut costs so you must perform the rescue within strict economic restraint. This means submitting your structural design and travel route to the chief accountant for approval, before you set off on the rescue journey.

1. Jawas are technology scavengers native to Luke Skywalker’s home planet of Tatooine.

Mission Brief

1. To design and build a structure to aid in the recovery of a spacecraft.
   - Your structure has to span the 0.7m ravine and is 0.2m deep.
   - You need to lift the spaceship 0.3m.
   - The spacecraft weighs 0.5kg.

2. You must execute the rescue as economically as possible.
   - You must submit a rescue plan to accounts for their approval.
   - Your plan must include:
     - A sketch of your structure complete with a loading diagram
     - A route plan and the program required by rescue robot to complete the recovery
     - The material cost of the structure.
     - The cost of erecting the structure.
     - The cost of any trailer you need to build to transport the structure to the site and return the spacecraft to base.
     - The transportation costs of travelling from the base to the site and back to base.

3. You must implement your rescue plan and submit a report to accounts.
   - Your report must include any changes to your plans.
   - It must include the extra costs incurred as a result of those changes.
Spacecraft Rescue

Get Organised!

There is a lot of work to do.

You can’t do it by yourself. You need team work!

Select a Project Manager

1. Structure
2. Robot
3. Budget

Break the project into tasks. Assign people to the tasks.

Book of Structures

Quickly look at the Invents Book of Structures. This will help you understand structures and give you ideas.

Places to Look

Basic Ideas Section 2
Loads, materials, stress and strain, how structures fail and structural stability.

Basic Structural Parts Section 3
Ties, columns, struts and beams.

Structural Ideas Section 5
Arches, Vaults, Domes, the Butress, Beams, the Truss, frames, space frames, ropes and catenaries, bicycle wheels and dishes, slabs and plates, folded plates, formed structures, Fabric and membrane structures, inflated structures and dynamic structures.

How to Improve Structures Section 4
Materials, composite materials, size, shape, arrangement, avoiding the load, spreading the load, supports and fixings and ribs and stringers.

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Spacecraft Rescue

Forces and Stress

Do this with a friend.

What type of force is this?

Which makes your arms longer?

Which makes them shorter?

What type of force is this?

What stress is involved?

What you will need

1. 1 short link clip.
2. 1 long adaptor pin.
Spacecraft Rescue

Basic Structures 2

What happens when I push down?

How do these structures relate to those on page 4?

How can I improve the structure?

What happens with this structure?

How does this structure work?

What you will need
1. 6 short link strips.
2. 2 short adaptor pins.
3. 3 x 5mm dowel.

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Spacecraft Rescue

Basic Structures 3

Why is this not a good structure?

What is the new structure called?

Use link strip or canal to improve it.

What you will need
1. 4 long link strip.
2. 4 x 5mm dowel; 10mm long.

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Spacecraft Rescue

Tent Structures

What you will need
1. 1 End adaptor
2. 1 Straight adaptor
3. 6.0cm. Sewn dowel
4. String
5. Wood board

Catenary Structures

What you will need
1. 1 Long length strip
2. 2 Short length strips
3. 1 Long adaptor pin
4. 60cm string
Spacecraft Rescue

Beams

Can you think of a way to make this bend less?

Make a structure like this.

What is that structure called?

What is it called and how is it like the other structure?

What you will need
1. Inertia board.
2. Wood strip.
3. Adaptor pins.
4. Link rings.

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Strength from Shape

What happens if you do this with paper?

Make it into a structure.

What load can it take?

Make a stronger structure. You can use other materials.

Compare the weight of the structure and the load taken.

What you will need
1. Several sheets of A3 paper.
2. 2 blocks (blocks could be used)

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Spacecraft Rescue

Struts and Columns

Stand the paper on its edge. What happens?

Can you make it into a structure?

Remember: Structures support loads — and stand up!

What you will need
1. 2 sheets of A3 paper.
2. Adhesive tape or paper glue.
3. Some small weights.

How can you make your structure stronger?

How much load can your structure take?

Paper Engineering
Spacecraft Rescue

Paper Engineering

Spacecraft Rescue

Loads on a Structure

Your structure needs to safely carry the load of 0.5 kgf. Your report should include:

1. A load analysis in the main parts of your structure
2. Identification of structural member carrying the heaviest load
3. Vector diagrams showing the load distribution

You can use algebraic or graphical methods to calculate the loading vectors.
Spacecraft Rescue

Transportation
One aspect of transportation is the navigation from one location to another. You also need to consider how you carry the structure to the ravine and how do you return with the spacecraft?

Or perhaps a carrier to go on the top of Roamer.

Perhaps you want to build a trailer to drag behind Roamer.

Navigation Vectors

All other keys have their Standard Junior Roamer Functions.

$V_F$ is the Navigation Vector makes the Roamer move forward.

$V_{FL}$ is the Navigation Vector to make the Roamer move off to the left.

The subscripts have the normal meanings of forward, back, left and right.

Each vector is a unit vector so the command $V_F$ 5 has a magnitude of 5 in the direction defined by $V_F$.

The program:

$V_F 4 + V_L 4$ represents a vector addition.

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Spacecraft Rescue

Programming Roamer

Your Roamer is a special activity Roamer called a Vector Roamer. Many of the functions are just the same as any other Roamer - but it moves using Vector keys.

Watch the video Roamer Basics:

Here you see the program, the equation and a graphical representation of the Roamer’s movement.

Try out some programs until you think you understand how it works.

Robot Route

Find the following:

1. The magnitude of the shortest possible route from Base to the load in the ravine.

2. The shortest possible route, avoiding the obstacles.

Write a vector equation for your proposed route.
### Material Costs

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Sheet of Paper</td>
<td>$1.00 each</td>
</tr>
<tr>
<td>2 Sheet of Cardboard</td>
<td>$2.00 each</td>
</tr>
<tr>
<td>3 Sheet of Plastic</td>
<td>$5.00 each</td>
</tr>
<tr>
<td>4 Corrugated Cardboard</td>
<td>$4.00 per cm</td>
</tr>
<tr>
<td>5 Wood Strip</td>
<td>$3.00 per cm</td>
</tr>
<tr>
<td>6 Link Strip</td>
<td>$1.00 per cm</td>
</tr>
<tr>
<td>7 Wood Dowel</td>
<td>$2.00 per cm</td>
</tr>
<tr>
<td>8 5mm Plastic Tube</td>
<td>$1.00 per cm</td>
</tr>
<tr>
<td>9 7.5mm Plastic Tube</td>
<td>$1.50 per cm</td>
</tr>
<tr>
<td>10 Straws</td>
<td>$0.50 per straw</td>
</tr>
<tr>
<td>11 String</td>
<td>$0.50 per m</td>
</tr>
<tr>
<td>12 Thread</td>
<td>$0.25 per m</td>
</tr>
</tbody>
</table>

Cost of all other components (Pins, Blue Tac, Nuts and Bolts) = $0.10
Cost of staples = $0.01 each
Cost of elastic bands, adhesive tape and glue = $0.05 per application.

### Manufacturing Costs

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Drill or Punch a Hole</td>
<td>$0.50 per hole</td>
</tr>
<tr>
<td>2 Cut with a Hacksaw</td>
<td>$0.50 per cut</td>
</tr>
<tr>
<td>3 Cut with Scissors</td>
<td>$0.10 per cut</td>
</tr>
<tr>
<td>4 Fold</td>
<td>$0.05 per fold</td>
</tr>
<tr>
<td>5 Rolling Paper or Card</td>
<td>$0.05 per roll</td>
</tr>
<tr>
<td>6 Staple</td>
<td>$0.01 per staple</td>
</tr>
<tr>
<td>7 Glue</td>
<td>$0.20 per joint</td>
</tr>
<tr>
<td>8 Tie string</td>
<td>$0.01 per knot</td>
</tr>
<tr>
<td>9 Use Nut and Bolt</td>
<td>$0.50 per cm</td>
</tr>
<tr>
<td>10 Push Pin</td>
<td>$0.10 per pin</td>
</tr>
<tr>
<td>11 Adhesive Tape</td>
<td>$0.05 per use</td>
</tr>
<tr>
<td>12 Elastic Bands</td>
<td>$0.01 per band</td>
</tr>
<tr>
<td>13 Blue Tac</td>
<td>$0.15 per use</td>
</tr>
</tbody>
</table>

### Cost Calculations

Total Costs = Material Costs + Manufacturing Costs + Transport Costs

#### Transport Costs

- Allow $5 for every metre travelled.
- Charge pro rata for part metres.
- Surchage $1 for each major structural element transported.
- Surchage $5 for transporting an assembled or part assembled structure.
- Surchage $5 for transporting the spacecraft back to base.

### Notes

- Staples, tape, pins etc. do not count as major structural elements.
- String does count if it is used as a structural element (e.g. in a catenary)
- String does not count as a structural element where it is used to join parts together.
## Spacecraft Rescue

### Material Costs

<table>
<thead>
<tr>
<th>Type</th>
<th>Size</th>
<th>Unit Cost</th>
<th>Total Cost</th>
</tr>
</thead>
</table>

**Total**

### Manufacturing Costs

<table>
<thead>
<tr>
<th>Type</th>
<th>Size</th>
<th>Unit Cost</th>
<th>Total Cost</th>
</tr>
</thead>
</table>

**Total**

### Transport Costs

<table>
<thead>
<tr>
<th>Type</th>
<th>Size</th>
<th>Unit Cost</th>
<th>Total Cost</th>
</tr>
</thead>
</table>

**Total**

### Cost Area

<table>
<thead>
<tr>
<th>Cost Area</th>
<th>Cost ($)</th>
<th>Total ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacture Cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transport Cost</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Total**

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Final Report

Please circle your answer and describe your response in the area below:

<table>
<thead>
<tr>
<th>Strongly Agree</th>
<th>Neither Agree or Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

1. The spacecraft was rescued.

2. The project came in on budget.

3. The mission was completed on time.

---

Spacecraft Rescue

**Final Report**

**Summary**
Did you:
1. Rescue the spacecraft?
2. Did your project come in on budget?
3. Did you complete the mission on time?

**What did not work?**

**What worked best?**

**How could you improve your performance?**

---

© June 2012 Dave Catlin and Neil Cooper Drawings by Malcolm Livingstone

www.valiant-technology.com
Please circle your answer and describe your response in the area below:

<table>
<thead>
<tr>
<th>Strongly Agree or Disagree</th>
<th>Neither Agree or Disagree</th>
<th>Strongly Disagree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. The project was enjoyable
   1   2   3   4   5

2. We worked as a team.
   1   2   3   4   5

3. I learned a lot
   1   2   3   4   5
Appendix B: Student Attitudes Toward STEM Survey (S-STEM)
Student Attitudes toward STEM Survey (S-STEM)

Upper Elementary (4-5th)

Last Updated October 2012

Appropriate Use
The Upper Elementary School (4-5th) S-STEM Survey is intended to measure changes in students’ confidence and efficacy in STEM subjects, 21st century learning skills, and interest in STEM careers. The survey is available to help program coordinators make decisions about possible improvements to their program.

The Friday Institute grants you permission to use these instruments for educational, non-commercial purposes only. You may use an instrument as is, or modify it to suit your needs, but in either case you must credit its original source. By using this instrument you agree to allow the Friday Institute to use the data collected for additional validity and reliability analysis. The Friday Institute will take appropriate measures to maintain the confidentiality of all data.

Recommended citation for this survey:

The development of this survey was partially supported by the National Science Foundation under Grant No. 1038154 and by the Golden LEAF Foundation.

The framework for part of this survey was developed from the following sources:

DIRECTIONS:

There are lists of statements on the following pages. Please mark your answer sheets by marking how you feel about each statement. For example:

<table>
<thead>
<tr>
<th>Example 1:</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neither Agree nor Disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I like engineering.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

First: As you read the statement, think about your life and how you feel. Do you agree or disagree with the statement when you think about yourself? How strongly do you agree or disagree?

Second: Fill in the circle that best describes how you feel.

There are no "right" or "wrong" answers! How you feel is the best answer.

PLEASE FILL IN ONLY ONE ANSWER PER QUESTION.
<table>
<thead>
<tr>
<th></th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neither Agree nor Disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Math has been my worst subject.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>2. When I’m older, I might choose a job that uses math.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>3. Math is hard for me.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>4. I am the type of student who does well in math.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>5. I can understand most subjects easily, but math is difficult for me.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>6. In the future, I could do harder math problems.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>7. I can get good grades in math.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>8. I am good at math.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neither Agree nor Disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>9. I feel good about myself when I do science.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>10. I might choose a career in science.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>11. After I finish high school, I will use science often.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>12. When I am older, knowing science will help me earn money.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>13. When I am older, I will need to understand science for my job.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>14. I know I can do well in science.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>15. Science will be important to me in my future career.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>16. I can understand most subjects easily, but science is hard for me to understand.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>17. In the future, I could do harder science work.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>
**Engineering and Technology**

Please read this paragraph before you answer the questions.

Engineers use math and science to invent things and solve problems. Engineers design and improve things like bridges, cars, machines, foods, and computer games. Technologists build, test, and maintain (or take care of) the designs that engineers create.

<table>
<thead>
<tr>
<th>Question</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neither Agree nor Disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>18. I like to imagine making new products.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19. If I learn engineering, then I can improve things that people use every day.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20. I am good at building or fixing things.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21. I am interested in what makes machines work.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22. Designing products or structures will be important in my future jobs.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23. I am curious about how electronics work.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24. I want to be creative in my future jobs.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25. Knowing how to use math and science together will help me to invent useful things.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26. I believe I can be successful in engineering.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Below is a list of types of work that you could do when you are older. As you read about each type of work, you will know if you think that work is interesting. Fill in the circle under the words that describe how interested you are in doing that when you are older.

There are no “right” or “wrong” answers. The only correct responses are those that are true for you.

<table>
<thead>
<tr>
<th></th>
<th>Not at all Interested</th>
<th>Not So Interested</th>
<th>Interested</th>
<th>Very Interested</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. <strong>Physics</strong>: People study motion, gravity and what things are made of. They also study energy, like how a swinging bat can make a baseball switch directions. They study how different liquids, solids and gas can be turned into heat or electricity.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>2. <strong>Environmental Work</strong>: People study how nature works. They study how waste and pollution affect the environment. They also invent solutions to these problems.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>3. <strong>Biology</strong>: People work with animals and plants and how they live. They also study farm animals and the food that they make, like milk. They can use what they know to invent products for people to use.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>4. <strong>Veterinary Work</strong>: People who prevent disease in animals. They give medicines to help animals get better and for animal and human safety.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>5. <strong>Mathematics</strong>: People use math and computers to solve problems. They use it to make decisions in businesses and government. They use numbers to understand why different things happen, like why some people are healthier than others.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>6. <strong>Medicine</strong>: People learn how the human body works. They decide why someone is sick or hurt and give medicines to help the person get better. They teach people about health, and sometimes they perform surgery.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>7. <strong>Earth Science</strong>: People work with the air, water, rocks and soil. Some tell us if there is pollution and how to make the earth safer and cleaner. Other earth scientists forecast the weather.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Not at all Interested</td>
<td>Not So Interested</td>
<td>Interested</td>
<td>Very Interested</td>
</tr>
<tr>
<td>---</td>
<td>----------------------</td>
<td>-------------------</td>
<td>------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>8. <strong>Computer Science:</strong> People write instructions to run a program that a computer can follow. They design computer games and other programs. They also fix and improve computers for other people.</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
</tr>
<tr>
<td>9. <strong>Medical Science:</strong> People study human diseases and work to find answers to human health problems.</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
</tr>
<tr>
<td>10. <strong>Chemistry:</strong> People work with chemicals. They invent new chemicals and use them to make new products, like paints, medicine, and plastic.</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
</tr>
<tr>
<td>11. <strong>Energy/Electricity:</strong> People invent, improve and maintain ways to make electricity or heat. They also design the electrical and other power systems in buildings and machines.</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
</tr>
<tr>
<td>12. <strong>Engineering:</strong> People use science, math and computers to build different products (everything from airplanes to toothbrushes). Engineers make new products and keep them working.</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
</tr>
</tbody>
</table>
Appendix C: Space Craft Rescue STEM Exam

Name: ____________________________  Date: ____________________________

Space Craft Rescue STEM Exam

Please answer the following as the relate to engineering (You may use the back of this paper if necessary):

1) What is a force? Can you give an example?

2) What is a stress? Can you give an example?

3) Which is a stronger structure a triangle or a square? Why?

4) What is a Catenary Structure?

5) What is a load? Why is it important?

6) What is a vector?

7) Draw an example of a vector load diagram:

8) Why are vectors important in programming?

9) How do you write the following program for the Roamer Too in vector format?: Forward 2  Left 6  Back 4 Right 7

10) Diagram the above program using vectors:
Appendix D: Listing of Related Content Standards

RELATED CONTENT STANDARDS

Mathematics Grade 4 Overview

- **Operations and Algebraic Thinking**
  - Use the four operations with whole numbers to solve problems.
  - Gain familiarity with factors and multiples.
  - Generate and analyze patterns.

- **Number and Operations in Base Ten**
  - Generalize place value understanding for multi-digit whole numbers.
  - Use place value understanding and properties of operations to perform multi-digit arithmetic.

- **Number and Operations—Fractions**
  - Extend understanding of fraction equivalence and ordering.
  - Build fractions from unit fractions by applying and extending previous understandings of operations on whole numbers.
  - Understand decimal notation for fractions, and compare decimal fractions.

- **Measurement and Data**
  - Solve problems involving measurement and conversion of measurements from a larger unit to a smaller unit.
  - Represent and interpret data.
  - Geometric measurement: understand concepts of angle and measure angles.

- **Geometry**
  - Draw and identify lines and angles, and classify shapes by properties of their lines and angles.

- **Mathematical Practices**
  1. Make sense of problems and persevere in solving them.
  2. Reason abstractly and quantitatively.
  3. Construct viable arguments and critique the reasoning of others.

Science Big Idea: SC.4.N.1

A: Scientific inquiry is a multifaceted activity; The processes of science include the formulation of scientifically investigable questions, construction of investigations into those questions, the collection of appropriate data, the evaluation of the meaning of those data, and the communication of this evaluation.

B: The processes of science frequently do not correspond to the traditional portrayal of "the scientific method."

C: Scientific argumentation is a necessary part of scientific inquiry and plays an important role in the generation and validation of scientific knowledge.

D: Scientific knowledge is based on observation and inference; it is important to recognize that these are very different things. Not only does science require creativity in its methods and processes, but also in its questions and explanations.

BASIC INFORMATION
### RELATED Benchmark (7)

<table>
<thead>
<tr>
<th>Benchmark</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SC.4.N.1.1:</strong></td>
<td>Raise questions about the natural world, use appropriate reference materials that support understanding to obtain information (identifying the source), conduct both individual and team investigations through free exploration and systematic investigations, and generate appropriate explanations based on those explorations.</td>
</tr>
<tr>
<td><strong>SC.4.N.1.2:</strong></td>
<td>Compare the observations made by different groups using multiple tools and seek reasons to explain the differences across groups.</td>
</tr>
<tr>
<td><strong>SC.4.N.1.4:</strong></td>
<td>Attempt reasonable answers to scientific questions and cite evidence in support.</td>
</tr>
<tr>
<td><strong>SC.4.N.1.5:</strong></td>
<td>Compare the methods and results of investigations done by other classmates.</td>
</tr>
<tr>
<td><strong>SC.4.N.1.6:</strong></td>
<td>Keep records that describe observations made, carefully distinguishing actual observations from ideas and inferences about the observations.</td>
</tr>
<tr>
<td><strong>SC.4.N.1.7:</strong></td>
<td>Recognize and explain that scientists base their explanations on evidence.</td>
</tr>
<tr>
<td><strong>SC.4.N.1.8:</strong></td>
<td>Recognize that science involves creativity in designing experiments.</td>
</tr>
</tbody>
</table>

### RELATED AccessPoint (14)

**Independent**

<table>
<thead>
<tr>
<th>AccessPoint</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SC.4.N.1.In.1:</strong></td>
<td>Ask a question about the natural world and use selected reference material to find information, observe, explore, and identify findings.</td>
</tr>
<tr>
<td><strong>SC.4.N.1.In.2:</strong></td>
<td>Compare own observations with observations of others.</td>
</tr>
<tr>
<td><strong>SC.4.N.1.In.3:</strong></td>
<td>Relate findings to predefined science questions.</td>
</tr>
<tr>
<td><strong>SC.4.N.1.In.4:</strong></td>
<td>Communicate observations and findings through the use of pictures, writing, or charts.</td>
</tr>
<tr>
<td><strong>SC.4.N.1.In.5:</strong></td>
<td>Recognize that scientists perform experiments, make observations, and gather evidence.</td>
</tr>
</tbody>
</table>
**Supported**

<table>
<thead>
<tr>
<th>SC.4.N.1.Su.5</th>
<th>Recognize ways that scientists collect evidence, such as by observations or measuring.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC.4.N.1.Su.4</td>
<td>Record observations using drawings, dictation, or pictures.</td>
</tr>
<tr>
<td>SC.4.N.1.Su.3</td>
<td>Answer questions about objects and actions related to science.</td>
</tr>
<tr>
<td>SC.4.N.1.Su.2</td>
<td>Identify information based on observations of self and others.</td>
</tr>
<tr>
<td>SC.4.N.1.Su.1</td>
<td>Ask a question about the natural world, explore materials, observe, and share information.</td>
</tr>
</tbody>
</table>

**Participatory**

<table>
<thead>
<tr>
<th>SC.4.N.1.Pa.1</th>
<th>Explore, observe, and select an object or picture to solve a simple problem.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC.4.N.1.Pa.2</td>
<td>Recognize differences in objects or pictures.</td>
</tr>
<tr>
<td>SC.4.N.1.Pa.4</td>
<td>Recognize that people share information about science.</td>
</tr>
<tr>
<td>SC.4.N.1.Pa.3</td>
<td>Select an object or picture to represent observed events.</td>
</tr>
</tbody>
</table>

**Science Big Idea: SC.4.P.12**

A. Motion is a key characteristic of all matter that can be observed, described, and measured.  
B. The motion of objects can be changed by forces.

**BASIC INFORMATION**

<table>
<thead>
<tr>
<th>Subject</th>
<th>NGSSS: Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade Level</td>
<td>4</td>
</tr>
<tr>
<td>Body of Knowledge</td>
<td>Physical Science</td>
</tr>
<tr>
<td>Date Adopted or Revised</td>
<td>02/08</td>
</tr>
</tbody>
</table>

**RELATED AccessPoint (6)**

*Independent*
Identify that the position of an object changes when the object is in motion.

Identify speed as how long it takes to travel a certain distance.

**Supported**

Identify objects that move at different speeds.

Recognize that movement causes an object to change position.

**Participatory**

Recognize that an object can move in different directions, such as left to right, straight line, and zigzag.

Recognize an object as moving fast or slow.

Source: fldoe.org (2013)

**Listing of STL Content Standards Relevant to this Study**

**The Nature of Technology**

Standard 1. Students will develop an understanding of the characteristics and scope of technology.

Standard 2. Students will develop an understanding of the core concepts of technology.

Standard 3. Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

**Technology and Society**

Standard 4. Students will develop an understanding of the cultural, social, economic, and political effects of technology.

**Design**

Standard 8. Students will develop an understanding of the attributes of design.

Standard 9. Students will develop an understanding of engineering design.
Standard 10. Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem-solving.

**Abilities for a Technological World**

Standard 11. Students will develop abilities to apply the design process.

Standard 12. Students will develop abilities to use and maintain technological products and systems.

**The Designed World**

Standard 18. Students will develop an understanding of and be able to select and use transportation technologies.

Standard 19. Students will develop an understanding of and be able to select and use manufacturing technologies.

Standard 20. Students will develop an understanding of and be able to select and use construction technologies.

Source: iteaconnect.org
### Appendix E: Learning Activity Rubric

**LEARNING ACTIVITY RUBRIC**

**Interactive Process**

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>2</th>
<th>Moderate</th>
<th>4</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student Engagement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Substantative Knowledge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knowledge Production</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Depth of Knowledge**

<table>
<thead>
<tr>
<th></th>
<th>Shallow</th>
<th>2</th>
<th>Moderate</th>
<th>4</th>
<th>Deep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth of Knowledge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix F: IRB Documentation

Certificate of Completion

Stephanie Holmquist

Has Successfully Completed the Course in

Foundations in Human Research Protections at USF

On

Saturday, June 06, 2009
Certificate of Completion

Stephanie Holmquist

Has Successfully Completed the Course in

CITI Social & Behavioral Investigators and Key Personnel

On

Tuesday, August 20, 2013

UNIVERSITY OF SOUTH FLORIDA
Appendix G: Consent Letter to Parents

Parental Permission to Participate in Research Involving Minimal Risk

Information for parents to consider before allowing their child to take part in this research study

IRB Study # Pro00014698

The following information is being presented to help you and your child decide whether or not your child wishes to be a part of a research study. Please read this information carefully. If you have any questions or if you do not understand the information, we encourage you to ask the research.

We are asking you to allow your child to take part in a research study called:

A case study of student interactions with educational robots and impact on Science, Technology, Engineering, and Math (STEM) learning and attitudes

The person who is in charge of this research study is Stephanie Holmquist This person is called the Principal Investigator. However, other research staff may be involved and can act on behalf of the person in charge. She is being guided in this research by Dr. Victor Hernandez-Gantes.

The research will be conducted at Nocatee Elementary School

Why is this research being done?
The purpose of this study is to find out explore the use of educational robotics to learn science, technology, engineering and math (STEM) concepts.
Why is your child being asked to take part?
We are asking your child to take part in this research study because they are in the 4th grade which is the targeted grade level for this study.

Should your child take part in this study?
As a participant in the study, your child will be asked to participate in activities that will take place within 5 sessions over a 5-day period. Sessions 1 & 5 will be approximately 1-3 hours long and sessions 2-4 will be approximately 1 hour long. Times for these sessions will be alternated between mornings and afternoons. This will minimize and time away from pre-set academic time blocks. The student will be permitted by the teacher to make up any class work missed during the study.

Before you decide:
- Read this form.
- Have a friend or family member read it.
- Talk about this study with the person in charge of the study or the person explaining the study. You can have someone with you when you talk about the study.
- Talk it over with someone you trust.
- Find out what the study is about.
- You may have questions this form does not answer. You do not have to guess at things you don’t understand. If you have questions, ask the person in charge of the study or study staff as you go along. Ask them to explain things in a way you can understand.
- Take your time to think about it.

The decision to provide permission to allow your child to participate in the research study is up to you. If you choose to let your child be in the study, then you should sign this form. If you do not want your child to take part in this study, you should not sign the form.

What will happen during this study?
Your child will be asked to spend about the following time in the study:

Time required by the student during school hours:
Session 1: 1-2 Hours
Session 2: 1 Hour
Session 3: 1 Hour
Session 4: 1 Hour
Session 5: 1-2 Hours
Total time commitment: 5-7 hours

In session 1, all participants will be brought in to a classroom and introduced to the activity. They will be given a pre-test testing their knowledge of a particular academic subject that will be taught during the study. From sessions 2-5, the groups will be divided. Some of the materials will vary between groups. This is to determine if some materials are more beneficial towards learning a particular concept than others.
All information you provide in this study will be confidential. Your student’s name will not be used in the final write-up. All video tapes will remain in my possession locked in a safe for the next 5 years as required and will then be destroyed.

Your child’s participation in this study is voluntary. Your child has the right to withdraw from this study at anytime without penalty. To withdraw, they only need to contact myself of the facilitator of the activity.

During the study, all sessions will be videotaped. These videotapes will serve as part of the data record of the study. They will be reviewed and analyzed only by those involved with the study. Portions of these videotapes may be shown to other members of the research committee or to members of the education community; however, the participant will remain anonymous. By signing this form you give permission for your child’s participation in this study to be videotaped as described above.

**How many other people will take part?**
About 20 4th grade students will take part in this study.

**What other choices do you have if you decide not to let your child to take part?**
If you decide not to let your child take part in this study, that is okay. Instead of being in this research study your child can choose not to participate and will remain in his or her classroom.

**Will your child be compensated for taking part in this study?**
There is no direct payment for participation in the study; however the school will receive a set of Roamer Too robots to use within the school upon completion of the study. There are no risks the student associated with participation in this study. There are no direct benefits to the student for participating in the study.

**Who will disclose (share), receive, and/or use your child’s information?**
To conduct this research, USF and the people and organizations may use or share your child’s information. They may only use and share your child’s information:

- With the people and organizations on this list;
- With you or your personal representative; and
- As allowed by law.

**How will my information be used?**
By signing this form, you are giving permission to use and/or share the study information as described in this document for any and all study/research related purposes. Your authorization to use your child’s information will not expire unless you revoke it in writing.

As part of this research, USF may collect, use, and share the following information:

- Your child’s academic record.
You can list any particular information that you do not want us to use or share in the space below. If you list nothing here, we can use and share all of the information listed above for this research but for nothing else.

**Your Rights:**
You can refuse to sign this form. If you do not sign this form your child will not be able to take part in this research study.

**How Do I Withdraw Permission to Use My Child’s Information?**
You can revoke this form at any time by sending a letter clearly stating that you wish to withdraw your authorization to use of your child’s health information in the research. If you revoke your permission:

- You child will no longer be a participant in this research study;
- We will stop collecting new information about your child;
- We will use the information collected prior to the revocation of your authorization. This information may already have been used or shared with other, or we may need it to complete and protect the validity of the research; and
- Staff may need to follow-up with your child if there is a medical reason to do so.

To revoke this form, please write to:

Principal Investigator: Stephanie Holmquist
For IRB Study
PO Box 3564
Plant City, Florida 33563-0010

While we are conducting the research study, we cannot let you see or copy the research information we have about your child. After the research is completed, you have a right to see the information about your child, as allowed by USF policies.

**Privacy and Confidentiality**
We will keep your child’s study records private and confidential. Certain people may need to see your child’s study records. By law, anyone who looks at your child’s records must keep them completely confidential. The only people who will be allowed to see these records are:

- The research team, including the Principal Investigator, study coordinator, research nurses, and all other research staff.
- Certain government and university people who need to know more about the study. For example, individuals who provide oversight on this study may need to look at your records. This is done to make sure that we are doing the study in the right way. They also need to make sure that we are protecting your rights and your safety.
- The USF Institutional Review Board (IRB) and its related staff who have oversight responsibilities for this study, staff in the USF Office of Research and Innovation, USF Division of Research Integrity and Compliance, and other USF offices who oversee this research.

We may publish what we learn from this study. If we do, we will not include your child’s name. We will not publish anything that would let people know who your child is.
What happens if you decide not to let your child take part in this study?

You should only let your child take part in this study if both of you want to. You or child should not feel that there is any pressure to take part in the study to please the study investigator or the research staff.

If you decide not to let your child take part:

- Your child will not be in trouble or lose any rights he/she would normally have.
- You child will still get the same services he/she would normally have.
- Your child can still get their regular classroom instruction.
- You can decide after signing this informed consent form that you no longer want your child to take part in this study. We will keep you informed of any new developments which might affect your willingness to allow your child to continue to participate in the study. However, you can decide you want your child to stop taking part in the study for any reason at any time. If you decide you want your child to stop taking part in the study, tell the study staff as soon as you can.
- We will tell you how to stop safely. We will tell you if there are any dangers if your child stops suddenly.

Even if you want your child to stay in the study, there may be reasons we will need to withdraw him/her from the study. Your child may be taken out of this study if we find out it is not safe for your child to stay in the study or if your child is not coming for the study visits when scheduled. We will let you know the reason for withdrawing your child’s participation in this study.

You can get the answers to your questions, concerns, or complaints.

If you have any questions, concerns or complaints about this study, call Stephanie Holmquist at (813) 759-6500.
If you have questions about your child’s rights, general questions, complaints, or issues as a person taking part in this study, call the USF IRB at (813) 974-5638.

Consent for My Child to Participate in this Research Study

It is up to you to decide whether you want your child to take part in this study. If you want your child to take part, please read the statements below and sign the form if the statements are true.

I freely give my consent to let my child take part in this study and authorize that my child’s health information as agreed above, be collected/disclosed in this study. I understand that by signing this form I am agreeing to let my child take part in research. I have received a copy of this form to take with me.

_____________________________ ____________________
Signature of Parent of Child Taking Part in Study Date

_____________________________
Printed Name of Parent of Child Taking Part in Study
Statement of Person Obtaining Informed Consent
I have carefully explained to the parent of the child taking part in the study what he or she can expect from their child’s participation. I hereby certify that when this person signs this form, to the best of my knowledge, he/ she understands:
- What the study is about;
- What procedures/interventions/investigational drugs or devices will be used;
- What the potential benefits or risks might be.

I can confirm that this research subject speaks the language that was used to explain this research and is receiving an informed consent form in the appropriate language. Additionally, this subject reads well enough to understand this document or, if not, this person is able to hear and understand when the form is read to him or her. The parent signing this form does not have a medical/psychological problem that would compromise comprehension and therefore makes it hard to understand what is being explained and can, therefore, give legally effective informed consent. The parent signing this form is not under any type of anesthesia or analgesic that may cloud their judgment or make it hard to understand what is being explained and, therefore, can be considered competent to give permission to allow their child to participate in this research study.

___________________________________________  ______________
Signature of Person Obtaining Informed Consent  Date

___________________________________________
Printed Name of Person Obtaining Informed Consent

You will receive a copy of this form for your records
Please note: Consent of participation does not necessarily guarantee your child will be selected to participate in the study. Students will be selected at random from the list of returned permission forms.
Appendix H: Assent to Participate

Participant Verbal Assent Script – Roamer Study

I am assisting a graduate student in the College of Education at the University of South Florida who is conducting a research study on the use of certain hands-on materials to learn science, technology, engineering, and math concepts. We are inviting all 4th grade students at your school to participate in the study which will take approximately 5 days, for a total of 5-7 hours. You will miss some class time, but will be allowed by your teacher to make up all missed work. Your parent or guardian has given permission for you to participate in this study. Even though they have said it is OK for you to participate, there are some things you need to know before you decide if you want to participate:

1. You do not have to participate if you do not want to.
2. If you choose not to participate, your class grade will not be affected.
3. If you decide you do want to participate but change your mind later, we can stop and we won’t be upset and you will not get into trouble.
4. This study presents no risks to you.
5. The sessions will be videotaped, so we can go back to look at the activity.
6. The results of the research may be published, but your name will not be used.
7. You may feel free to talk to me, or anyone else at the school about questions you may have about the study at anytime.

Do you have any questions? (answer questions)

Do you want to participate (talk with me)?

☐ Yes
☐ No
<table>
<thead>
<tr>
<th>Name of person obtaining consent</th>
<th>Date</th>
</tr>
</thead>
</table>

| Signature of person obtaining consent |   |
Appendix I: IRB Approval Letter
10/23/2013

Stephanie Holmquist
University of South Florida
College of Education, Adult, Career and Higher Education
4202 E. Fowler Avenue
Tampa, Florida 33620

RE: Expedited Approval for Initial Review
IRB#: Pro00014698
Title: A case study of student interactions with educational robots and impact on Science, Technology, Engineering, and Math (STEM) learning and attitudes.

Study Approval Period: 10/23/2013 to 10/23/2014

Dear Ms. Holmquist:

On 10/23/2013, the Institutional Review Board (IRB) reviewed and APPROVED the above application and all documents outlined below.

Approved Item(s):
Protocol Document(s):
9-27-2013Holmquist Dissertation Proposal

Consent/Assent Document(s)*:
Assent To Participate Revision 1
Parental Consent Revision 1

*Please use only the official IRB stamped informed consent/assent document(s) found under the "Attachments" tab. Please note, these consent/assent document(s) are only valid during the approval period indicated at the top of the form(s).

It was the determination of the IRB that your study qualified for expedited review which includes activities that (1) present no more than minimal risk to human subjects, and (2) involve only procedures listed in one or more of the categories outlined below. The IRB may review research through the expedited review procedure authorized by 45CFR46.110 and 21 CFR
56.110. The research proposed in this study is categorized under the following expedited review category:

(6) Collection of data from voice, video, digital, or image recordings made for research purposes.

(7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

As the principal investigator of this study, it is your responsibility to conduct this study in accordance with IRB policies and procedures and as approved by the IRB. Any changes to the approved research must be submitted to the IRB for review and approval by an amendment.

We appreciate your dedication to the ethical conduct of human subject research at the University of South Florida and your continued commitment to human research protections. If you have any questions regarding this matter, please call 813-974-5638.

Sincerely,

John Schinka, Ph.D.
Chairperson
USF Institutional Review Board
Appendix J: Valiant Approval Letter

Stephie Holmquist
PO Box 3564
Plant City
Florida
33563 – 0010

3rd February 2014

Dear Stephie

We are happy for you to use any Valiant or Roamer® images, references or research published by Valiant or through David Catlin, or other owned copyright material for use in your dissertation. Please reference their use.

Good Luck,

Best Wishes

Kate Hudson
Sales and Marketing Director

Valiant Technology Ltd, Valiant House, 3 Grange Mills, Weir Rd, London SW12 0NE
Company Reg 1980281   VAT No. GB 428893603