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The Effects of Incorporating Educational Robotics in Mathematics Instruction

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THE EFFECTS OF INCORPORATING EDUCATIONAL ROBOTICS IN MATHEMATICS INSTRUCTION

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Abstract

This literature review explores the effects of incorporating educational robotics into mathematics instruction on students' problem-solving abilities, motivation, mathematical performance, computational thinking, and communication and collaboration skills. It investigates the impact of constructivist teaching methods on engaging students with robotics-based activities. The review highlights the positive influence of hands-on experiences and group collaboration using platforms like LEGO and Scratch. While this innovative approach shows promising outcomes, the review acknowledges challenges related to cost, time, space constraints, and the need for teacher professional development. These findings have significant implications for future research, pedagogical practices, and the transformative potential of educational robotics in promoting student-centered learning experiences.

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CHAPTER I: INTRODUCTION

Introduction

Constructivism and constructionism were central learning theories in robotics education. Constructivism portrays learning as an active process wherein individuals construct their understanding and knowledge of the world through firsthand experiences and thoughtful reflection upon those experiences (Piaget, 1954). Assimilation and accommodation were two fundamental concepts from Piaget's theory of cognitive development. Assimilation occurs when students incorporate new knowledge and skills into their existing understanding of concepts. When students encounter new math concepts or robotics principles, they try to relate them to real-life situations they have experienced or learned before. Accommodation occurs when students adjust their current mindset to incorporate current information that does not match with their existing understanding. In educational robotics and math, students might encounter situations where their problem-solving strategies were insufficient and they must create new strategies. When students use educational robots to explore math concepts, they assimilate new knowledge by connecting it to what they already know (Piaget, 1954). This constructivist approach of actively engaging with educational robotics provides hands-on learning opportunities.

Seymour Papert's learning theory, termed “constructionism," was formulated as a direct response to Piaget's constructivism (Papert, 1980). Papert's groundbreaking research demonstrates the effectiveness of emphasizing learners’ actively constructing knowledge through hands-on experiences. This approach transitioned the emphasis from passive learning to active involvement. Papert pioneered and investigated how technology could be used to help children learn mathematics differently. The LOGO programming language was developed to enable students to command a computer to control the movements of a turtle. The concept of programming was introduced using the analogy of teaching the turtle a new command or instruction. There was a physical floor turtle that had wheels and a pen and a virtual turtle that could be manipulated on the computer. The turtle can turn or move in different directions and draw lines on paper or on the screen using a pen. The turtle was seen as a "constructed computational object-to-think-with" (Papert, 1980, p. 11). By programming robots, students were presented with a visual representation of the math they were utilizing, offering a hands-on learning experience. Constructionism emphasizes that learners actively construct knowledge and understanding through hands-on experiences. This constructionist approach allowed students to externalize their thinking and helped foster collaboration. Students were most often working in teams with robotics, sharing ideas, and working together to solve problems. Papert (1980) described how his work would have an impact on the learning process and help create the next generation of mathematicians:

> Very powerful kinds of learning are taking place. Children working with an electronic sketchpad are learning a language for talking about shapes and fluxes of shapes, about velocities and rates of change, about processes and procedures. They are learning to speak mathematics, and acquiring a new image of themselves as mathematicians (p. 13).

Overall, the intention was to provide a different environment for teaching and learning that would motivate students to have a new relationship with mathematics. His ideas remain relevant today and continue to influence educational research. By fostering innovation in education and challenging traditional instructional approaches, teachers can create a more student-centered, experiential, and hands-on approach in the mathematics classroom.

Rationale

Students in the United States rank behind many other advanced industrial nations in math, as measured by a worldwide study of 15-year-old students (OECD, 2019). Programme for International Student Assessment (PISA) measures scholastic performance in mathematics, science, and reading across 78 countries. The most recent PISA results, from 2018, placed the United States at 37th out of 78 countries in math. The United States scored above average in reading and science when compared to the Organisation for Economic Co-operation and Development (OECD) average but scored significantly below the OECD average in mathematics. On the state level, according to the National Assessment of Educational Progress (NAEP), from 2022, grades four and eight saw their largest mathematics score declines since the initial assessment in 1990. Minnesota ranks 13th among fourth graders and ninth among eighth graders. The future global economy requires 21st-century job skills, and mathematics is a prerequisite for these fields of study.

Science, technology, engineering, and mathematics (STEM) related courses are experiencing an extraordinary surge in growth. There is more than just learning science and math in STEM courses. These courses combine multiple fields of study that focus on hands-on learning with real-world applications. Robotics is an interdisciplinary approach that is tangible and applicable to students. Educational robotics provides an opportunity for students to see the real-world application of STEM and the importance of learning math. Robots allow students to immerse themselves in mathematics and apply their math skills in a real-world setting.

Multiple mathematical concepts were used, including algebra and geometry, to find solutions to robotic problems. Algebra was used to find the distance traveled using ratios and proportions. Geometry was used when figuring out turns and applying the use of angles. The instructor will need to help the students move beyond basic conceptual understanding and procedural fluency toward developing problem-solving skills and making bigger connections between seemingly isolated topics. Mathematical understanding should improve by executing these intimately connected concepts using educational robotics.

Definitions of Terms

Important terminology, used throughout this paper, is defined as follows:

Computational Thinking (CT):

Incorporating four central thinking skills: decomposition, pattern recognition, abstraction, and algorithmic thinking (Hoyles, & Noss, 2015).

Constructivist Approach:

A learner-centered approach to learning that emphasizes the importance of individuals actively constructing knowledge and understanding with guidance from the teacher (Santrock, 2011).

Educational Robotics:

A field of study that aims to improve the learning experience of people through the creation and implementation of activities, technologies and artifacts, where robots play an active role (Angel-Fernandez, & Vincze, 2018).

Scratch Programming:

Scratch is a visual programming environment that lets users create interactive, media-rich projects. Images and sounds can be imported or created in Scratch using a built-in paint tool and sound recorder. Programming was done by snapping together colorful command blocks to control 2-D graphical objects called sprites moving on a background called the stage (Maloney et al., 2010).

STEM Education:

An interdisciplinary approach to teaching science, technology, engineering, and math, STEM instruction integrates key concepts between two or more STEM disciplines as students apply the practices of science and engineering to real-world problems (National Science Teachers Association, n.d.)

Guiding Question

This literature review answered the following research question: What are the effects of incorporating educational robotics in mathematics instruction?

CHAPTER II: LITERATURE REVIEW

This chapter is a review of educational robotics and its effect on mathematics instruction. To find the literature and information for this thesis, searches of Academic Search Premier, ERIC, Google Scholar, and ProQuest Education Journals were conducted for peer reviewed studies and publications from 2010-2023. The key words that were used in these searches included “mathematics and robotics”, “mathematics and LEGO”, “mathematics and vex”, “mathematics and programming”, “mathematics and coding”, and “mathematics and scratch.”

Effects of Incorporating Educational Robotics in Mathematics Instruction

This section explores how educational robotics influences students' problem-solving abilities, motivation, mathematical performance, computational thinking, and communication and collaboration in mathematics instruction. All these concepts are closely related to the integration of educational robotics, programming (e.g. Scratch), and mathematics in education. By integrating these elements, educators can create engaging and impactful learning experiences that empower students to excel in mathematics and develop essential skills for the future. It reviews relevant studies to examine the positive effects of incorporating physical and virtual technological artifacts in these areas.

Influence on Problem-Solving Abilities

The impact of educational robotics on students' problem-solving abilities was analyzed. It discusses how robotics-based activities provide students with hands-on, interactive learning experiences to engage in problem-solving activities. Building, programming, and controlling robots require students to apply creative problem-solving skills, logical reasoning, and critical thinking to design solutions to real-world challenges.

Problem-Solving Strategies

Different problem-solving strategies were used to tackle problems and find solutions. The use of robots not only improves students' understanding but also promotes alternative strategies for solving math problems (Shankar et al., 2013). The study was a semester-long course for 17 students in ninth grade with the goal of improving students' exposure to and comfort with robotic technology in math. This study was sparked by a robotics club that met once a week but did not have any robots. The authors helped the students in seeking a low-cost solution for purchasing, operating, and maintaining the robots. The students programmed and used Arduino robots to draw geometric art on a six-foot by six-foot canvas. Students programmed robots to autonomously solve math equations and solve word problems. Geometric shapes were drawn using the robots and the groups presented their geometric art in class. Interviews were completed with students at the conclusion, and it was found that robotic art aids students in solving math problems using visual and spatial knowledge, enhancing their understanding and problem-solving abilities. For example, students were given a problem stating that if a person walked six blocks to the east and eight blocks to the north, how far would a pigeon have to fly to get to the same location? The students recognized this as a triangle problem and the need to use the Pythagorean Theorem to solve for the hypotenuse and produce the correct answer of 10 blocks. The interviews revealed students used robotic art for better perception of real-world math problems. Visually solving problems using robots enhances understanding, identifying trends, and approaching problems from various angles. The findings showed the importance of integrating robotics into the curriculum, as it could help students learn about other disciplines and apply knowledge of math in novel ways to real-world problems (Shankar et al., 2013).

Blanchard et al. (2010) studied 45 students in fifth and sixth grade who participated in five activities over the course of a year. These small groups of three to four students were tasked to program a LEGO Mindstorm robot. Their objective was to guide the robot from point one to point two while moving around three sides of a rectangular fence to inspect a suspicious object. This study examined students' problem-solving strategies for programming robots and examining higher-order thinking skills. Inspired by constructionism, the researchers connected to problem-based learning for students by using robots to develop 21st-century skills. The students were asked to make comments and explain their work. The analysis focused on transcribed video recordings and blog posts to examine how children develop strategies to overcome obstacles in the process of problem-solving while utilizing situational awareness from their collective work. The students needed to determine the direction and route between the two points. Many teams divided the problem into five smaller sections and then programmed the robot to complete these sections in aggregate. The analysis of the groups led to a trial-and-error method and using different strategies to solve the problem. The trial-and-error method allowed the students to adjust strategies, see the problem from multiple perspectives, and develop better problem-solving skills. It was found that robotic learning offers immediate, constructive feedback for problem-solving (Blanchard et al., 2010).

La Paglia et al. (2017) studied sixth grade students, consisting of 30 students in an experimental group and 30 students in a control group. A LEGO Mindstorms robot was used in an extracurricular setting once a week for 10 weeks. Each experimental group adjusted the strategies used to solve tasks that increased in level of difficulty. The students participated in a qualitative questionnaire that evaluated their attitudes, beliefs, and control processes in math learning. Students built a physical robot body and created a program for the robot to move. They performed increasingly difficult tasks, measured by the number of blocks required to move the robot. For example, the first task was to program the robot to move in a linear route, the second was to create a geometric shape like a square. The tasks continued to increase in difficulty as color detection sensors were added and the robot was required to change directions based on items or colored lines in its path. The results suggested that robot kits enhance mathematical attitude, self-reflection, and control components. Specific to problem-solving strategies, the students were found to be using higher-level thinking skills such as forecasting, planning, monitoring, and evaluation. Additionally, the experimental group actively monitored, reflected, and adjusted processes to solve problems. Educational robotics provides unique opportunities for teachers to integrate mathematics learning with engaging problem-solving tasks, helping students develop problem-solving strategies while exploring and understanding mathematics and technology concepts (La Paglia et al., 2017).

Logical Reasoning

Logical reasoning serves as a fundamental tool within problem-solving, providing a structured and systematic approach to analyzing information, evaluating options, and drawing sound conclusions. Forsstrom and Kaufman (2018) reviewed literature on how schools have integrated programming into mathematics using cross-curricular approaches, such as in Finland and Sweden. A total of 15 relevant articles were identified for students aged six to 16. The articles covered a wide range of topics, artifacts used, age ranges, methods, and durations. The authors chose to exclude studies that reviewed extracurricular or summer camps and focused on the interdisciplinary application in a traditional classroom. Furthermore, pre-school and high school studies were also excluded. The authors identified four common themes from the literature: motivation, performance, collaboration, and the changed role of the teacher. Policies for programming in education were crucial because of the limited research on mathematics education potential. Constructivist and social constructivist learning theories were widely cited in the literature review. Robotics and programming activities showed meaningful connections to the geometry curriculum, but not to all traditional mathematics topics. Overall, programming's potential in mathematics education was justified. Programming activities provided real-life connections to mathematics education, fostering problem-solving, and logical-thinking skills.

Ardito et al. (2014) studied sixth grade students for about fourteen weeks using a mixed-methods approach. The students were measured quantitatively against their state mandated mathematics exam and qualitatively by evaluating blog posts using textual analysis software. Trained undergraduate students were assigned as mentors to the students and provided in-person, videoconferencing, and email support. The students were given two introductory sessions on Turtle Art. Turtle Art involves users snapping bricks or small parts of programming components together to create a functioning program. The lessons included an introduction to the tool, making more complex programs, and highlighted specific skills related to future programming.

The students were organized into groups and worked with LEGO Mindstorms robots for the rest of the semester, focusing on challenges that increased in complexity. The goal of the study was to introduce robotics into mathematics instruction, aiming to connect skills learned with robots, foster problem-solving, and collaboration. One of the goals of the teacher involved in the study was to map the robotics curriculum to her state's math standards, which specifically included number sense, operations, and formulas. One of the biggest improvements found in math content was related to area and circumference. The robotics program provided the setting that allowed for a much deeper and richer understanding of these specific topics. The robotics program positively impacted students' problem-solving and logical thinking skills, which were strongly associated with the skills developed during the robotics experiences (Ardito et al., 2014).

To investigate robotic usage with younger students, Muñoz et al. (2020) conducted a study on 240 students in kindergarten and first grade using the Bee-Bot robot. The robots followed their programming to execute coherent sequences on mats by stopping on spaces with different images and symbols to solve problems. This project aimed to enhance preschool and first grade students' logical-mathematical skills. The objective was to assess students' ability to overcome small challenges through robotics and programming by observing and analyzing their mistakes. The goal of introducing early programming instruction was to develop logical-mathematical skills that were constructive when solving a problem. In one task, the students were asked to program the robot in the correct sequence to move the Bee-Bot to a number on the mat indicated by the teacher. If the robot ended at a different number, the students would have to go back into the programming and determine where the error occurred. This allowed the students to observe, analyze, and reflect on the error and think about the logical steps to solve the problem. The playful nature of the activities was also found to improve positive attitudes and acceptance of the robots, which helped strengthen the educational process. It was found that programmable educational robots improved logical-mathematical skills in preschool and first grade students (Muñoz et al., 2020).

Critical Thinking

The interconnection between problem-solving and critical thinking was closely examined and demonstrated. Critical thinking was the cognitive process used to solve complex problems. Kim et al. (2021) studied 24 students in fourth and fifth grade enrolled in a two-week STEM summer school program. Three robotics-coding activities addressed various STEM practices and standards, which included geometry, measurement, proportionality, expressions, equations, and relationships. This study investigated robotic coding activities' impact on elementary school mathematical problem-solving and critical thinking, specifically the measures of complementary and supplementary angles.

Students were assessed using a pre-test involving measures of angles and special angle pairs. The three activities used geometric concepts, which included acute, right, obtuse, straight angles, complementary angles, and supplementary angles. In the first activity, the students used different headings like 0° and 180° to drive the circular robot in distinct directions for a specific distance. The second activity required the students to code the robot to trace specific polygons such as squares, right triangles, and equilateral triangles. The final activity allowed the students to apply their knowledge of the mathematical concepts learned in a fun bowling game. Throughout all the activities, the observers noted how the students adopted a trial-and-error method of solving problems that allowed for constant correction and adjustment of code. Students scored 35% on the pre-test for complementary and supplementary angles and increased this score to 66% on the post-test, which was a statistically significant increase. After reviewing the findings, providing visual and kinesthetic activities could be successfully employed in a mathematics curriculum. It was proposed that educational robotics and coding activities, such as Sphero SPRK+, could enhance students' problem-solving and critical thinking skills (Kim et al., 2021).

In a narrow study, Casler-Failing (2018) conducted an action research investigation consisting of six students in a seventh grade class. Social constructivist theory underpinned the analysis of this research. The study utilized LEGO Mindstorms EV3 robots, specifically the PenBot. The unit consisted of eight lessons and three activities that were designed for growth problems, ratios and proportions, and proportional reasoning. Student data revealed the robots provided the conditions for learning, focusing on what the robots did or did not do based on the students' predictions. By analyzing the robot’s actions, the students developed an understanding of proportional relationships. The data showed that the integration of robotics in mathematics could promote students' development of necessary life skills, such as critical thinking and problem-solving (Casler-Failing, 2018).

Blanchard et al. (2010) examined the strategies used by students to foster critical thinking skills. Different teams used different methods to solve the problem of moving the robot around three sides of a rectangle. For example, one team scrutinized why error after error occurred, and they showed flexibility in their problem-solving strategy. By analyzing the problem, new plans of action emerged to complete the task. The other team used a trial-and-error method as an estimation strategy to get closer and closer to the actual results. The study found that robotics-based learning could enhance cognitive and metacognitive skills, as well as critical thinking, which are essential 21st-century skills. The authors established that robotic-based learning provided instant feedback during problem-solving situations, which highlighted the importance of critical thinking (Blanchard et al., 2010).

The Benitti (2012) literature review developed a list of 10 articles and had specific criteria for inclusion, including a 10-year time horizon, having only quantitative data, and being a physical robot. Three main items were reviewed in the literature: what topics were taught, student learning outcomes, and if robotics is an effective tool. The math concepts taught in the articles consisted of: distance, angles, graphs, fractions, and ratios. The students were evaluated most often in an after-school program or summer camp, and 90% of the studies used LEGO robots for instruction. The results show a general learning gain with the use of robotics; however, there were cases where no learning gain was observed. The researchers support self-guided learning experiences that promote experimentation as a learning strategy. Another positive finding was related to skill development, particularly, thinking skills, which included observation, estimation, and manipulation (Benitti, 2012).

Effects on Motivation

This section focused on the effects of incorporating educational robotics in mathematics instruction on students' motivation. The interactive and playful nature of robotics engages students, making math concepts more meaningful and relevant. It explores how robotics-based activities improve attitudes, captivate students' interest, and increase engagement with the subject. Motivation has a dynamic relationship with these factors and has implications for effective teaching and learning strategies.

Attitude

Students' attitudes influenced their motivation towards a task or subject. Positive attitudes foster positive motivation and could contribute to their ability to succeed. Zhong and Xia (2020) conducted a literature review of 20 papers, covering students aged three to thirty-three years old, ranging from kindergarten to college level. Virtual robots were excluded because of the hands-on utilization of physical robots. The study considered how educational robotics were incorporated into mathematics and what approaches were effective in teaching and learning through robots. The papers had a wide range of specific robotics kits that were adopted, with LEGO in the dominant position (53%), and the humanoid robot NAO in second (15%). The sample size was not large, with only one study including more than 80 participants and seven studies with five to 20 participants. The largest sample of papers were on elementary school students and secondary school students. Content knowledge showed that most studies were done in geometry (63%), followed by algebra (47%), practice and synthesis (32%), and finally, statistics and probability (5%). Seven data collection methods were used in the papers: observation (75%), test/examination (55%), questionnaire (40%), verbal (40%), evaluation of artifacts (15%), think-aloud (5%), and sociograms (5%). Three significant themes were found among the papers: understanding of mathematical concepts, change of attitude, and skill development. Robots' interactive and hands-on nature aids students' mathematical knowledge. Finally, this literature review showed that robotics could help students improve their understanding of mathematical concepts, change attitudes, and develop skills (Zhong & Xia, 2020).

The study done by La Paglia et al. (2017) analyzed the effectiveness of robot kits in improving students' attitudes towards mathematics and their metacognitive abilities. Three metacognitive skills, attitude, belief, and control processes were evaluated during a pre-test and post-test questionnaire. In the questionnaire, situations and problems were presented, and the students were asked questions related to their experiences and attitudes toward mathematics. The control group increased their mean score from 52.8% to 54.4%, and the experimental group increased their mean score from 58.4% to 62.4%, which was statistically significant. The results showed that using robot kits improved students' attitudes towards mathematics. The results also suggested that students enhanced their self-reflection and self-learning attitudes through how they monitored, reflected, and adjusted their strategies to solve problems. The experimental group showed an increase in post-test performance compared to the control group, suggesting that using robot kits improves students' attitudes towards mathematics, self-reflection, and higher-level control components. The results were statistically significant in positive attitudes towards mathematics between the experimental and control groups (La Paglia et al., 2017).

Leoste and Heidmets (2019) completed a literature review of 20 articles before conducting a pilot study. Only articles that studied physical robots were included in this study. A variety of research methods were conducted in the study; 75% of the studies used a qualitative approach, 20% used mixed methods, and only 5% were quantitative studies. Eleven of the papers recommended using robots as an educational tool for teaching mathematics. Only one study concluded that robot usage does not improve mathematics skills. Ten of the papers concluded that students had a positive attitude towards using robots for teaching mathematics, and eight papers noted that teachers had a positive attitude towards using robots as an educational tool (Leoste & Heidmets, 2019).

The pilot study completed by Leoste and Heidmets (2019) in Estonia consisted of 208 students in an experimental group and 196 students in a control group in the third and sixth grade. The experimental group used robots to visualize numbers, shapes, distances, and calculations. The control group conducted math classes using the traditional method. Three different educational robotics platforms were used in the pilot study: the Edison robot, the LEGO Mindstorms EV3 robot, and the LEGO WeDo 2.0 robot. Twenty lesson plans were carefully designed in cooperation between the researchers and the pilot study teachers. The lesson plans were designed around exercises and examples found in the current textbook or tied to national math standards. Each lesson was designed to be completed in one 45-minute class period. Students were in groups of two individuals using one robot.

Both quantitative and qualitative data were used by Leoste and Heidmets (2019) in evaluating national standardized test scores, administering questionnaires, and conducting interviews. The researchers attempted to answer four questions: problems and challenges, differences between the groups, attitudes, and learning outcomes. Teachers found their students to be highly motivated and engaged, although a temporary loss of motivation was observed on easier tasks. The pilot study found that students' attitudes towards learning mathematics by using educational robots were generally positive, with 86% of them finding the lessons interesting. The data shows robotics-based instruction boosts motivation, engagement, and attitude, which mostly confirms observations from previous studies. While this study focused mostly on the attitudes of students, more work needs to be completed on improving educational outcomes (Leoste & Heidmets, 2019).

Gerretson et al. (2008) performed an interdisciplinary study on 27 students in eighth grade as they worked to integrate robotic technology into a mathematics and science curriculum. The technology used was a robotic arm that could be operated through computer commands or using a joystick. The duration of the interdisciplinary study started in November and ended in June. Data was collected by performing teacher interviews before and after the implementation of the technology and through four in-person observations. The researchers sought teachers' concerns for technology use, student attitudes, curriculum connections, and interdisciplinary collaboration. The robotic arm could move in a specific direction, be adjusted for magnitude of movement, and moved at a rotational angle, which would only be helpful to math concepts such as, estimation, fractions and percentages, and degrees. The biggest impact of the robotic arm was on students' attitudes with respect to collaboration and motivation. Using the technology had great reward potential for the students. Finally, the technology appeared more powerful as a management device related to attitudes and motivation than as a content-learning tool (Gerretson et al., 2008).

Interest

When a student develops greater interest in a topic, they should see a higher level of motivation and find it personally meaningful and valuable. Witherspoon et al. (2018) suggested that students' interest in a topic could predict how they choose to spend their free time, what courses they select, and what major they pursue. The sample for their study consisted of 136 students in sixth and eighth grade. A constructivist approach was taken as these lessons were applied in seven robotics classrooms. The students completed tasks using VEX IQ robots in a simulated virtual environment. The online virtual environment was designed to replicate the physical robotic behavior. The study cited that learning gains in previous virtual classes have been equivalent to gains seen in settings using physical robots and at a reduced cost. The lessons comprised three units, Basic Movement, Sensors, and Program flow. Students applied programming skills learned in earlier lessons to complete more complex tasks in later lessons. This study investigated what aspects of a robotics programming curriculum may lead to transferrable knowledge that would prepare students for a range of future computer science careers. The assessment results showed interest declines in programming, but not for students completing the final Program Flow unit (Witherspoon et al., 2018).

Leoste and Heidmets (2020) studied 208 students in the third and sixth grade. Each class was required to take 10 to 20 robot-supported math lessons over a period of four months. The robot platforms selected were based on what was available at the participating school: the Edison robot, the LEGO Mindstorms EV3 robot, and the LEGO WeDo 2.0 robot. Teachers experimented with various approaches to lesson plans without the special scripting provided by the designers. Results were reviewed using interviews, lesson diaries, and questionnaires. The teachers were supported by five educational technologists during this study. The authors were interested in bringing educational robots into a mainstream classroom, which was a different approach than offering the curriculum as an intervention or as an extracurricular activity. The main goal was to have mainstream math teachers use robots as a supplement in a regular math classroom and not as a separate class or after-school activity. Much time was spent connecting the math lessons to robotics through real and perceivable word problems. The study also included one class of students with special education needs, and these students enjoyed the robotics-supported class considerably more than the regular math classroom (Leoste & Heidmets, 2020).

Deploying innovative technology, like robotics, in education enhances its relevance. Educational robotics, designed for younger students, could be used to increase students' interest in the learning process. The researchers highlighted the importance of modernizing math and say that it was crucial for preparing students for future jobs. Integrating modern technology could enhance the relevance of the math classroom. The students with special education needs found robot-supported math lessons engaging and developmentally stimulating. It was found that to make math more interesting and engaging, constructivist teaching methods should be introduced, allowing collaborative learning and more student independence, and stopping students’ fading interest in mathematics (Leoste & Heidmets, 2020).

Likewise, Shankar et al. (2013) designed a course to enhance interest in STEM classes, particularly math classes. Students built, programmed, and used robots to draw geometric shapes. One of the goals was to integrate robotics into the K-12 math and science curriculum, as opposed to an extracurricular activity that only attracts students who already have an interest in learning robotics and math. The authors highlighted the need for math curricula to adapt to 21st-century students' goals, interests, and motivation. Students built concrete bonds through doing, leading to deeper understanding. By providing multiple representations of real-world problems, students showed more interest in mathematics using the visual representations that educational robots provide. Robots enhance mathematics teaching through meaningful lessons that require integrated instruction, and unit activities to motivate students and promote learning. It was found that, while students applied their knowledge with robots, they showed more interest in their math education (Shankar et al., 2013).

In a study on fourth graders, Kim and Lee (2016) examined 121 students who were randomly assigned to either a “robot” group with 58 students or a “ruler and protractor” group with 63 students. Each group took 10 geometry lessons with the same teacher, with the robot group using robots and the ruler and protractor group using traditional methods. In this experimental design, the study investigated differences in achievement and attitude in mathematics. The students were assessed using a pre- and post-test; additionally, a delayed test performed three months after the completion of the lessons was utilized. The delayed test measured the level of retention related to achievement and attitude. The timeline for this study was three weeks, with students meeting twice a week.

The results for achievement showed the robot group increased their mean score from 34.3% to 59.6%, and the ruler and protractor group increased their mean score from 37.5% to 57.3%. The robot group's average was higher, but no significant difference was found. This does show that both methods were successful at teaching students’ geometry. Additionally, no significant difference was found in achievement during the delayed test three months later. The results for attitude during the pre-test showed no significant difference, which shows attitudes were approximately the same prior to the lessons. However, the results of the post-test do show a significant difference in two categories related to attitude: ‘interest in and curiosity toward mathematics’ and ‘participation in mathematics class’. The data inferred that robots increased students' interest in mathematics and participation. Additionally, the results from the delayed test show that the robot group's participation was higher than that of the ruler and protractor group.

The findings demonstrated that even though the robots were gone from class, the pattern of participation persisted for the robot group three months later (Kim & Lee, 2016).

Engagement

Engagement was the state of being actively involved, focused, and absorbed in a task or activity. Motivation plays a crucial role in fostering engagement. When individuals were motivated, they were more likely to be engaged in the task at hand, putting forth effort and persistence to achieve desired outcomes. Highfield (2010) provided motivating tasks to promote the problem-solving of diverse mathematical ideas. Thirty-three young children, ages three to five, participated in the study. The children engaged in experiences involving play and completed weekly tasks with two robots, a Bee-bot or a Pro-bot. The lessons were developed collaboratively by teachers and researchers and lasted approximately two hours per week over 12 weeks. The children completed geometry tasks related to measurement, space, position, and estimation. The robots have a series of directional buttons as an interface, which gives younger children the ability to program the robot using these buttons. Three scaffolded tasks were offered: structured, exploratory, and extended tasks. The tasks provided opportunities for children to program and observe the robot and to reflect on its movement. For example, the children were able to create their own adventure by creating an island and having the robot navigate different obstacles and create different routes through the island. These challenging tasks encouraged perseverance and lasting engagement. Overall, it was found that robotic toys encourage playful engagement with challenging mathematical concepts. In view of the research, a multifaceted approach promotes rich mathematical thinking and engagement through dynamic tasks (Highfield, 2010).

Witherspoon et al. (2018) investigated whether a robotics programming curriculum helped prepare students for a career in computer science and developed their beliefs in their ability to be successful in computer science. There were 136 students in sixth and eighth grade in this virtual curriculum. The students were using ROBOTC to program VEX IQ robots in a virtual program. This study focused on a constructivist approach that uses scaffolding to help students solve problems with increasingly difficult tasks. There were three separate tasks to complete, with each task increasing in difficulty, and the students were working in groups at their own pace. Not all groups made it to the most challenging task. The setting was a traditional classroom, as opposed to an elective or club, to determine if robotics could foster engagement for a wider range of students. The students completed a 12-question survey before and after the unit that asked four questions in each of the following three categories: interest, competency beliefs, and identity. Witherspoon et al. (2018) were interested in determining if there was a relationship between programming and shifts in motivational factors, which may also be relevant to learning computer science skills. The results showed a decline in motivational characteristics. A significant decline in interest was found for the groups that only made it to the first task. A small decline was found for the groups that made it to the second task. Finally, there was no significant decline for groups that made it to the most challenging and final task (Witherspoon et al., 2018).

Williams et al. (2012) examined illustrative lessons developed and aligned with the science and math standards for New York State. There were a total of 140 students assessed in the science activities and a total of 130 students assessed in the math activities. This material was taught as a supplement in a traditional classroom setting. Six LEGO Mindstorms lessons were analyzed in elementary, middle, and high school science and math classes. The study was conducted in two consecutive class sessions consisting of two 20-minute sessions in each class. The math concepts taught included a wide range of topics: measurement, units, comparing data, line segments, rotations, pi, circumference, radius, diameter, area, ratios, rational numbers, mean, median, mode, and outliers. Students were engaged by connecting abstract mathematical concepts to tangible hands-on activities. In consideration of the evidence, the LEGO Mindstorms platform engaged students by utilizing scaffolding, providing hands-on instruction, and problem-based learning (Williams et al., 2012).

Overall, motivation, attitude, interest, and engagement were interwoven aspects that affect individuals' learning experiences and performance. Motivation acts as a driving force, influencing attitude, interest, and engagement, towards a task or subject. Engaging and stimulating activities could enhance interest and foster positive attitudes, which, in turn, could further enhance motivation and engagement in a positive feedback loop.

Impact on Mathematical Performance

This section explores the effects of incorporating educational robotics and programming into mathematics instruction on students' mathematical performance. By experiencing math concepts in a tangible and practical context, students may deepen their understanding and retention of mathematical content. It examines relevant studies and research findings to highlight how educational robotics deepens students' understanding of mathematics for a richer understanding and improves overall mathematical achievement.

Deepen Understanding

A student's mathematical performance, typically measured through their math scores or assessments, could be an indicator of their level of understanding of the topic. However, it is important to note that mathematical performance alone may not fully capture the depth of a student's understanding. There is a connection between mathematical performance and a deeper understanding of the topic. Williams et al. (2012) found that hands-on robotic activities enhance traditional classroom instruction, support deeper understanding of the subject matter, and promote active learning through discovery. The math activities were assessed on 41 students in elementary school, 45 students in middle school, and 44 students in high school. Pre- and post-assessment surveys were administered to assess LEGO Mindstorms lab activities' effectiveness in science and math lessons. On the measurements and accuracy activity, students increased their mean scores from 62% to 81%. On the mean, median, and mode activity, students increased their mean scores by a smaller amount, from 91% to 95%. The biggest improvement in scores was achieved in the ‘Pi-What is it activity’ where students' scores increased from 23% to 76%. In the ‘Pi-What is it activity’ students explored the irrational properties of pi through hands-on applications using LEGO Mindstorms robots. The lesson had the students draw circles, measure radius, calculate circumference, and calculate area, fostering conceptual understanding. This deeper understanding and active learning could be attributed to a significant improvement in students' knowledge on post-lesson assessment surveys (Williams et al., 2012).

Ardito et al. (2014) investigated a sixth-grade robotics program and whether it deepened the students’ understanding of mathematics. In the hallway activity, students built a robot to navigate a long hallway, working together to determine its length. Some groups determined the hallway length based on a multiple of the robot's wheel circumference. The students did not demonstrate statistically significant scores when compared to peers in other classrooms; however, they showed a larger percentage of students in the above or within ranges, surpassing peers in both the building and the county. One of the participating teachers commented on the significant improvement in topics like area and circumference because the real-world activity, combined with traditional instruction, gave the students an opportunity to dive deeper into the subject matter (Ardito et al., 2014).

Casler-Failing (2018) studied the impact of incorporating LEGO robotics into middle school mathematics education to support the development of students' proportional reasoning skills. The case study used a mixed methods framework, combining qualitative and quantitative data for objective analysis of proportional reasoning accuracy; however, due to the small sample size, the quantitative data was not included in the research report. The study suggested a deeper understanding of proportions and proportional reasoning skills, with whole class discussions enabling students to compare and contrast strategies, supporting the inclusion of robotics in the seventh-grade curriculum. While mathematical performance was an important indicator, a deeper understanding allowed students to make connections between different and complex mathematical ideas (Casler-Failing, 2018).

Mathematical Performance

A student's mathematical performance, typically measured through their math scores or assessments, could be an indicator of their level of understanding of the topic. Mathematical performance scores were often used as an indicator of academic achievement in mathematics. They could typically be found by analyzing quantitative data, pre- and post-test scores, artifact assessments, and using experimental and control groups. Performance measures varied by the diverse types of studies, grade level, length of time, standards, and countries.

One of the main themes Forsström and Kaufmann (2018) sought to prove was the effect of introducing programming and robots in a math classroom on students' performance in mathematics. Programming had a positive impact on students' math performance, with some studies reporting gains for particular groups. However, the results only showed improvement for certain groups. Positive results were found for topics involving circle geometry, fractions, and proportions. Programming and Scratch tasks were often connected to geometry activities involving circumference, circles, angles, squares, and triangles.

Martínez Ortiz (2015) studied the impact of an integrated LEGO robotics and mathematics learning experience on students' proportional reasoning strategy levels. The research intended to determine if a short but intensive extracurricular setting (15 hours in one week) would lead to an improvement in student learning. The goal of the LEGO-based robotics program was to teach ratios and proportions. The study was conducted in a fifth-grade class with 15 students in the experimental group and 15 students in the control group. This research employed a mixed-methods study that lasted for one week, with a follow-up assessment 10 weeks later. Three assessments were completed: one at the start, one in the middle, and the final assessment at the 10-week mark. The students were encouraged to use a four-step engineering design process that included the following iterative steps: plan, build, check, and improve. The results indicated that students in the experimental group were able to make significant progress in learning new concepts of ratio and proportions compared to the control group. Based on the study's outcomes, a constructionist approach was successful in providing the motivating context for learning ratios and proportions (Martínez Ortiz, 2015).

In a connected study, Moreno-León et al. (2016) expanded on this topic by introducing Scratch programming to second and sixth grade classes studying math, social studies, and language arts in Spain and Argentina. There were a total of 66 students in the control group and 63 students in the experimental group. Specifically, the math class was only for sixth grade, and it was a topic on angles. The teachers received four weeks of training prior to the study, and the study lasted for four additional weeks. The results showed that both control and experimental groups had significant improvements between pre-test and post-test conditions in every participating school; however, the experimental group had a bigger improvement overall. The control groups' mean increased from 4.73 to 6.27, and the experimental groups' mean increased from 5.12 to 7.48. The research revealed that Scratch programming enhanced the sixth-grade math learning curve (Moreno-León et al., 2016).

Hussain et al. (2006) conducted a large long-term study on 12 different schools in Sweden, consisting of two hours a week over a 12-month period. There were 322 students in the experimental group in fifth and ninth grade. There were 374 students in the control group. The qualitative analysis was completed by observation and interview. The quantitative analysis was performed with students taking a pre- and post-test like the Swedish national standards test. A constructivist approach was taken when applying the use of LEGO Dacta materials with students working in groups of three to four. There were three areas of focus: whether students would develop better knowledge, better problem-solving skills, and better attitudes while applying robotics to mathematics (Hussain et al., 2006).

Different learning methods were observed by Hussain et al. (2006), which included a trial-and-error method and a more cooperative or collaborative method. The teacher role was changed in these settings, with more time committed to being prepared and engaging in conflict resolution efforts within groups. The fifth grade mean achievement scores increased from 0.711 to 0.817, demonstrating improved mathematical performance for the experimental group. The results showed positive results for the fifth-grade experimental group; however, the ninth-grade results showed no significant difference after training. The authors found it hard to confirm the hypothesis that LEGO construction kits enhance mathematical knowledge in students because of the mixed results (Hussain et al., 2006).

Muñoz et al. (2020) sought to improve logical-mathematical skills with educational robotics in kindergarten and first grade students. The study consisted of 240 students who were given a pretest at the start and a post-test at week 10. The objectives of the study included the ability to memorize numbers and to match the number of objects with a corresponding number. The pre-test mean for the kindergarten group increased from 3.177 to 4.167, and the pre-test mean for the first-grade group increased from 3.92 to 4.48. Statistical analysis showed significant differences in the calculated values representing students' performance. The study found that programmable educational robots improved logical-mathematical skills in preschool and first grade students (Muñoz et al., 2020).

Barak and Assal (2018) studied 32 students in eighth grade after 30 hours of instruction over a 15-week period. Students worked on a range of new tasks: operating a robot, programming, taking measurements, and analyzing a final project. For the final project, the students needed to navigate the robot through a simple labyrinth and blow up a balloon at the end. The students were observed using a trial-and-error method and group collaboration to solve the labyrinth problem. Qualitative data was collected through documentation and student interviews. Also, the students participated in a questionnaire measuring their attitudes toward learning technology. The students were given a subject matter final exam that consisted of factual knowledge, procedural knowledge, and conceptual knowledge.

Table 5

Mean Scores on the Final Exam

Item Type	Girls Mean	Boys Mean	Total Mean
Factual Knowledge	86.01	78.74	84.76
Procedural Knowledge	92.00	87.37	89.69
Conceptual Knowledge	79.58	73.06	78.88
Total	86.43	80.67	85.15

Girls' mean scores were higher than boys' in all categories, including procedural and conceptual knowledge questions. The mean scores were highest in procedural knowledge for girls, boys, and the total. The authors found the results encouraging, considering students with limited backgrounds in learning science and math (Barak & Assal, 2018).

A more recent study done by Talan (2021) used the meta-analysis method to find and analyze 32 studies. The study involved 2606 participants, with 1300 in the experimental group and 1306 in the control group. The investigation illuminated the academic achievement of applying educational robotics in a large-scale inquiry of quantitatively based research studies. The studies were evaluated by subject area, duration, and sample size. Science and computer classes constituted most studies (84%) with math and other classes trailing in number of articles. The most common sample size was less than 50 students involved, and the most common duration of application was less than five weeks. There were two studies that lasted over 12 weeks and three studies had an unspecified duration. There was no data provided about the artifacts used, grade level, or specific curriculum content. Evidence indicated that educational robotics is significant and effective in improving academic achievement, albeit at a low level. The positive effect size indicates that the experimental group benefited from the inclusion of robotics and showed improved academic achievement. The researchers found that robotics was preferred in science and computer classes over math classes. Multiple items should be considered when looking at the varied academic results from the studies, instruction delivery, differences in activities, and teacher management of the process. Insights by Talan (2021) suggest that increasing robot applications in education improves students' academic achievement.

Components of Computational Thinking

The key components of computational thinking (CT) and their significance in the context of educational robotics were examined. It highlighted how educational robotics fosters computational thinking skills among students by integrating CT concepts. By engaging in robotics-based activities, students were exposed to real-world problem-solving scenarios that require them to apply computational thinking concepts and strategies to solve mathematical problems. Examples and studies illustrate the integration of computational thinking and robotics in mathematics instruction. Computational thinking involves a set of problem-solving skills and strategies, such as decomposition, pattern recognition, abstraction, and algorithmic thinking (Hoyles, & Noss, 2015). Another definition, which provided a simple approach to computational thinking, is “the ability to think with the computer-as-tool” (Berland, & Wilensky, 2015, p. 630). Each component will be explored, highlighting its relevance to developing computational thinking skills among students engaged in robotics-based activities.

In a more recent study, Chan et al. (2023) reviewed 73 journal articles related to integrating computational thinking into mathematics instruction. A total of 64 unique CT tools were identified and categorized into five main groups: programming languages (21.8%), digital tangibles (physical artifacts) (25.0%), apps and games (7.9%), and other technological tools (6.25%). There were 21 unique programming languages identified: Scratch, Scratch Jr., Dr Scratch, MATLAB, Mathematica, Thermo-Calc, COMSOL, Statistical programming language R, Python, Google's Blockly/Code.org coding problems, Sketchpad, Logo, BlockyTalky, LaPlaya, ViMAP, Visual Studio IDE, Bitbloq, mBlock, Ardublockly, Processing, and Bootstrap Algebra. There were 16 unique digital tangibles identified: LEGO EV3 robotics/Lego Mindstorms EV3/NXT robots, Lego Education WeDo 2.0 robotics kit, Arduino, mBot robot, SRA-programming Lego NXT Mindstorms robots, TurtleBot, KIBO robotics kit, Sphero, micro:bit, Zowi, Dash and Dot, Anprino, Codey Rocky, Bee-Bot robot, and Robotics Dream ER kits. There were seven unique apps and games identified: Scalable Game, Kinect games, Bee-bot iPad app, SmartMeasure App, Hour of Code, Lightbot, and Digital Educational Material (DEM). The artifact most utilized was Scratch programming. Most CT tools were used to assess algorithms and algorithmic thinking, abstraction, testing and debugging, loops, sequences, pattern recognition, parallelism, logical thinking, variables, and iteration. Algorithmic thinking and abstraction were the most assessed CT competencies, followed by loops and sequences. Geometry and measurement were the most assessed mathematics topics, followed by numbers and operations, and algebra. Finally, Chan et al. (2023) found that CT tools play a crucial role in integrating mathematics topics in the classroom; however, the focus of the studies was primarily on CT outcomes compared to academic outcomes.

Kopcha et al. (2017) conducted a qualitative study on 263 students in their traditional fifth grade classrooms. The curriculum lasted for 10 days, with 50 minutes devoted to each lesson. There were no specific brands of robots identified or specific math topics discussed. Teacher interviews asked four questions as a reflection, and student interviews had three questions after the study was completed. The purpose of the study was to use robots to develop students' computational thinking. The curriculum consisted of six lessons, each spanning engineering, math, and science standards. The lessons were designed to engage students, allowing them to apply mathematical concepts in the engineering design cycle. Teachers in the study recognized the students' struggle with robots as a meaningful learning tool. The students in the study were thrilled to see if and how their programming ideas successfully completed tasks. Students and teachers appreciated the curriculum's integrative approach of combining mathematical and scientific thinking. This implied that a robotics curriculum grounded in real-world problem-solving enhances the integration of STEM materials (Kopcha et al., 2017).

Berland and Wilensky (2015) wanted to see the outcome of students programming either a virtual or physical robot and its effect on computational thinking. The study was conducted in a two-week long robotics course in multiple eighth grade classrooms with a total of 78 students. The students worked in groups on increasingly difficult tasks of programming either a physical or virtual robot. The physical artifact was a LEGO Mindstorms robot that was prebuilt for the students prior to the study, and the virtual robot was in the VBOT programming environment. The student groups were evaluated on their uniqueness, difficulty, and density of programming. It was found that students using the physical robots created more unique, difficult, and dense programming than their counterparts using the virtual robots. However, the authors cautioned, the three metrics may not necessarily indicate positive performance in all aspects with respect to computational thinking. The virtual class learned the same concepts differently than the physical class. The virtual class created more circuits that were simpler, and this helped them perform better on questions that addressed complex movements. The physical class created more complex robots that showed a better understanding of programming. The data suggested by Berland and Wilensky (2015) was that the virtual class saw the tasks through a different lens and thus learned programming skills in a unique way than the physical class, and vice versa.

In a pioneering study, Brennan and Resnick (2012) did considerable research on how to support computational thinking in students and used Scratch programming as that medium. These were the components of the computational thinking framework they have developed: computational concepts, computational practices, and computational perspectives. After many years of studying what students were creating in the Scratch community, they have identified seven concepts used to develop computational thinking: sequences, loops, parallelism, events, conditionals, operators, and data. The next step identified in computational thinking is practice, which includes iteration, testing and debugging, reusing and remixing, and abstracting. Students saw their experience with Scratch as a platform for design and self-expression, providing them with an opportunity to devise and create rather than merely consume social media. This perspective proved to be valuable for their overall learning experience. Perspective allows the students to connect with a larger audience, and it shows the value of creating content with and for others. Brennan and Resnick (2012) provided a set of general suggestions for assessing the learning of students: supporting further learning, incorporating artifacts, illuminating processes, checking in at multiple waypoints, valuing multiple ways of knowing, and including multiple viewpoints.

Ke (2014) studied 64 middle school students who participated in a math game making activity using Scratch. The goal of the study was to determine if computer game design would foster mathematical thinking in students. The students participated in two hours of curriculum each week for six weeks. These activities were not performed in their traditional math classes; they were performed in the participants' computer classes. Five graduate students facilitated the lessons and provided mentoring to the students during the game design unit. These graduate students were highly trained; they were majoring in education and had previously completed a course in game design. The students brainstormed math concepts they would like to teach a younger sibling, then created a fun and enjoyable mini game that included this math concept. An artifact analysis was completed at the end of the program, examining the math content included in the games and how computational thinking was reflected in the games. Additionally, qualitative analysis was completed by performing student interviews, completing a survey, and analyzing video recordings of the class (Ke, 2014).

The study by Ke (2014) revealed insights into the relationship between game creation in Scratch and math learning among participants. During interviews, 91% of participants enjoyed creating computer games; however, only 52% of participants mentioned math learning. The primary math theme that emerged from this activity was students using multiplication or division of integers to solve math problems. Other math concepts related to geometry, like XY-coordinates, perimeter, and area, were mentioned in the prototype phase; however, these concepts were never integrated into the actual game. Another curious theme that was exposed was that the game examples showed math as an undesirable incident, an obstacle to overcome before getting back to the fun. The students were observed using an iterative trial-and-error method to debug and decode their programming. Overall, (Ke, 2014) found that Scratch helped aid children in developing mathematical thinking through animation and game creation by linking abstract math ideas to the real world.

Promoting Communication and Collaboration Skills

This section emphasizes the role of educational robotics in promoting communication skills during collaborative problem-solving activities in mathematics instruction. Groups of students share a common goal when working together, which encourages them to function as a team and help overcome challenges. It discusses how robotics-based tasks encourage students to articulate their ideas, communicate their reasoning, and engage in effective peer-to-peer and group discussions. Forsström and Kaufmann (2018) highlighted the importance of collaboration between students and the changing role of the teacher. Their literature review discussed the changing dynamics of the classroom because of the introduction of robotics, collaboration between students, and the new role of the teacher. Student collaboration in programming and robot-based activities depended on the new teacher's role in the classroom. First, a more student-centered classroom emerged with the teacher as more of a guide and less of a lecturer. Second, the teacher deals more with conflict resolution when collaboration breaks down within the groups. Finally, the classroom culture created by the teacher either fostered collaboration by being open to sharing ideas and having good listening skills or deterred collaboration because of a lack of respect. Forsström and Kaufmann (2018) summarized their findings by stating that students learn from each other through collaboration and knowledge sharing.

In a related study, Ardito et al. (2014) described an innovative collaboration in a sixth-grade classroom. One of the key objectives was to determine how robotics could reshape a math classroom environment toward collaboration. Classroom observations were conducted, and student-to-student and student-to-teacher collaboration was examined. Interviews and blog responses were reviewed as well, with the researchers looking for keywords like: “collaboration”, “group work”, “group process”, “teamwork”, and “cooperation”. One of the teachers in the program noted that the biggest effect of the study was her students' ability to collaborate. The classroom observations revealed the same information: students huddled, were animated in discussing strategies, and worked together to solve the current problem.

An intriguing aspect of the study involved students' response to five blog posts as a means of reflecting on their experiences with robots. A textual analysis was conducted on the blog posts to reveal trends in student writing. The most common terms used were: “we”, “our”, “robot”, “group”, “think”, and “programming”. Additionally, the word “group” came up in greater frequency in the first couple of blog posts, but then the word “team” took its place at the end of the writings. Overall, it was noted that the students worked effectively in groups, and the classroom environment was reshaped to be more collaborative (Ardito et al., 2014).

The study done by Leoste and Heidmets (2020) paid special attention to how collaboration was implemented into their study. Teams of two students were created and asked to solve a math word problem. They were then asked to solve three robotic activities related to the math word problem. The goal was to design robot-supported lessons by integrating math content with the robotic exercises. One class of students with special education needs also participated in the study. Initially, the students with special education needs were reluctant to work in teams;

they required more guidance with the group work. Based on this body of research, robot-supported math lessons promote independence, collaboration, and peer tutoring (Leoste & Heidmets, 2020).

Kopcha et al. (2017) highlighted the importance of collaboration in creating a functional environment. One way to enable collaboration was to create a safe environment for learning and exploration. Collaboration allows students to engage in complex cognitive tasks, fostering deeper learning. Students were encouraged to explain and justify their thinking with peers, which stimulates problem-solving abilities. Additionally, collaboration enhances understanding and bridges knowledge gaps by enabling students to critically observe and monitor each other.

Part of creating the functional environment was putting students in groups and having the teachers facilitate guided support through the lessons. The small-group work started with learning programming and building robots. The group work continued by developing, testing, and revising strategies for applying mathematics to the problems. Finally, the students had to present their results, answer questions, and discuss the multiple approaches to solving the problems. One of the teachers in the study commented on how programming and building the robot promoted students' collaboration in their problem solving. Also, the students' comments echoed the teachers' thought: "you could talk with other groups if something went wrong" (Kopcha et al., 2017, p. 36). Overall, creating a functional environment that allowed students to foster collaboration was seen as positive by both teachers and students (Kopcha et al., 2017).

In a literature review testing different physical and virtual robotic kits, Samuels and Haapasalo (2012) proposed simultaneous deployment of both instruments. This approach was closely aligned with constructivist teaching and problem-based learning, which fosters collaboration and increased interest in mathematics. The technologies for this study were chosen for pedagogical reasons, familiarity, and motivational appeal. Two physical robots and one virtual program were reviewed when thinking about 15 to 19-year-old students. The two physical robots were the LEGO Mindstorms robot and the Bioloid Comprehensive Kit. The virtual robotics program used was GeoGebra, which could be used to represent mathematical concepts using its dynamic geometry software. No specific math topics were discussed for implementation.

Next, Samuels and Haapasalo (2012) evaluated the learning experiences and suggested an approach to assess robot-based problem-solving. Robot-based problem-solving encourages collaboration and the testing of mathematical ideas. The structure of the learning environment should include the ability to ‘play’ in spontaneous activities. Robotics fosters collaborative social creations, team-centered decision-making, and the opportunity for students to engage in distinct roles within a group. Finally, the biggest advantage found was that physical robots provide a concrete representation of abstract mathematical ideas and that virtual programs allow users to model behavior through animation.

In conclusion, the integration of educational robotics, programming, and mathematics holds immense promise for shaping modern education. Their integration had a profound impact on students' problem-solving abilities, motivation, mathematical performance, computational thinking, and communication and collaboration skills. By leveraging robotics and programming, educators could create dynamic and engaging learning environments that foster deeper understanding and enthusiasm for mathematics. However, alongside the potential benefits, it is crucial to acknowledge the negative implications. Challenges such as technical issues, time and cost constraints, and the need for teacher professional development will arise when implementing educational robotics. However, by tackling these challenges and using insights from relevant studies, schools could unlock the innovative potential of educational robotics, empowering students with vital skills to navigate the future effectively.

CHAPTER III: CONCLUSION

Summary of Literature

This thesis reviewed a wide range of recently published literature to answer the guiding question: What are the effects of incorporating educational robotics in mathematics instruction? Educational robotics is still a relatively new field when looking at interdisciplinary applications in a mainstream mathematics classroom. Through this literature review, many common themes emerged as well as some conflicting results.

Problem-solving, strategies, logical reasoning, and critical thinking were interconnected and played integral roles in addressing challenges and finding effective solutions. Strategies provide a structured framework, guiding individuals on how to approach and address problems systematically. Logical reasoning involves analyzing information, identifying patterns, and drawing logical conclusions. Critical thinking enhances problem-solving by promoting deep analysis and the ability to make sound judgments.

Three main themes were presented when looking at problem-solving: problem-solving strategies, logical reasoning, and critical thinking. Various problem-solving strategies were used to achieve the same goal when looking at math problems. Shankar et al. (2013) looked at how visually solving a problem using robotics promotes alternative strategies for solving math problems. Blanchard et al. (2010) highlighted the trial-and-error method to help overcome obstacles in the process of problem-solving. La Paglia et al. (2017) emphasized higher-level thinking skills such as forecasting, planning, monitoring, and evaluation. These methods all involve multiple steps in the problem-solving process.

Logical reasoning serves as a systematic approach to analyzing information, evaluating options, and drawing sound conclusions. Forsstrom and Kaufman (2018) looked at how programming activities provide real-life connections to mathematics education, fostering problem-solving and logical-thinking skills. Ardito et al. (2014) pointed out how visualizing a problem positively impacted students' problem-solving and logical thinking skills. Muñoz et al. (2020) focused on the logical steps used to solve a problem. Using a systematic and structured framework and connecting abstract mathematical ideas to physical examples fosters logical reasoning skills.

Before students could apply solutions to a problem, they must be able to synthesize information to make informed decisions. Critical thinking skills were developed by providing visual and kinesthetic activities (Kim et al., 2021). Casler-Failing (2018) highlighted the importance of analyzing the robot’s actions and making connections with proportional reasoning. The students in the Blanchard et al. (2010) study were able to adjust strategies through trial-and-error by using different estimates. Benitti (2012) emphasized the thinking skills that students developed, which included observation, estimation, and manipulation. By breaking problems down into smaller components, students were able to apply reasoning to help with problem solving.

Educational robotics has shown a significant positive impact on students' motivation. Three important parts of motivation were identified: attitude, interest, and engagement. If a task is enjoyable and increases a student’s belief in their ability to succeed, this could show big improvements in motivation. Zhong and Xia (2020) showed how an interactive and hands-on learning experience could improve students' attitudes. La Paglia et al. (2017) identified how students enhanced their self-reflection and self-learning attitudes through robotics. Physical robots were shown to boost motivation, engagement, and attitude (Leoste & Heidmets, 2019). Gerretson et al. (2008) found that students using the technology of a robotic arm had great reward potential for learning the material. The active engagement in robotics fostered a positive attitude in the students.

Genuine interest could be a struggle in the traditional math classroom, and robotics could provide the catalyst to spark curiosity and interest. Witherspoon et al. (2018) saw interest decline in programming for students who struggled with the material but not for students who progressed to the more challenging tasks. Constructivist teaching methods should be introduced, allowing for collaborative learning and more student independence (Leoste & Heidmets, 2020). Shankar et al. (2013) provided multiple representations to real-world problems and students showed more interest in mathematics. Kim and Lee (2016) did a questionnaire three months after students worked with physical robots and found that participation persisted over that period as compared to the control group. Fading interest is a real problem in the modern math class and motivation could improve if students could find it personally meaningful and valuable.

Teachers could increase students' involvement in a task by providing a playful, immersive environment, which could lead to higher levels of engagement. Highfield (2010) found robotic toys encouraged playful behaviors, which stimulated imagination and increased engagement. However, Witherspoon et al. (2018) saw a significant decline in interest for groups that struggled to complete basic tasks but did not see any declines for groups that made it to the most challenging and final task. Williams et al. (2012) observed increased engagement by the students by connecting abstract mathematical concepts to tangible hands-on activities.

Playful learning encourages students to take risks, try out innovative ideas, and approach challenges with a positive mindset.

The impact of educational robotics on students' mathematical performance yielded varied results. Mathematical performance was influenced by a deeper understanding of the material, which could show an interconnectedness that goes beyond surface-level memorization. Williams et al. (2012) viewed the scaffolding provided in the lessons as leading to a deeper understanding and active learning. Ardito et al. (2014) applied a real-world activity, which gave the students an opportunity to dive deeper into the subject matter. Students in the Casler-Failing (2018) study used a compare and contrast strategy by looking at different methods to solve the same problem, which led to a deeper understanding of proportions. The combination of guided support, hands-on experiences, and identifying connections led to increased deeper understanding.

Math performance was affected by a student's proficiency in applying mathematical concepts using different problem-solving strategies. Forsstrom and Kaufman (2018) witnessed positive results when students applied circle geometry, fractions, and proportions to real-world situations. The physical manipulatives for Martínez Ortiz (2015) provided a constructionist approach that provided a concrete and interactive way of learning ratios and proportions. Moreno-León et al. (2016) used Scratch programming that enabled students to visualize and interact with angles that enhanced their sixth-grade math scores. The 12-month study done by Hussain et al. (2006) showed mixed results. The fifth-grade experimental group used a trial-and-error method that allowed different approaches to learning. However, the ninth-grade results showed no significant difference after training. Playfulness was a successful strategy with preschool and first grade students in the Muñoz et al. (2020) study. This exploratory approach used programmable educational robots to improve logical-mathematical skills. The Barak and Assal (2018) article showed encouraging results with students with limited backgrounds in learning science and math. These eighth-grade students showed persistence when using a trial-and-error method. Talan (2021) analyzed a large number of papers and showed that increasing robot applications in education improves students' academic achievement. Multiple methods and varied skills were recognized in students' learning, which resulted in a positive and effective learning environment for mathematics.

Computational thinking forms the basis for programming robots and developing problem-solving skills to solve math challenges in our evolving world. Kopcha et al. (2017) found that educational robotics provides a practical, real-world context for problem-solving in STEM classes. Berland and Wilensky (2015) observed strengths in both virtual and physical robots. The virtual class approached problems from a unique perspective and applied their programming skills in a separate way than the physical class, and vice versa. Brennan and Resnick (2012) incorporated Scratch as a medium for students to devise and create material to improve their computational thinking skills. Students in the Ke (2014) study used debugging and decoding skills in Scratch to help develop mathematical thinking through game creation. Finally, Chan et al. (2023) identified 64 unique physical and virtual artifacts used in developing computational thinking skills. The number one item used in each category was LEGO robotics and Scratch programming. By creating tangible objects in a real-world setting, students were allowed to develop mathematical concepts that enhance understanding.

The integration of educational robotics had demonstrated a notable and beneficial influence on students' communication and collaboration skills. Communication and collaboration play a vital role in constructivist learning through the exchange of ideas, providing an interactive classroom, and critically observing each other's work. Forsström and Kaufmann (2018) witnessed students learning from each other through collaboration and knowledge sharing. Building on this research, Ardito et al. (2014) recognized students working effectively in groups as the classroom environment was reshaped to be more collaborative. Likewise, Leoste 2020 found robot-supported math lessons promoted peer tutoring while students supported each other in their learning journey. Kopcha et al. (2017) found collaboration allowed students to critically observe and monitor each other's work and progress. Samuels and Haapasalo (2012) detailed how robotics could provide the opportunity for team-centered decision-making. Collaboration could enrich the learning experience and provide important tools to help develop students' 21st-century skills.

Professional Application

The integration of robotics and programming into the mathematics classroom yielded numerous positive outcomes; nevertheless, several challenges require ongoing resolution. Many authors outlined beneficial pedagogical implications for effectively using robotics in teaching mathematics and multiple suggestions on implementation (Forsström & Kaufmann, 2018; Kim & Lee, 2016; Zhong & Xia, 2020). Robotics is most appropriate for short tasks that are relevant and realistic to solve (Zhong & Xia, 2020). There needs to be an improvement in the curriculum and a direct connection to state math standards or national math standards (Forsström & Kaufmann, 2018; Gerretson et al., 2008; Kopcha et al., 2017; Leoste & Heidmets, 2020; Shankar et al., 2013; Zhong & Xia, 2020). Tasks need to be tied explicitly to these standards. Teachers may be more open to robotics if it meets their standards and can be used with their current curriculum. Much time and effort would need to be devoted to curriculum development, either at the national or the state level.

There were three major time components related to robotics that need to be solved. First, robotics can take a considerable amount of time to set up and disassemble (Leoste & Heidmets, 2020; Kim & Lee, 2016). Items need to be prepared before teaching, and there were a lot of parts included in these kits that need to be organized and continuously cleaned up after activities. This can be alleviated by incorporating virtual options like virtual robotics and Scratch programming. Second, there were not many extra days in a school year to work robotics into a current math curriculum. Teachers do not have excess time to develop and incorporate these extra lessons (Gerretson et al., 2008; Leoste & Heidmets, 2019; Williams et al., 2012). The best use of physical or virtual technologies was as a supplement or a second-day activity for challenging math concepts. Finally, and most importantly, was the time component related to teachers. There would be a considerable amount of time committed to training current and future teachers, as well as the time required to prepare for lessons.

Experienced teachers might be reluctant to consider robotics, as this might be a technological challenge they prefer to avoid. Additionally, any other support personnel, like paraprofessionals, would need to be trained to support students in these classes (Kim et al., 2021; Leoste & Heidmets, 2020; Moreno-León et al., 2016; Forsström & Kaufmann, 2018; Zhong & Xia, 2020). This relates back to curriculum development, emphasizing the necessity for well-structured, concise, and practical lessons that can be integrated into the current math curriculum.

Key considerations must be explored for the integration of this technology into specific subjects in the math classroom. Significant attention needs to be devoted to connecting robotics and programming to other fields of mathematics, not just geometry (Forsström & Kaufmann, 2018; Gerretson et al., 2008). Geometry has many applications for this technology, but thoughtful consideration needs to be conducted for other content areas for mainstream implementation. Robots may have limited options in educational settings. Virtual options may provide the flexibility to offer more specific math content.

Cost was a significant factor in all aspects of education (Kim & Lee, 2016; Leoste & Heidmets, 2020; Shankar et al., 2013; Talan, 2021; Zhong & Xia, 2020). Robotics can have significant expenses not only during the initial acquisition but also throughout their lifecycle due to ongoing maintenance costs. Over time, robotics equipment might become obsolete. Manufacturers may discontinue specific models or versions of robotics equipment as they introduce newer and more advanced versions. This was witnessed multiple times in the literature review, even exemplified by the industry's leading company, LEGO. For example, LEGO Mindstorm was the number one robot used in the studies (Zhong & Xia, 2020), and it has been replaced with LEGO SPIKE, which has a cost of $399.95 and supports two students (LEGO Education, n.d.). One advantage of virtual robotics was its cost-effectiveness because it eliminates the need for physical components.

Space constraints pose challenges when accommodating robotics equipment in a traditional classroom setting (Benitti, 2012; Hussain et al., 2006; Talan, 2021; Zhong & Xia, 2020). Physical robots require dedicated space for storage and usage, which might pose challenges in classrooms with limited resources. The classroom environment differed significantly from a traditional classroom with students actively collaborating and freely moving around the space. Physical robotics requires students to spread out and work in groups, which can cause a hectic classroom environment (Leoste & Heidmets, 2020; Talan, 2021). An advantage of virtual robotics was that there were no space constraints. Additionally, virtual robotics can be used for remote learning, and the only requirement is internet access.

Many students tend to hold fixed beliefs about their mathematical abilities. The education system has created a binary system of: good or bad, right or wrong, smart or dumb, A or F. Students exhibit a fear of making mistakes in our traditional educational setting. Errors must be concealed and minimized as they serve as reminders of one's perceived inadequacy in mathematics and aversion to the subject. The programmer's mindset differs from this view because when you write code, you rarely get it right the first time (Papert, 1980). When programmers encounter errors, they do not view them as right or wrong, but rather as an opportunity to debug the program and find a solution (Brennan & Resnick, 2012; Chan et al., 2023; Ke, 2014; Papert, 1980). Errors were just stepping stones, providing valuable feedback and driving continuous improvement. These skills were the basis of computational thinking, which include debugging, iteration, and trial-and-error. Instead of approaching the problem as a whole, programmers adopt the strategy of breaking it down into smaller, manageable components and then seeking solutions for each part (Brennan & Resnick, 2012). The programmers' mindset of debugging can help students be uncritical of mistakes and break down problems into smaller component parts to be improved.

The conventional teacher-centered classroom should undergo a transformation towards a student-centered learning environment (Ardito et al., 2014; Barak & Assal, 2018; Berland &

Wilensky, 2015). In a teacher-centered classroom, students lack the active engagement and independent exploration provided by a hands-on activity like robotics. Teachers were viewed as guides who provide side-by-side learning rather than lecturers. The entire learning process should be considered. There were challenges with a student-centered classroom. Classroom management was more challenging because the learning environment was more chaotic (Berland & Wilensky, 2015). Traditional assessment methods need to be adapted, with students working collaboratively in groups and then being evaluated individually (Leoste & Heidmets, 2019).

This literature review reveals educational robotics' potential for learning and teaching mathematics. This thesis aims to offer guidance for educators, practitioners, and researchers interested in incorporating robotics into a mathematics curriculum.

Limitations of the Research

There are multiple areas of limitation provided in this literature review. Technology is rapidly evolving and is significantly impacting educational robotics. Only the most recent studies are most useful, and this required limiting the search criteria. There were some older articles available, but the technology was obsolete. The articles available for selecting ready-to-use information that educators could immediately bring into the classroom was a priority, but difficult to locate. Parts of these articles discussed socioeconomic factors, gender, and racial biases, but this was not the focus of this literature review. To apply the literature to the author’s professional context, research focused more on studies in grades six through eight, as well as studies that took place in a traditional classroom as opposed to an extracurricular activity or summer club elective.

Implications for Future Research

Future studies should be completed to find out how educational robotics can be incorporated into a mathematics classroom. The potential and need for this technology are crucial for students to stay competitive in this 21st-century environment. Firstly, longitudinal studies are crucial to determining the long-term impact and feasibility of robotics on students' problem-solving skills, motivation, and performance. These performance metrics need to be tied directly to state or national math standards. Additionally, exploring different educational robotics platforms and programming languages for diverse student populations could provide insights into mainstream integration. Future research should also focus on how to effectively integrate computational thinking, trial-and-error, and playfulness into robotics-based activities to promote problem-solving skills and creativity. Moreover, investigating the role of teacher professional development in enhancing robotics integration and teacher readiness is essential. Finally, artificial intelligence (AI) technology is growing at an exponential rate, with breakthroughs being made in various fields. The merger between AI and robotics is taking place and has broad implications for education.

Emerging research highlights the significance of standards-based considerations in shaping mathematics curriculum as demonstrated by Shivraj (2017). Shivraj's study sought to analyze the alignment between the content covered in the PISA assessment and the content standards designed for students using the Common Core State Standards in Mathematics. The goal was to foster the development of mathematical skills in students with the intention of applying these skills in a real-world setting. A noteworthy observation was the divergent traits of the U.S. standards, leaning more towards procedural aspects, in comparison to the analytical emphasis of PISA. Notably, the United States ranks third among OECD countries in education expenditure, highlighting the substantial investment in education. Finally, it was suggested that the education system has failed to effectively address the issue of the United States’ 'mile-wide and an inch-deep' curricula (Shivraj, 2017). These findings emphasize the growing importance of establishing a cohesive mathematics curriculum that aligns with both international benchmarks like PISA and the specific standards of U.S. state education systems. Further research in this direction can shed light on optimal approaches for achieving this alignment while fostering students' meaningful mathematical learning outcomes.

Conclusion

This literature review recommends the incorporation of educational robotics into mathematics. We are at the forefront of an educational renaissance by adapting new digital technologies in schools. Failure to expedite this process will have significant repercussions for future generations. Students have low motivation and a negative attitude towards mathematics, and robotics and programming can be seen as a solution. Many children do not view math as meaningful, fun, or useful, and this tedious subject matter could be more compellingly presented using the real-world, kinesthetic, interactive nature of robotics (Shankar et al., 2013).

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