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The Integration of Robotics in Mathematics Education: A Systematic Literature Review

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Abstract
The integration of robotics in mathematics education is of paramount importance, driven by the need for innovative teaching methods to engage students and enhance their mathematical learning experiences. This systematic literature review meticulously examined empirical studies using the PRISMA methodology, identifying 57 relevant papers from the Scopus and Web of Science (WOS) databases. After stringent selection criteria, 13 studies were chosen for comprehensive analysis. Findings highlight the transformative impact of robotics on students' mathematical proficiency and attitudes. Notably, robotics integration has led to improvements in comprehension, problem-solving skills, and overall interest in mathematics. However, challenges such as conceptual understanding difficulties and resource constraints persist. This review underscores the need for concerted efforts to address these challenges and capitalize on robotics' potential in mathematics education. Embracing innovative pedagogical approaches and leveraging technology advancements can create immersive learning environments. Further research is needed to explore specific mathematical subdomains and diverse educational contexts. In summary, this synthesis emphasizes the significance of robotics in mathematics education and provides practical insights for educators and policymakers. By overcoming challenges and delving into targeted research areas, robotics integration promises to enrich mathematics education and prepare students for the digital age.
Keywords: Robotics, Mathematics Education, Empirical, STEM Education

Introduction

The education sector has experienced remarkable technological advancements, with robotics emerging as a prominent field of research and innovation, encompassing diverse domains. Particularly intriguing is the intersection of robotics with mathematics education, where the integration of robots, programmable devices, and virtual simulations offers a transformative learning experience. This multifaceted approach seamlessly blends mathematical concepts with other disciplines, such as engineering, computer science, and physics, providing students with a profound understanding of how mathematics underpins the design, programming, and operation of robots (Çetin & Demircan, 2018). Through hands-on learning, students actively participate in constructing and programming tangible robots, enabling them to apply mathematical principles in real-world contexts, thus strengthening their comprehension of abstract concepts in practical settings.

A pivotal aspect of robotics in math education lies in its emphasis on problem-solving, as students engage in real-world challenges that demand the application of mathematical skills. This process fosters critical thinking and enhances problem-solving abilities, as students employ mathematical concepts to design and control robots efficiently. Furthermore, robotics encourages the exploration of geometry and measurement as students navigate robots, learning about geometric shapes, angles, distances, and coordinate systems (Kert et al., 2020). By programming robots with variables, formulas, and algebraic expressions, students reinforce their grasp of algebraic concepts, gaining valuable insights into the relevance of algebra in practical settings. Students also acquire data analysis skills by collecting and analyzing data from robot experiments, employing statistical methods and graphical representation techniques to interpret their findings.

Moreover, robotics cultivates proportional reasoning as students manipulate speed, distance, and time to dictate robot movements, unveiling the intricate relationships between variables. The creation of mathematical models to mirror robot behavior bridges the gap between abstract mathematical notions and their real-world applications (Silva et al., 2021). Robotics also entails pattern recognition, a key component of robot behavior, which aligns with mathematical pattern recognition and sequence analysis. The integration of coding and algorithms empowers students with fundamental programming skills and logical thinking, further enriching their problem-solving abilities.

For advanced robotics, students delve into concepts of kinematics and dynamics, intertwining mathematics with physics and engineering and offering a comprehensive understanding of mathematical principles' role in scientific domains. Collaboration and communication thrive as students work together to construct and program robots, fostering an environment of teamwork and collective learning (Chen & Chang, 2018). Inclusivity and diversity in mathematics education are enhanced through robotics, as it captivates students who may not have initially shown interest in math, creating an inclusive and engaging learning environment for all. Additionally, exposure to robotics sparks an awareness of STEM careers, emphasizing the significance of strong mathematical skills in the ever-evolving landscape of science, technology, engineering, and mathematics professions.

Within the context of the Fourth Industrial Revolution (4IR), characterized by the integration of digital, physical, and biological technologies, education faces the challenge of adapting to the changing needs of communities and economies (Mabinya et al., 2021). As a foundational subject, mathematics plays a pivotal role in nurturing critical thinking, problem-solving ability, and logical reasoning, which are highly sought-after competencies during the 4IR era (Naidoo and Singh-Pillay, 2020). The introduction of robots into classrooms has led to a quest for innovative approaches to integrate this emerging technology into mathematical teaching (Cahyono and Ludwig, 2018).

Despite the increasing interest and anecdotes from educators and students, the effectiveness of robotics in math education remains a subject of ongoing investigation, mainly due to the relatively new field of robotics in math education and the limited number of high-quality research studies available (Sauza et al., 2019). Methodological challenges, such as isolating the specific impact of robotics, controlling for confounding factors, and accurately measuring contributions, add complexity to the research landscape. Moreover, the diverse approaches

to implementing robotics in math education hinder direct comparisons and definitive conclusions (Messias et al., 2018). Addressing these challenges requires rigorous empirical research to strengthen the evidence base and comprehend fully the impact of robotics on learning outcomes.
The present systematic literature review aims to investigate the effects of using robotics in math education and provide valuable insights into its integration. The primary objective of this study is to explore empirical research on the impact of robotics in mathematics education. To achieve this, a comprehensive analysis of various research methodologies, data collection techniques, and analytical approaches used in existing studies will be conducted. Additionally, this study seeks to examine the impact of robotics on students' math achievement, including improvements in their conceptual understanding, problem-solving abilities, and overall academic performance. Furthermore, the influence of robotics on students' attitudes towards math will be evaluated, exploring potential changes in their levels of interest, enjoyment, and motivation. Finally, this study aims to identify the challenges and limitations associated with implementing robotics in math education, offering practical considerations and suggesting areas for improvement.
To address these research objectives, this systematic review will encompass research published since 2013, which specifically investigates the impact of robotics in math education. Four primary research questions will guide the investigation: (1) How are the effects of robotics in mathematics education investigated in empirical research?, (2) What are the effects of robotics in mathematics education on students' mathematical achievement?, (3) What is the effects of robotics in mathematics education on students' mathematical attitudes?, and (4) What challenges and limitations are associated with implementing robotics in mathematics education? By comprehensively analyzing the existing literature and drawing upon rigorous research methodologies, this systematic review endeavors to provide valuable insights into the role of robotics in mathematics education and contribute to a deeper understanding of its impact on students' learning outcomes and attitudes.

Methodology

A review that is clearly described and uses systematic and explicit techniques to search for, select, and critically evaluate relevant research, as well as to obtain and analyse data from the included studies, is called a systematic review (Moher et al., 2009). A systematic review of the research literature was conducted by consulting two databases, namely, Scopus and Web of Science. These databases collectively compile the majority of international educational research. There are two phrases for the search terms: robotics and mathematics. The search term "robotics" uses truncation to enable different forms of a word to be searched simultaneously. We put an asterisk (*) at the end of the word "robot" such as "robot*" to include search terms like robotic and. While the search term "mathematics" uses truncation at the end of the word "math" such as "math*" to include search terms like math, maths, mathematic, mathematics, and mathematical. Boolean Operator AND and OR are used to merge both phases. Therefore, the search terms for this systematic review were "robot*" AND "math*". In Scopus, the search terms mentioned in the title, abstract and/or keywords (TITLE-ABS-KEY). While in Web of Science, the search terms were mentioned in title (TI) and topic (TS). These search terms produced a total number of 185,655 results (39890 in Scopus, and 8343 in Web of Science). Narrowing down this number was done using the following criteria. First, the contributions had to be published in peer-reviewed journals and, secondly, written in English. These two selection criteria were applied to guarantee the inclusion of research of a scholarly and authoritative nature. Third, in order to respect the focus of this review study, to be selected the articles had to explicitly published between 2013 and 2023. Fourth, given the focus of this review with regard to the subject matter of the articles, the articles had to be about mathematics, and not about science or any other content area. Fifth, because of the nature of the questions that we asked for this study, we were only able to include publications that reported on empirical research and had to leave out papers that were solely conceptual or discussion pieces with all access. The sixth criterion emphasizes that empirical research should focus specifically on students rather than on in-service teachers or educators. The application of these six selection criteria resulted in a dataset of 57 research articles. Next, we conducted the selection process using PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) (Moher et al. 2009). In PRISMA, there are four phases: identification, screening, eligibility and included. The selection process in the four-phase shown in Figure 1. After a careful selection process, only 13 individual studies were selected for this analysis. We first conducted a vertical analysis or within-case analysis of each of the 13 research articles that were included in our dataset.

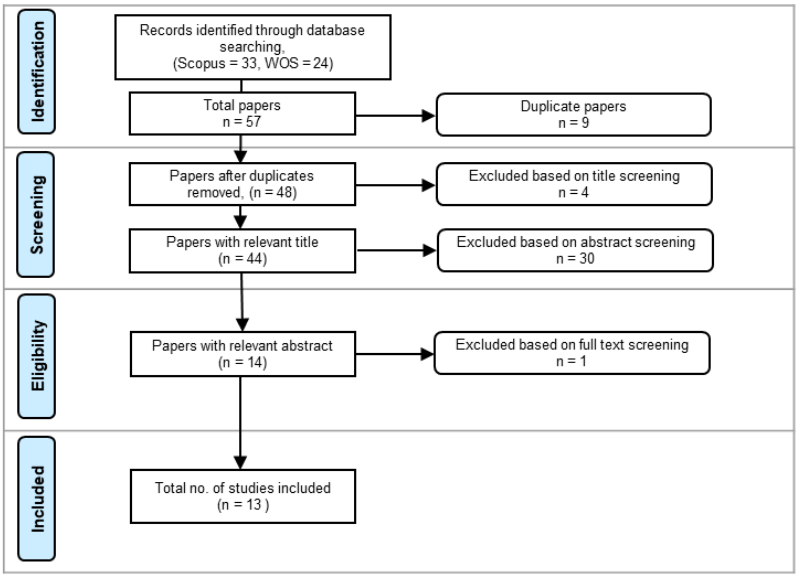

Figure 1. PRISMA flow diagram

In this vertical analysis, the unit of analysis was the article. Each article was analyzed and summarised using a classification scheme that included the following eight components: (1) the country in which the study was conducted; (2) the level of education; (3) the type of research; (4) the research design; (5) the mathematical subdomain; (6) the type of robot used; (7) research instruments; (8) the learning achievement; (9) the attitude effects and (10) the difficulties or challenges faced. Following the completion of this vertical analysis, we went on to conduct a horizontal analysis. This time, the unit of analysis was not a specific research paper but rather our four research questions and the ten components that were developed from them. We examined all of the articles that were included in our dataset for every single aspect, looking for systematic similarities and differences. In the following paragraphs, we will show the findings of this horizontal analysis with regard to the research questions. The first seven of these eleven components may be traced back to the first research question that we posed, while the later three of these components were generated from the second, third and fourth research questions that we posed. Following the completion of this vertical analysis, we went on to conduct a horizontal analysis. This time, the unit of analysis was not a specific research paper but rather our two research questions and the eight components that were developed from them. We examined all of the articles that were included in our dataset for every single aspect, looking for systematic similarities and differences. In the following paragraphs, we will show the findings of this horizontal analysis with regard to both of the research questions.

Findings/Results

The country in which the study was conducted

Table 1

Country Analysis of Studies Conducted

Continent	Country	N	Research
Amerika Utara	Amerika Syarikat	4	Garofalo, Sandler & Seth (2020), Kimm & Chaffers (2019), Francis et al. (2022), Chen et al. (2020)
	Guatemala	1	Canek, Torres & Rodas (2020)
	Mexico	1	Lopez-Caudana et al. (2021)
Amerika Selatan	Brazil	1	Chen et al. (2020)
Eropah	Czech Republic	1	Coufal (2022)
	Spain	4	Plaza et al. (2019), Hilario et al. (2022), Garcia-Piqueras & Ruiz-Gallardo (2021), Seckel et al. (2022)
Asia	Taiwan	1	Wang (2016)

***N = Number of Articles**

Based on Table 1, in North America, four studies from the United States explored this topic, including research by (Garofalo et al., 2020; Kimm and Chaffers, 2019; Francis et al., 2022; Chen et al., 2020). Guatemala had one study conducted by Canek, Torres, and Rodas (2020), while Mexico had a study by (Lopez-Caudana et al., 2021). In South America, Brazil had one study by (Chen et al., 2020). Moving to Europe, the Czech Republic had one study by Coufal (2022), and Spain had four studies by (Plaza et al., 2019; Hilario et al., 2022; Garcia-Piqueras & Ruiz-Gallardo, 2021; Seckel et al., 2022). Finally, in Asia, there was one study conducted in Taiwan by (Wang, 2016). These studies collectively examined the investigation of the effects of robotics in mathematics education, the impact on students' mathematical achievement, the influence on students' mathematical attitudes, and the challenges and limitations associated with implementing robotics in this educational context.

The level of education

Table 2

The level of education studied

Education Level	N	Research
Primary Education	4	Coufal (2022), Francis et al. (2022), Plaza et al. (2019), Seckel et al. (2022)
Secondary Education	4	Chen et al. (2020), Wang (2016), Da Cruz Silva & De Oliveira Costa (2022), Garcia-Piqueras & Ruiz-Gallardo (2021)
Tertiary Education	3	Garofalo, Sandler & Seth (2020), Kimm & Chaffers (2019), Hilario et al. (2022)
Primary & Secondary Education	1	Lopez-Caudana et al. (2021)
Primary, Secondary and Tertiary Education	1	Canek, Torres & Rodas (2020)

*N = Number of Articles

The effects of robotics in mathematics education have been investigated across different education levels in Table 2. Studies focusing on primary education include those by (Coufal, 2022; Francis et al., 2022; Plaza et al., 2019; Seckel et al., 2022). In the context of secondary education, research has been conducted by (Chen et al., 2020; Wang, 2016; Da Cruz Silva and De Oliveira Costa, 2022); Garcia-Piqueras and Ruiz-Gallardo, 2021). Tertiary education has also been a focus, with studies by (Garofalo et al., 2020; Kimm and Chaffers, 2019; Hilario et al., 2022). Additionally, the effects of robotics in mathematics education have been examined in a combined primary and secondary education setting by Lopez-Caudana et al (2021), as well as in the context of primary, secondary, and tertiary education by (Canek et al., 2020).

The mathematical subdomain

Table 3

The mathematical subdomains associated in this study

Mathematical Subdomain	N	Research
Algebra	2	Lopez-Caudana et al. (2021), Wang (2016)
Geometry	5	Lopez-Caudana et al. (2021), Seckel et al. (2022), Chen et al. (2020), Wang (2016), Garcia-Piqueras & Ruiz-Gallardo (2021)
Trigonometry	3	Lopez-Caudana et al. (2021), Da Cruz Silva & De Oliveira Costa (2022), Garcia-Piqueras & Ruiz-Gallardo (2021)
Problem Solving	1	Coufal (2022)
Spatial Reasoning	1	Francis et al. (2022)
Not mention	2	Kimm & Chaffers (2019), Hilario et al. (2022)

*N = Number of Articles

Empirical research on the effects of robotics in mathematics education has investigated various mathematical subdomains in Table 3. Studies focusing on algebra include those by (Lopez-Caudana et al., 2021; Wang, 2016). Geometry has been a prominent subdomain, with studies conducted by (Lopez-Caudana et al., 2021; Seckel et al., 2022; Chen et al., 2020; Wang, 2016; Garcia-Piqueras and Ruiz-Gallardo, 2021). Trigonometry has also been explored, as evidenced by studies by (Lopez-Caudana et al., 2021; Da Cruz Silva and De Oliveira Costa, 2022; Garcia-Piqueras and Ruiz-Gallardo, 2021). Coufal (2022) focused on problem-solving, while Francis et al (2022) investigated spatial reasoning. Additionally, Kimm and Chaffers (2019); Hilario et al (2022) explored the effects of robotics in mathematics education without specifying a particular subdomain.

The type of research

Table 4

The type of research studied

The Type of Research	N	Research
Mixed	5	Canek, Torres & Rodas (2020), Lopez-Caudana et al. (2021), Wang (2016), Kimm & Chaffers (2019), Seckel et al. (2022)
Qualitative	1	Plaza et al. (2019)
Quantitative	7	Chen et al. (2020), Coufal (2022), Francis et al. (2022), Da Cruz Silva & De Oliveira Costa (2022), Garcia-Piqueras & Ruiz-Gallardo (2021), Garofalo, Sandler & Seth (2020), and Hilario et al. (2022)

*N = Number of Articles

Table 4 shows empirical research on the effects of robotics in mathematics education has employed a variety of research methods. Five studies, including Canek et al (2020); Lopez-Caudana et al (2021); Wang (2016); Kimm and Chaffers (2019); Seckel et al (2022), utilized mixed methods approaches to investigate these effects. One study, conducted by Plaza et al (2019), employed qualitative research methods. Quantitative research methods were utilized in seven studies, including (Chen et al., 2020; Coufal, 2022; Francis et al., 2022; Da Cruz Silva and De Oliveira Costa, 2022; Garcia-Piqueras and Ruiz-Gallardo, 2021; Garofalo et al., 2020; Hilario et al., 2022).

The Research Design

Table 5

The research design used

Research Design	N	Research
Case study	6	Lopez-Caudana et al. (2021), Canek, Torres & Rodas (2020), Wang (2016), Plaza et al. (2019), Seckel et al. (2022), and Kimm & Chaffers (2019)
Experimental	1	Hilario et al. (2022)
Pre-test/post-test	4	Coufal (2022), Francis et al. (2022), Da Cruz Silva & De Oliveira Costa (2022), and Garcia-Piqueras & Ruiz-Gallardo (2021)
Quasi-experimental	2	Chen et al. (2020) and Garofalo, Sandler & Seth (2020)

*N = Number of Articles

Empirical research on the effects of robotics in mathematics education has employed various research designs. Based on Table 5, case studies were the most commonly used design, with six studies utilizing this approach, including (Lopez-Caudana et al., 2021; Canek et al., 2020; Wang, 2016; Plaza et al., 2019; Seckel et al., 2022; Kimm and Chaffers, 2019). One study, conducted by Hilario et al (2022), employed an experimental design. Four studies utilized a pre-test/post-test design, including (Coufal, 2022; Francis et al., 2022; Da Cruz Silva and De Oliveira Costa, 2022; Garcia-Piqueras and Ruiz-Gallardo, 2021). Two studies used a quasi-experimental design, namely (Chen et al., 2020; Garofalo et al., 2020).

The type of robot used

Table 6

The type of robot used in the research

Type of robot	N	Research
LEGO EV3	6	Coufal (2022), Francis et al. (2022), Lopez-Caudana et al. (2021), Wang (2016), Da Cruz Silva & De Oliveira Costa (2022), and Hilario et al. (2022)
Bee-Bot	1	Seckel et al. (2022)
Crumble	1	Plaza et al. (2019)
CubeSat	1	Garcia-Piqueras & Ruiz-Gallardo (2021)
PUMA 560	1	Kimm & Chaffers (2019)
Self-driving mini racing car	1	Chen et al. (2020)
Snake jaw robot	1	Garofalo, Sandler & Seth (2020)
Various	1	Canek, Torres & Rodas (2020)

*N = Number of Articles

Table 6 shows empirical research on the effects of robotics in mathematics education has investigated the use of various types of robots. The LEGO EV3 robot was the most commonly used, with six studies employing this robot (Coufal, 2022; Francis et al., 2022; Lopez-Caudana et al., 2021; Wang, 2016; Da Cruz Silva & De Oliveira Costa, 2022; Hilario et al., 2022). Other robots used in the studies include the Bee-Bot Seckel et al (2022), Crumble Plaza et al (2019), CubeSat Garcia-Piqueras & Ruiz-Gallardo (2021), PUMA 560 (Kimm & Chaffers, 2019), self-driving mini racing car Chen et al (2020), snake jaw robot Garofalo et al (2020), and various types of robots (Canek et al., 2020).

Research Instruments

Table 7

The research instruments

Research Instrument	N	Research
Document Analysis	3	Lopez-Caudana et al. (2021), Garcia-Piqueras & Ruiz-Gallardo (2021), Canek, Torres & Rodas (2020)
Observation	3	Lopez-Caudana et al. (2021), Kimm & Chaffers (2019), Wang (2016)
Pre-test and post-test	4	Chen et al. (2020), Wang (2016), Hilario et al. (2022), Da Cruz Silva & De Oliveira Costa (2022)
Semi-structured interview	1	Seckel et al. (2022)
Survey	4	Seckel et al. (2022), Kimm & Chaffers (2019), Garofalo, Sandler & Seth (2020), Canek, Torres & Rodas (2020)
Test	3	Lopez-Caudana et al. (2021), Coufal (2022), Francis et al. (2022)
Interview	3	Kimm & Chaffers (2019), Wang (2016), Plaza et al. (2019)

*N = Number of Articles

Document analysis was used in three studies, including Lopez-Caudana et al. (2021), Garcia-Piqueras and Ruiz-Gallardo (2021), and Canek, Torres, and Rodas (2020). Observation was employed in three studies (Lopez-Caudana et al., 2021; Kimm & Chaffers, 2019; Wang, 2016). A pre-test and post-test design was utilized in four studies (Chen et al., 2020; Wang, 2016; Hilario et al., 2022; Da Cruz Silva & De Oliveira Costa, 2022). Seckel et al. (2022) conducted a study using a semi-structured interview. Surveys were utilized in four studies (Seckel et al., 2022; Kimm & Chaffers, 2019; Garofalo, Sandler, & Seth, 2020; Canek, Torres, & Rodas, 2020). Tests were employed in three studies (Lopez-Caudana et al., 2021; Coufal, 2022; Francis et al., 2022). Lastly, interviews were utilized in three studies (Kimm & Chaffers, 2019; Wang, 2016; Plaza et al., 2019).

The effects of robotics in mathematics education on students' mathematical achievement

Table 8

The learning outcomes from robotics in mathematics education

Learning Outcome	N	Research
Academic Performance	1	Garcia-Piqueras & Ruiz-Gallardo (2021)
Career and Interest	1	Garofalo, Sandler & Seth (2020)
Cognitive Abilities	5	Coufal (2022), Francis et al. (2022), Lopez-Caudana et al. (2021), Da Cruz Silva & De Oliveira Costa (2022) and Seckel et al. (2022)
Knowledge and Skills	6	Canek, Torres & Rodas (2020), Wang (2016), Plaza et al. (2019), Kimm & Chaffers (2019), Hilario et al. (2022) and Chen et al. (2020)

*N = Number of Articles

The findings from the reviewed literature suggest that the effects of robotics in mathematics education have been investigated in relation to various learning outcomes. Academic performance was examined in one study (Garcia-Piqueras & Ruiz-Gallardo, 2021), while another study explored career and interest outcomes (Garofalo, Sandler, & Seth, 2020). Cognitive abilities were the focus of investigation in five studies (Coufal, 2022; Francis et al., 2022; Lopez-Caudana et al., 2021; Da Cruz Silva & De Oliveira Costa, 2022; Seckel et al., 2022). Additionally, six studies assessed knowledge and skills (Canek, Torres, & Rodas, 2020; Wang, 2016; Plaza et al., 2019; Kimm & Chaffers, 2019; Hilario et al., 2022; Chen et al., 2020), highlighting the diverse range of learning outcomes investigated in relation to robotics in mathematics education.

The effects of robotics in mathematics education on students' mathematical attitudes

Table 9

The attitudes impacts from robotics in mathematics education

Attitude impacts	N	Research
Improved Attitudes towards STEM Subjects and Careers	4	Chen et al. (2020), Canek, Torres & Rodas (2020), Wang (2016) and Kimm & Chaffers (2019)
Increased Interest and Motivation in Mathematics	4	Lopez-Caudana et al. (2021), Da Cruz Silva & De Oliveira Costa (2022), Seckel et al. (2022), and Garcia-Piqueras & Ruiz-Gallardo (2021)
Positive attitude towards STEM education	5	Coufal (2022), Francis et al. (2022), Plaza et al. (2019), Garofalo, Sandler & Seth (2020), and Hilario et al. (2022)

*N = Number of Articles

Empirical research has shown that robotics in mathematics education has a positive impact on students' attitudes. Robotics interventions were shown to improve attitudes towards STEM subjects and careers in four studies (Chen et al., 2020; Canek, Torres, & Rodas, 2020; Wang, 2016; Kimm & Chaffers, 2019). Robotics also increased students' interest and motivation in mathematics, as found in another four studies (Lopez-Caudana et al., 2021; Da Cruz Silva & De Oliveira Costa, 2022; Seckel et al., 2022; Garcia-Piqueras & Ruiz-Gallardo, 2021). Furthermore, five studies demonstrated a positive attitude towards STEM education when robotics was integrated into mathematics instruction (Coufal, 2022; Francis et al., 2022; Plaza et al., 2019; Garofalo et al., 2020; Hilario et al., 2022).

Challenges and limitations associated with implementing robotics in mathematics education

Table 10
The Difficulties challenge implementing robotics in mathematics education

Difficulties challenge	N	Research
Conceptual Understanding	2	Da Cruz Silva & De Oliveira Costa (2022) and Plaza et al. (2019)
Material and Time Constraints	1	Garcia-Piqueras & Ruiz-Gallardo (2021)
Programming Challenges	5	Coufal (2022), Francis et al. (2022), Wang (2016), Garofalo, Sandler & Seth (2020) and Hilario et al. (2022)
Resource and Technical Constraints	4	Canek, Torres & Rodas (2020), Lopez-Caudana et al. (2021), Seckel et al. (2022) and Kimm & Chaffers (2019)

*N = Number of Articles

Based on Table 10, shows several challenges and limitations associated with implementing robotics in mathematics education. Difficulties in conceptual understanding were highlighted in two studies (Da Cruz Silva & De Oliveira Costa, 2022; Plaza et al., 2019). Garcia-Piqueras and Ruiz-Gallardo (2021) focused on material and time constraints. Programming challenges were identified as significant difficulties in five studies (Coufal, 2022; Francis et al., 2022; Wang, 2016; Garofalo, Sandler, & Seth, 2020; Hilario et al., 2022). Additionally, resource and technical constraints were emphasized as challenges in four studies (Canek, Torres, & Rodas, 2020; Lopez-Caudana et al., 2021; Seckel et al., 2022; Kimm & Chaffers, 2019).

Discussion

Exploring the Role of Robotics in Mathematics Education through Empirical Research

The reviewed studies demonstrate several strengths. Firstly, they employ diverse research designs, including case studies, experimental designs, pre-test/post-test designs, and quasi-experimental designs, which enhance the comprehensiveness of the findings. Secondly, the studies cover a wide range of educational levels, from primary to tertiary education, providing a comprehensive understanding of the effects of robotics in mathematics education across different age groups. Thirdly, the studies utilize various types of robots, such as LEGO EV3, Bee-Bot, Crumble, CubeSat, PUMA 560, self-driving mini racing car, and snake jaw robot, allowing for a comprehensive analysis of the effects of different robotics platforms on mathematics education.

The systematic literature review highlights several gaps and areas for future research. Firstly, there is a need for more research in diverse geographical contexts to ensure the generalizability of the findings. Secondly, more studies are needed to explore the effects of robotics in specific mathematical subdomains, as most studies have focused on general mathematics education. Additionally, future research could investigate the long-term effects of robotics in mathematics education, as many of the reviewed studies focused on short-term outcomes. Moreover, further research is needed to examine the differential effects of robotics in mathematics education across various student populations, such as students with different backgrounds, abilities, and learning styles.

The Impact of Robotics in Mathematics Education on Students' Mathematical Achievement

The existing body of literature suggests that researchers have examined the impact of robotics on mathematics education with regards to a range of learning outcomes. The aforementioned outcomes encompass various aspects such as academic performance, cognitive abilities, knowledge acquisition, and skill development. Several research studies have investigated the influence of robotics on students' academic performance, revealing favorable outcomes in terms of improving mathematical attainment. Previous studies have directed their attention towards the cognitive capacities exhibited by students, revealing enhancements in critical thinking, problem-solving, and logical reasoning proficiencies. Furthermore, the utilization of robotics in mathematics education has been observed to have a positive impact on the acquisition of knowledge and skills, particularly in areas such as mathematical comprehension and proficiency in specific mathematical subfields.

The Impact of Robotics in Mathematics Education on Students' Mathematical Attitudes

The results indicate that the incorporation of robotics into mathematics instruction yields favorable outcomes in terms of students' attitudes towards STEM disciplines and professional pathways. The implementation of robotics interventions among students resulted in a notable enhancement in their inclination and enthusiasm towards mathematics, consequently fostering more positive dispositions towards STEM education. The integration of robotics into mathematics education has been correlated with a favorable influence on students' attitudes, cultivating an enhanced recognition and enthusiasm for the subject of mathematics.

Challenges and Limitations Associated with the Implementation of Robotics in Mathematics Education

The study revealed a number of obstacles and constraints that are linked to the integration of robotics into mathematics instruction. One of the challenges encountered by individuals pertained to the acquisition of conceptual comprehension, specifically in comprehending intricate mathematical principles associated with the field of robotics. The discussion also emphasized the importance of having appropriate resources and a suitable timeframe to ensure successful implementation, taking into account material and time limitations. The presence of programming challenges has been identified as a notable obstacle, suggesting that both students and educators encountered difficulties in effectively programming robots. Challenges related to resource and technical constraints were also identified, underscoring the importance of adequate resources and technical assistance for the seamless integration process. It is of utmost importance to confront and overcome these challenges in order to fully exploit the potential advantages of incorporating robotics into mathematics education.

In general, the literature review reveals various effects of robotics on mathematics education, encompassing enhancements in students' mathematical performance and cognitive skills, as well as favorable shifts in their attitudes towards mathematics and STEM disciplines. Nevertheless, it is imperative to recognize the obstacles and constraints associated with the implementation of robotics in order to achieve a seamless integration and optimize its advantages in the realm of mathematics education. Additional investigation is required in this domain to enhance our comprehension of the influence of robotics in the field of mathematics education and to rectify the deficiencies and methodological constraints present in the current body of literature.

Conclusion

The review identified a range of empirical research studies that investigated the effects of robotics on students' mathematical achievement and attitudes. The studies employed various research designs and covered different educational levels. The findings indicated that robotics in mathematics education has a positive impact on students' mathematical achievement, with improvements in mathematical skills and performance. Additionally, robotics activities were found to positively influence students' mathematical attitudes, including increased interest, motivation, and positive attitudes towards STEM subjects and careers. However, implementing robotics in mathematics education presents certain challenges and limitations, such as conceptual understanding difficulties, programming challenges, and resource constraints.

The research questions posed in this study have been addressed based on the findings of the literature review. Firstly, the effects of robotics in mathematics education were investigated through empirical research utilizing mixed methods, qualitative, and quantitative approaches. Secondly, the effects of robotics on students' mathematical achievement were examined, and evidence indicated positive impacts on improving mathematical skills and performance. Thirdly, the impact of robotics in mathematics education on students' mathematical attitudes was explored, revealing increased interest, motivation, and positive attitudes towards STEM subjects and careers. Lastly, the challenges and limitations associated with implementing robotics in mathematics education were identified, including conceptual understanding difficulties, programming challenges, and resource constraints.

The findings of this systematic literature review highlight the potential of robotics in mathematics education to enhance students' mathematical achievement and attitudes. The positive effects observed suggest that integrating robotics activities into mathematics instruction can engage students and promote active learning. However, it is important to address the challenges and limitations associated with implementing robotics, such as providing adequate support, addressing programming difficulties, and ensuring equitable access to resources. The identified gaps and areas for future research provide directions for further exploration, including investigating the effects of robotics in specific mathematical subdomains, exploring long-term outcomes, and examining the differential effects on diverse student populations. These insights have implications for educators, policymakers, and researchers in shaping effective practices and policies in the field of robotics in mathematics education.

Limitations

There are some limitations to consider. Firstly, the geographical distribution of the studies is skewed towards North America and Spain, with limited representation from other regions. This may limit the generalizability of the findings to a broader context. Secondly, there is a lack of studies focusing on specific mathematical subdomains, with only a few studies examining algebra, geometry, trigonometry, problem-solving, and spatial reasoning. Future research could explore the effects of robotics in mathematics education within specific subdomains to gain more in-depth insights

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