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April 25, 2024

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Abstract. The U.S. faces significant challenges in raising reading scores to match or surpass those of leading nations. This article posits that using educational robotics as a technology to teach reading literacy in early childhood, elementary, and after-school programs may improve reading literacy scores in the U.S. This paper provides historical context and definitions regarding STEAM in multiple iterations that combine science, art, technology, science, math, and engineering in classroom instruction. It provides analysis of factors which impact reading levels in the U.S. In addition, the distinction between robotics education and educational robotics is presented. Examples examining the impact of educational robotics on U.S. reading scores in multiple early education settings, including after school programs, at an elementary school are given with an emphasis on the activities, population, and the delivery method. The goal of this article is to provide empirical evidence regarding the usage of robotics in early education.

Keywords: After-School, Early Childhood, Education, Literacy, Reading, Educational Robotics, Roamer, Seymour Papert, Logo, STEM, STEAM, STREAM.

1 Introduction

The purpose of this article is to examine the use of basic educational robotics as a tool in literacy education among students in early childhood as well as early elementary and after-school education. From the time of birth, children have been exposed to smart technologies and robots [1]. Children are growing up in a world that is ever-changing technologically [2] Robots have been utilized in the classroom in one form or another since the early 1980's and became popular nationwide in the United States with introduction of Lego TC LOGO thanks to numerous federal and state grants for implementation into schools. Building on the constructivist work of Piaget and in partnership with Lego, Seymour Papert applied his constructionism theory of learning combined with play to these new Lego robotic kits and what was the state of the art at the time [3] Apple IIe's were utilized to bring robotics into the classroom on a large scale. This Lego LOGO curriculum was often introduced into a computer lab within the school. While students had to build a specific model such as a washing machine, or merry go round out of the Lego materials, the focus was learning to program in LOGO. This was before graphic or Graphical User Interface (GUI), so the students had to type in lines of code. Because of this, students in early grades who couldn't read or write yet were excluded from these activities. Thus, the focus was on upper elementary through high school programs. This continued for many years until the development of simpler, easier to use robotic products came on the market. However, the use of robots in early childhood and primary settings as an educational tool to support reading literacy still isn't common.

Over the past few years, the implementation of early childhood Science, Technology, Engineering, and Math (STEM) focused education has been increasing. The value of STEM in early childhood and primary education is becoming widely accepted. However, these activities tend to focus on science or math as opposed to true integrated STEM activities. For example, in many early learning centers, small plastic microscopes are available for students to look at leaves or bugs. While this addresses the science aspect of the activity, is it really a true STEM activity, or stand-alone science? In its true form, a STEM activity should integrate science, technology, engineering, math, as well as arts and literacy. Activities designed with educational robots as tools can be a fun [4] and an exciting way to implement STEM education and especially literacy which is a major focus at the early childhood and primary level.

Examining the Program for International Student Assessment (PISA) results in 2018, China's average reading score was 555, significantly higher than the Organization for Economic Cooperation and Development (OECD) average of 487 and the United States' average of 505. Japan's score was closely aligned with the United States, at 504 . Several trends and patterns from the data provided by the National Assessment of Educational Progress (NAEP) indicate that in 2022, the mean reading scores of fourth-grade children in the United States were 3 points below those recorded in 2019. When comparing the ratings from 2022 to those from 1992, we observe a combination of different patterns. In 2022, the reading score for fourth-grade pupils at the 10th percentile showed a decline when compared to the scores recorded in 1992. Conversely, pupils who performed better, specifically those at the 75th and 90th percentiles, achieved greater scores in 2022 compared to 1992. Would STEM activities that have a literacy focus increase scores?

The focus of this paper is the use of educational robotics as it pertains to literacy specifically within STEM, reading, and comprehension. The following examines factors impacting U.S. reading levels, suggest approaches to improve U.S. reading levels while integrating STEM oriented activities, and conclude with an examination of robotics as a usage of technology to improve U.S. reading scores.

2 Background and Related Work

2.1 Reading Levels in the U.S.

Impact of Poverty on Reading Scores. Research indicates a substantial correlation between poverty levels and reading scores in U.S. schools. According to the National Center for Education Statistics (NCES, 2020), students from low-income families scored an average of 29 points lower in reading assessments compared to their counterparts from higher-income families. This gap, attributed to factors like limited access to resources such as technology and educational support, highlights the challenges faced by students in impoverished communities. Poverty has a significant impact on reading development. A significantly higher proportion of children residing in households with income below the poverty threshold (17.4% of all children in the United States, as reported by the 2021 Census) are prone to encountering difficulties in reading when compared to their more affluent counterparts [5]. According to the National Center for Education Statistics (NCES, 2022), the percentage of 4th-grade children from low-income households who achieved proficiency in reading was just 58% in 2019, while the corresponding figure for pupils from high-income families was 75%. The disparity continues in middle school, as 64% of students from low-income families achieve competence in 8th-grade reading, in contrast to 79% of their high-income peers (NCES, 2022). The discrepancy can be ascribed to various causes, such as restricted availability of high-quality early childhood education programs, inadequate access to books, technology, and educational resources at home, as well as frequently unstable home circumstances impeding learning [6].

Parental Educational Attainment and Student Reading Levels. Parental educational attainment has a profound influence on children's reading scores. A study by the Education Trust (2021) found that children whose parents held a college degree scored, on average, 26 points higher in reading assessments than children whose parents had not completed high school. This disparity suggests that parental education level contributes significantly to a child's educational environment and access to learning resources. According to the National Center for Education Statistics (NCES) in 2022, 78% of fourth-grade students whose parents have a bachelor's degree or more achieved a proficient score in reading, but just 48% of children whose parents did not complete high school reached the same level. The correlation between parents' influence on their children's literacy skills can be attributed to various aspects, such as the parents' capacity to create a home atmosphere fostering literacy, demonstrate effective reading habits, and adeptly negotiate the educational system on behalf of their children [7].

2.2 Technology as a Tool to Improve Literacy

This investigation highlights the opportunities presented through utilizing technology, specifically simple robotics, to positively influence a child’s interest in reading at an early age. During the early stages of a child's development, it is crucial to focus on fostering literacy skills [8]. Educators are continuously exploring novel methods to cultivate a passion for reading in young children [9]. While traditional methods are still important, integrating future technologies such as robotics can provide distinct and captivating avenues to enhance engaging reading opportunities in a non-judgmental environment. [10].

The digital age offers innovative tools to enhance early literacy development, such as artificial intelligence and robotics [11]. Robotics, with its playful nature and interactive potential, emerges as a promising avenue to support reading skills in young children. Research suggests incorporating age-appropriate robots into early education can positively impact various aspects of literacy acquisition, including phonemic awareness, vocabulary development, and reading narrative comprehension [12](.

2.3 Brief History of Robotics in Early Childhood and Primary Education in the United States

In the sixties people started to invent computer languages for specific purposes, for example: FORTRAN for science and COBOL for business. In 1968 MIT's Professor Seymour Papert invented Logo. a computer language for children and learning [13] Papert said "*We tried to achieve a number of goals. It should be easily accessible, there should be corners of the language you could get into like baby talk getting into English, that are easy for the youngest beginner, but it shouldn't be a toy language, It's not that logo is easy, it's easy to get into but once you're in there you can progress to the most sophisticated ideas in the world of programming. Just as in English, you can start with baby talk, but the same language is also the vehicle of expression for poets and philosophers*." [14]

This '*low floor high ceiling' idea* typified Papert's approach to learning. He saw the computer enhanced by LOGO as a tool children could use to '*explore the world of ideas*'[15].

By the early seventies the basic technological elements existed, supported by Jean Piaget's theories on play and constructivism. Papert, who'd worked with Piaget, built on these concepts. In the following 5 decades researchers and teachers explored how to adapt the ideas and create effective educational activities.

2.4 These Differ: STEM, STEAM, STREAM… Acronyms Galore!

It is almost impossible to walk into a school without becoming aware of the concept of Science, Technology, Engineering, and Math (STEM) education. In the United States, the concept of STEM education has existed in one form or another for years dating back as far as to the publication of A Nation at Risk in 1983 [16].

To customize specific programs and depending on the school district or school, STEM education may be referred to by utilizing a variety of different acronyms. Some of the more popular acronyms are STEAM (Science, Technology, Engineering, Arts, and Math), STREAM (Science, Technology, Reading, Engineering, Arts, and Math.) STEAM (Science, Technology, Engineering, Arts, Math, and Medical), etc. While traditionally taught academic programs such as English, Math, and Science are easy to understand, integrated STEM programs utilizing the various acronyms can be confusing to educators, parents, stakeholders, as well as the community in general. To avoid confusion, and understanding these acronyms differ, this paper will refer to STEAM, STREAM, STEAMM, etc. as STEM.

Over the years, it has been acknowledged that STEM activities incorporate what can be considered soft skills such as creative problem solving, collaboration, self-expression, motivation, critical thinking, fosters independent thinking,[17], all within the scope referenced within the need for the development of 21st Century skills for students. In addition, Davidson (2011) notes that 65% of the children entering our schools today may have jobs as adults not in existence yet. Therefore, considerable funding has been made available in the U.S. for STEM activities. The Partnership for

21st Century Skills lists a variety of skills important to education reform. Among the many skills, critical thinking, problem solving, communication, collaboration, creativity, and innovation are considered core skills for success [18]. In addition, it is believed that in the future being able to program will be as important as being able to read [19].

Funding for STEM programs continues to be strong. There have been many STEM oriented federally funded programs such as the Race To The Top Grant (RTT) funded by the Department of Education [20]. This grant had an emphasis on early learning and was designed to incentivize education reform.

The CRS report to Congress on Science, Technology, Engineering, and Mathematics (STEM) Education: Background, Federal Policy, and Legislative action showed low levels of academic achievement specifically in STEM fields[21]. Several reports support considerable funding available to schools who adopt STEM programs. However, for some, actual STEM education in schools is difficult to understand. There are many methods that can be successfully utilized to teach these as integrated concepts. In fact, schools use a variety of names to define their programs including STEAM (Science, Technology, Engineering, Arts, and Math), STEAMM (the last "M" is for Medical), STREAM (the "R" is for Reading), and many other variations on the theme. Some schools teach STEM very well, and others not so well.

One of the major issues in the implementation of STEM into an educational setting is that it requires more time and costs both for preparation as well as implementation. However, elementary and pre-school settings are by design, more oriented towards these types of activities. Kisidou and Koppal [22] (2006) suggested three steps to implement successful STEM programs in an elementary setting:

1. Align your outreach efforts relevant to content standards.
2. Pay attention to what students are thinking, and
3. Take advantage of instructional strategies that work.

Thus, high quality teacher training is critical to the success of STEM oriented activities. However, teachers usually do not have the training to integrate and modify their curriculum [23]. Rich, et al [24] noted that more than 75% of teachers in the United States who work with students under the age of 10 have little or no experience in coding. "You can't throw a stone without hitting a STEM initiative these days, but most science, technology, and math initiatives overlook a fundamental problem [25]. This problem is the lack of teacher training at all levels. Even at an elementary level where there is a greater level of hands-on learning, teachers need to be trained in STEM education[26].

In addition, specifically within technology activities such as robotics or 3D printing may not have had the background in programming and lack the time or interest to learn. In some cases, they may become intimidated at the prospect of learning such skills and uncomfortable to go beyond their comfort level [27] . Sullivan & Bers [28] note that "teaching foundational programming concepts, along with robotics, makes it possible to introduce children to important ideas that inform the design of many of the everyday objects they interact with." These objects are commonly used within the context of literacy development.

There is general agreement that STEM education should be delivered using an integrated approach [29]. There is also an increased attention to target underrepresented groups who otherwise might not have the exposure to STEM [30].

Implementing high quality STEM education requires considerably more time than traditional methods of teaching as STEM programs tend to be hands-on by nature. If asked, “What do you remember from your classroom experiences?” Most will say it was when they “built”, “made”, “designed”, etc. It is not when they opened to page 36 of their algebra or chemistry book. It is the emphasis on hands-on activities that cross numerous academic areas that make STEM successful in the classroom. Skills are learned and retained by performing hands-on activities. For example, learning to cook or drive a car is by doing. While gaining knowledge from a textbook is important, it can only go so far to develop skill-based learning. It is the same with STEM in an educational setting. Children as well as adults learn and retain by doing hands-on interdisciplinary activities. These are the skills they will need to develop to compete in the global world they will be living and working in.

2.5 Educational Robotics vs, Robotics Education-Robotics as a Tool to Teach STEM and Literacy

Many school districts are faced with the dilemma of how to increase test scores, school grades, and interest in STEM Careers [31]. Thus, Robotics in early childhood and elementary education is being adopted at an increasing rate. However, research in this area is still rare [32]. In addition to those previously discussed, there are many factors that weigh into this trend. When introducing robotics into a curriculum, students find they can control their robots and discover that they can correct programming errors. Students’ general literacy tends to grow as their literacy skills grow. Ragusa and Leung [33] note that “as they move along the coding “ladder”, children are not only learning to code, but they are also coding to learn.” In some cases, the terms literacy and coding are intertwined. In other cases, these activities are very different.

Angel-Fernandez and Vincze [34] define educational robotics as “ *a field of study that aims to improve students' learning experiences through the creation and implementation of activities, technologies, and artifacts related to robots*.” Simply stated educational robotics is an instructional strategy that relies on the use of robots for teaching purposes [35]. Whereas robotics education focuses on teaching robotics theory and concepts.

Table 1. Educational Robotics vs. Robotics Education, Different Learning Outcomes

Educational Robotics	***Robotics Education***
Use robots to teach academic concepts.	Use robots to teach associated robotics concepts and theories i.e. PLTW
Constructivist by nature [39] (Papert,S. & Harel, I, 1991).	Tends to be competition oriented.
Examples: Roamer, BeeBot, Lego (Including WeDo),	Examples: VEX, FLL, FIRST, BEST, etc.

It is important to note that some of the robots lend themselves to teaching both robotics education and educational robotics concepts. There is also a difference between the use of robots that require construction (build bots) such as VEX and LEGO, and those that do not require construction (use bots) such as Roamer, BeeBot. Another important distinction that is usually not considered is the use of robots that do not require computers to program (Roamer, BeeBot, etc.).

With the ever-increasing level of technology available for the use of robotics at an educational level, educational robotics offers a unique and fun alternative to traditional "drill and grill" teaching methods within a variety of academic subjects. Most of us and our students learn the number line by drawing on a pencil and paper. Same with geometric shapes. Now imagine learning these concepts while programming a robot.

2.6 The Educational Robot

The educational robot used for both activities described below is the Roamer Too. It was used because it is easy for young students to learn basic programming skills and doesn't require use of a computer. The Roamer has a variety of interchangeable keypads that allow the student to advance in scaffolding at their own pace. This has also proven a cost-effective way to use the same robot for students at a variety of levels.

Roamer (Fig 1) also has accessories such as a pen pack, clear grid mat as well as a mat that already has letters and numbers and pictures. This makes the set-up and creation of activities easy for the teacher.

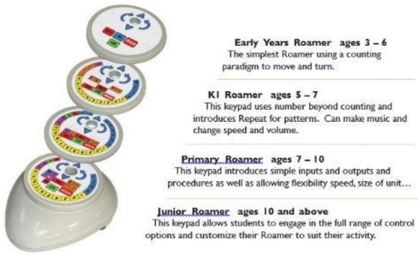

Figure 1. Roamer with Keypads

3 STEAM Literacy Activities

3.1 Spacecraft Rescue Activity

An activity that integrates true STEM concepts is the Valiant Spacecraft Rescue Activity (Fig 2). Participants were students in a rural elementary school in Florida. The school district is ranked 64th out of 67 counties in Florida. The cooperative elementary school in this study is ranked in the bottom 100 elementary schools in the state. Students at this school have had no previous experience with robots. While not the primary focus of the study, it became evident that both reading literacy and technological literacy played a crucial role in the success of the completion of activity for both the experimental and control groups. Students were tasked to design and build something that could be attached to a robot that would be sent across treacherous terrain to rescue a spacecraft that has crashed utilizing the Engineering Design Process which is a key component to the debugging process [36]. They were also instructed to journal the last 15 minutes of each activity daily. One of the pre/post activities was for students to identify, define, and comprehend a variety of grade level appropriate vocabulary terms. An example of a word given to the student to define was “Stress.” None of the students had previous exposure to the technical term, but had heard the word. When asked to define “Stress' ' on the pre-test one student wrote “My mom when my dad comes home.”. It is important to note that this student did give the correct definition of stress on the post-test. This demonstrates how while literacy may not be at the forefront of a study, it does factor in and should be considered.

Figure 2. Spacecraft Rescue

Further research would encourage exploration of this activity to include other literacy themes.

3.1 The Very Hungry Caterpillar Robotics Activity

A school board member with a Ph.D. in Early Learning Education, was interested in using robots as a tool to encourage literacy for elementary students within an afterschool program. The project was limited to having participants work in the media center for 2 hours a day for 3 days without computers. It was decided to use Roamer robots that were borrowed from the Tampa Housing Authority after school program because they were easily accessible, and the design of the robot is generic allowing for creative interpretation. This project was repeated twice at two different schools in Tampa, Florida. Both sites have a diverse student population and have over 50% eligible for free or reduced lunch. There were 13-15 girls and boys in grades 1-3 participating in each school. While costs were at a minimum, some funding was provided by the local McDonalds franchise. Because of this funding each student was given a copy of Eric Carle’s book “The Very Hungry Caterpillar.” [37]. This story was chosen due to the high integration of Science and Math Concepts. In addition, there has been speculation that children relate to robotics in a similar animal-like capacity [38] and that used within a computational thinking approach, storytelling can provide inclusive and sustainable learning opportunities [39]. Ching & Hsu [40] note that “Robotics activities support productive computational thinking development in young learners through tangible and interactive learning. This activity lends itself to pre-school students as well. As Almousa & Alghowinem [41] note “Aside from identifying colors and some vocabulary, preschool children can categorize things, such as animals and body parts.” Basic construction materials easily found in classrooms were provided. There was a 2-hour training for volunteers who were primarily from the afterschool programs and not certified teachers. Training was focused on the programming of the robot and a brief discussion of the engineering design process which was utilized throughout the project. Initially, the volunteers were unsure as to their confidence with the Roamer, but after the two hours felt extremely confident working with the robot and the students. A facilitator who is extremely knowledgeable with Roamer programming led the activities. The school board member was very active every day and initially read the story to the students on the first day. The facilitator also introduced Roamer programming on the first day using simple concepts such as Right Turn, Left Turn, Forward, and Backward. For most students the introduction of degrees was new. However, by the end of the 2nd day, students were comfortable programming the robot to turn 45, 90, 180 270, and 360 degrees. They were so proud of themselves that when they gave the program the command, they yelled out the turn.

On day 2, students were initially given reinforced instruction with the Roamer, then they were encouraged to design their own caterpillar that would fit and be attached to the robot. Students were told that they can design the caterpillar using their own imaginations, including the possibility that it could be an alien caterpillar from the materials provided. They were encouraged to name their caterpillar. At the end of day two the story was reinforced, specifically the sequencing of the caterpillar travels. The items (symbols) the caterpillar visits (Apple, Pear, Ice Cream Cone, etc.) were placed under a clear grid mat that used the same units of measurements as the Robot. Free printables that can be found online were used for each of the items. Students utilized a programming sheet to write their program which built on the path the robot followed. By the end of the second day, students were able to verbally describe the sequence of the caterpillar while creating the program. On day three, students attached their caterpillar on each Roamer. It is important to note that while each student created their own caterpillar so it could be taken home, students worked cooperatively to program the robot. The students were given about an hour to perfect their program. Then during the 2nd hour parents and invited guests arrived. All students gathered around the mat at the same time and each student then had the opportunity to show off their program and design (Fig 3). They were encouraged to explain their design, program, and caterpillar name. At the end of the day, students were given their own copies of the book and a certificate naming them an official “Robot Programmer.” While journaling was encouraged, the time limit each day prevented in depth writing. Younger participants were encouraged to draw their caterpillar and include the sequence the caterpillar followed. The older students were encouraged to build on this and write their thoughts, why they chose the name for their caterpillar, and describe any programming difficulties they encountered including how they solved the problem. All students kept programming sheets. The practical results were that students wanted to continue with their programming, and it was difficult for the parents to get their children to leave. Further, most asked how this project could be continued. Further research would include expansion of this activity over a longer time period as well as using different age-appropriate stories.

Figure 3. The Very Hungry Caterpillar Group

4 Conclusions

Research that examines educational robotics and early childhood literacy education is necessary to provide practical practitioner direction, future funding recommendations, and innovative ideas integrating technology toward future literacy initiatives to improve U.S. reading levels. Early literacy plays a vital role in the fundamental growth of children, greatly impacting their academic achievements and lifelong ability to learn. The incorporation of educational robotics in early school settings presents a distinct chance to improve literacy abilities while nurturing critical thinking and creativity in young students [42]. Research has demonstrated that robotics can offer dynamic and captivating opportunities that enhance language acquisition, reading understanding, and cognitive abilities. To explain the connection for children and literacy this approach posits that children engaged in robotics have a heightened 'passion' to read so they can program successfully. To measure this passion for reading, researchers must capture new words read, the level of definitions pursued, and the successful execution of instruction. Further, research that incorporates usage of robotics in early literacy programs serves to connect the divide between theoretical learning and practical implementation, rendering the learning process more concrete and pertinent for children.

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