



# Educational robotics in mathematics education: A systematic review

Marcelo Ibáñez-Carrasco <sup>1</sup>

 0009-0004-6050-235X

Carolina Henríquez-Rivas <sup>1\*</sup>

 0000-0002-4869-828X

<sup>1</sup> Facultad de Ciencias Básicas, Universidad Católica del Maule, Talca, CHILE

\* Corresponding author: [chenriquezr@ucm.cl](mailto:chenriquezr@ucm.cl)

**Citation:** Ibáñez-Carrasco, M., & Henríquez-Rivas, C. (2026). Educational robotics in mathematics education: A systematic review. *European Journal of Science and Mathematics Education*, 14(2), 222-240. <https://doi.org/10.30935/scimath/18086>

## ARTICLE INFO

Received: 29 Sep 2025

Accepted: 25 Jan 2026

## ABSTRACT

The implementation of technology in mathematics education signifies an interactive and dynamic learning experience, and educational robotics (ER) in particular has the potential to improve teaching and learning environments in mathematics education. The objective of the present study is to provide a current overview of the literature on robotics in mathematics education and, in turn, to identify the less explored aspects of this area along with emerging directions and ideas, with the aim of defining future research perspectives in robot-assisted mathematics teaching. Forty-four articles were selected from the Web of Science and Scopus databases through keyword searches and the preferred reporting items for systematic review and meta-analyses method, with all works published since 2020. The results indicate that ER plays a positive role in different aspects of mathematics education, both for students at all educational levels and for pre-service and practicing teachers. However, contradictions exist in certain results obtained in the studies reviewed. Ultimately, future research perspectives and challenges for the use of ER in mathematics education are analyzed.

**Keywords:** educational robotics, mathematics education, systematic review, educational technology

## INTRODUCTION

In recent years, digital technologies have become an established tool that facilitates and complements the education system. According to Muñoz et al. (2020), technology in education has contributed significantly to the revitalization of teaching methods. Likewise, international institutions emphasize the importance of integrating these technologies into teaching practices (European Commission, 2022; Organization for Economic Co-operation and Development [OECD], 2022). Within this context, the present study is a literature review centered specifically on studies on robotics in mathematics education.

As technology and technological devices have become progressively more accessible to teachers, perceptions of the benefits they can offer for enhancing teaching and learning have likewise increased (De la Hoz et al., 2024; Lai et al., 2023). In this line, authors including Cascales et al. (2017) have highlighted the need to include different and alternative technologies in education in order to adequately respond to students' learning needs, increase the resources available for teaching, and contextualize the content being taught. Among these classroom technologies, educational robotics (ER) stands out as a tool defined by the use of programmable robots that allow for the exploration and construction of teaching content (Scaradozzi et al., 2019). ER fosters the development of mathematical processes such as spatial thinking, mathematization, and measurement (González-Calero et al., 2019; Sung et al., 2017), in addition to facilitating the development of skills including computational thinking (CT) among students (Seckel et al., 2023). The latter is a 21<sup>st</sup> century skill that new generations must develop in order to adequately respond to the social requirements of the

coming decades (Zhang & Nouri, 2019). ER has already been integrated into the education system, gaining great momentum in the past several years, which has led to new curricular reform in various countries (Hsu et al., 2019; Soto-Ardila et al., 2020).

In this manner, ER has been utilized to facilitate processes of teaching and learning in diverse areas encompassing science, technology, engineering, and mathematics (STEM) (Plangg & Fuchs, 2022; Rahman, 2021). In mathematics teaching specifically, various authors have reported on how the use of ER helps to contextualize content when teaching and achieve greater understanding of a given material (Aslan et al., 2024; Vitale & Iacono, 2024). In addition, it facilitates the reinforcement of specific disciplinary challenges for students, including problem-solving, visualization, algorithmic thinking, abstraction, pattern recognition, and modeling (Al-Nawaiseh et al., 2024; Lee et al., 2023; Tzagkaraki et al., 2021). However, during recent years, the adoption of more advanced technologies in mathematics education has stalled (Bulut & Borromeo-Ferri, 2023), and some research cautions that mathematics could be relegated to the margins or merely serve as a data representation tool within STEM activities, or that it could be otherwise integrated into said activities in a manner that does not include concrete learning improvements in mathematics (Coad, 2016; Goos et al., 2023).

Other findings indicate that ER has a positive effect on students in areas including interest, knowledge construction, motivation, collaboration, and critical thinking (Lopez-Caudana et al., 2020; Varaman et al., 2024). Additionally, a positive increase in knowledge has been observed among students with learning disorders (Arshad et al., 2020), along with cognitive development in different areas of learning in multigrade classrooms (Castro et al., 2023).

Meanwhile, findings show that the use of robots in initial teacher training has improved levels of self-confidence for implementing this technology in future classes (De la Hoz et al., 2024), affording both pedagogical and content skills, along with greater motivation (Casler-Failing, 2021; Sala-Sebastià et al., 2023; Soto-Ardila et al., 2020). Likewise, it has been demonstrated that teachers who have participated in ER training programs have a greater predisposition to implement these tools in the future (You et al., 2021). However, some authors state that ER is not capable of transmitting theoretical concepts effectively (Reyes et al., 2021), and therefore, its use amounts to a support tool for teachers. In this sense, it should be noted that factors including teachers' lack of experience in technological integration, high numbers of students, and the high cost of robotics kits restrict its implementation (Seckel et al., 2021; Silva et al., 2024; Soto-Ardila et al., 2020).

In accordance with the above, the present study seeks to provide a current overview of research conducted on robotics in mathematics education. In turn, it also aims to identify less explored aspects, as well emerging directions and ideas, with the objective of contributing to the community of researchers in this area.

## CONCEPTUAL FRAMEWORK

This section presents the general conceptual framework that underpins the research reviewed in this study: CT and ER in mathematics education.

### Computational Thinking

Today, CT is considered an essential 21<sup>st</sup> century skill that must be developed among the citizenry (Brennan & Resnick, 2012). For this reason, a growing number of international education systems have incorporated it into their programs (Hsu et al., 2019; Soto-Ardila et al., 2020; Zhang & Nouri, 2019). One strategy for introducing CT into the curriculum is integrating it into an existing subject. Specifically, it has been noted that it can be joined with mathematics education, given the link between CT and mathematical thinking (Papert, 1980), which could lay the groundwork for establishing definitions, encouraging more abstract thinking, and using notation specific to the area (Miller, 2019).

CT is considered to be a set of skills that involves the process of problem-solving, systems design, and the understanding of human behavior through abstraction or decomposition when solving a complex task or system using heuristic reasoning (Wing, 2006). Fuchs and Caba (2016) offer an algorithmic vision of this skill type, describing it as the ability to analyze tasks, formulate steps that allow for the associated problems to be solved, and define a program in order to arrive at the solution. This type of thinking entails the development of fundamental skills such as matching, sequencing, decomposition, and pattern creation (Lee et al., 2023).

In addition, the incorporation of CT into learning assumes that students can become active participants in the construction of their knowledge, promoting critical and analytical thinking (Davide, 2021; Voogt et al., 2015). Moreover, activities involving the use of programming facilitate the development of abilities inherent to computer science including abstraction, debugging, and remixing for problem-solving (Lye & Koh, 2014), among these activities, those based on RE stand out as a suitable resource that fosters this type of thinking (Seckel et al., 2023).

### ER and Mathematics Education

The integration of robotics in education (RIE) has its origins in the late 1960s with the use of a mobile, programmable turtle as part of the Logo Project (Feurzeig & Papert, 2011; Papert, 1980). This early example suggests how students who participate in the programming of a robot can explore spatial concepts, measurement, and geometry, along with taking part in metacognitive processes when problem-solving (Clements & Meredith, 1992). The learning outcomes expected from the application of this type of tool correspond to the development of varied skills including problem-solving and CT, self-efficacy, creativity, motivation, and collaboration (Dong et al., 2023; Evripidou et al., 2020; Tzagkarakaki et al., 2021).

In the use of robots in the educational sphere, a distinction is made between the concepts of RiE and ER (Scaradozzi et al., 2019). The former is a broader term referring to how robotics can aid people in the field of education, such as helping a student with disabilities overcome their limitations. The latter term refers to incorporating robotics into education with the objective of creating meaningful experiences that allow students to explore notions of content and surroundings, develop their skills, and acquire new knowledge. The present study is focused on the latter concept (ER).

For their part, Scaradozzi et al. (2019) classify the use of robotic devices in educational activities into four principal areas:

- (1) *assistive robots*, which help students overcome physical disabilities that limit their practice of educational activities;
- (2) *social assistive robots*, which are capable of helping users through social interaction, providing emotional, cognitive, and social signals suited to promoting learning development;
- (3) *social robots*, which can accompany students in their learning in the role of a peer or teacher by interacting to carry out various tasks; and
- (4) *educational robots*, which help students develop skills related to technology and teaching as a teaching support tool, which requires a basic understanding of the fundamentals of robotics.

Likewise, the use of robots in mathematics education as an intermediary in learning provides students with the opportunity to participate interactively in the process of acquisition and construction of knowledge, promotes diverse mathematical representations, facilitates the processes of mathematization, and encourages challenging real-world applications (Carreira & Jacinto, 2019; Shankar et al., 2013; Wei & Hung, 2011). Thus, ER as a teaching support tool allows for the development of students' mathematical skills through the programming of robots, creating new scenarios in which students learn specific curricular content and the fundamentals of robotics in a teaching environment nurtured by creativity and experimentation (Athanasiou et al., 2019; Scaradozzi et al., 2019; Seckel et al., 2023). Likewise, ER encourages the possibility of development of interdisciplinary and transdisciplinary activities, in addition to an integrated STEM focus (Eguchi, 2014).

### Research Questions

In order to elucidate the accumulated progress and research advances of ER in mathematics education in recent years, this study is organized based on the following research questions:

1. How is research on mathematics education supported by ER distributed in bibliometric terms, such as educational level of participants, stated methodological aspects, year of publication, and country of origin of the research?

**Table 1.** Inclusion and exclusion criteria

Inclusion criteria (IC)	Exclusion criteria (EC)
IC1. Studies conducted at all educational levels.	EC1. Studies that do not include mathematics education.
IC2. Studies focused on the teaching or learning of given mathematical contents with use of robotics.	EC2. Studies not published in English, Spanish, or Portuguese.
IC3. Studies published in English, Spanish, or Portuguese on mathematics teaching with the use of robots.	EC3. Conference proceedings, books, articles in press, and book chapters.
IC4. Scientific articles.	EC4. Studies not indexed in either of the databases included in IC5.
IC5. Studies indexed in WoS and Scopus databases.	EC5. Studies published before 2020.
IC6. Studies published between 2020 and 2025.	EC6. Studies that consider ER but are not focused on mathematical contents.

2. What are the research questions or objectives addressed by these studies? Likewise, what related factors can be determined, such as which mathematical domain predominates in the study and what type of robot is utilized?
3. Which theoretical or conceptual perspectives underpin these studies? And more specifically, are other disciplines explicitly considered in the research?
4. Finally, what challenges and future research opportunities are proposed in the studies reviewed in terms of mathematics education? By the same token, what tensions and contradictory results have these studies produced?

## METHODOLOGY

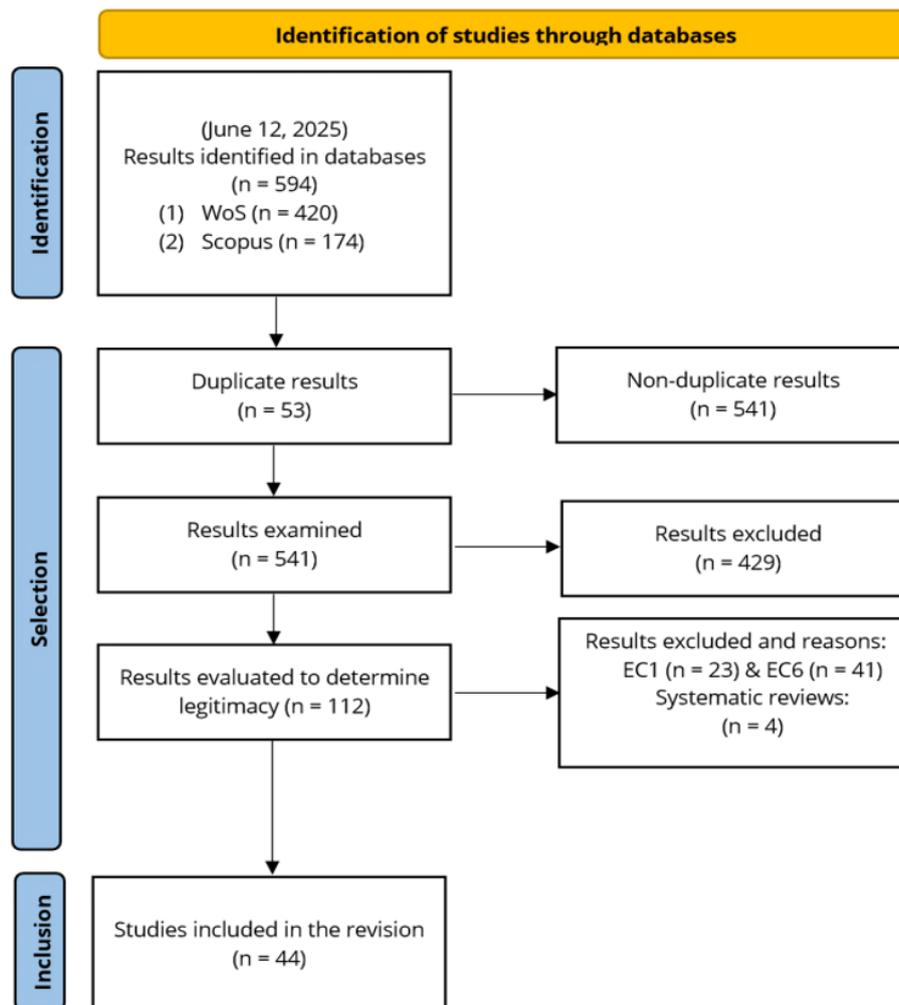
This review is based on the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines (Page et al., 2021), given that PRISMA allows for responding to the research questions posed by identifying the main topics of research interest and systematizing the search for and review of literature.

Regarding the selection of articles, the final bibliographic search was conducted on June 12, 2025. To identify the studies, the high-impact scientific databases Web of Science (WoS) and Scopus were utilized since they have high-quality indexing standards and contain numerous studies in the field of educational sciences, particularly on mathematics education. The search included the terms robotics\*, education\*, and mathematics\*, and, including asterisks (\*) to include all variations of each term, all were connected through the Boolean operator AND. The search included articles published during the last five years with the aim of demonstrating the most recent results and advances in the implementation of robotics in mathematics education at the international level.

Additionally, the manuscript selection process also considered translations into Spanish and Portuguese, as journals that accept work in these languages were considered. The selection process is carried out in three main stages: identification, selection, and inclusion (Page et al., 2021). In the *identification* stage, search strings were used in the two aforementioned databases, yielding 594 documents. In the *selection* stage, the documents obtained were exported to Excel to detect and eliminate duplicates, which involved remove 53 studies (duplicates). Subsequently, the titles, abstracts, and keywords of the remaining 541 documents were reviewed, discarding 429 for not belonging to the social sciences or having no relation to educational research. To finalize the selection stage, the inclusion and exclusion criteria (Table 1), were applied by reviewing the abstracts and full-text versions of the remaining 112 studies. In the final *inclusion*, 44 articles are included that support this review.

The complete article selection process—beginning with the 594 documents returned initially and ending with a final stage that included the 44 articles considered in this review—is presented in the following flowchart (Figure 1).

The data analysis began with a coding process guided by the research questions presented above; one of the researchers initially selected and organized the publications, allowing them to assign codes. Subsequently, the other researcher reviewed the work performed to ensure the consistency of the coding. In the following stage, the researchers collaboratively discussed the process, allowing them to refine the criteria applied and



**Figure 1.** Flowchart of the article selection process (the authors' own work)

reach a consensus when reviewing the codes, assembling them, and then interpreting the information (Creswell & Creswell, 2018).

The articles were examined using the method of qualitative content analysis (Kuckartz & Rädiker, 2023). To address the first research question, the bibliometric factors addressed in the studies were categorized according to the following: number of participants; educational level of participants; methodological approach utilized; year of publication; and country of origin of the research. For the second question, thematic analysis was conducted (Braun & Clarke, 2006), based on an inductive process, on the objectives and/or research questions of the studies, the mathematical domains involved, and the types of robots utilized. Subsequently, the theoretical and/or conceptual frameworks utilized in the studies were identified, together with other possible disciplines with which robotics is integrated in mathematics teaching. Finally, based on the discussions and conclusions presented by the authors of the studies, challenges and/or future opportunities in ER research in the area of mathematics education were identified.

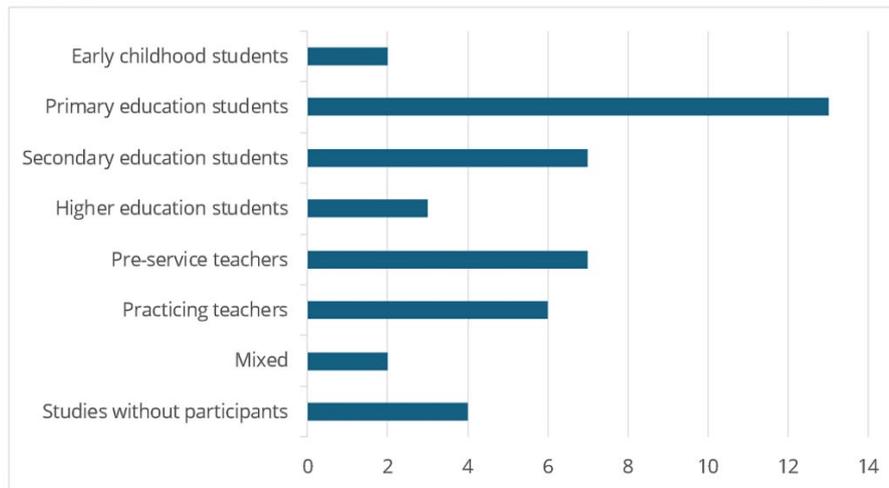
## RESULTS

The results from the 44 articles analyzed are presented below.

### Bibliometric and Methodological Aspects

#### *Educational level of participants*

**Figure 2** exhibits the coding of the studies based on the distribution of study participants, showing that ER in mathematics education is present at all educational levels. The educational level of study participants



**Figure 2.** Distribution of type of study participants in the articles analyzed (the authors' own work)

**Table 2.** Sample sizes of studies analyzed and participant categories

Sample size	Students (all levels)	Pre-service teachers	Practicing teachers	Number of studies
1-10	3	2	3	8
11-25	4	2	0	6
26-50	7	1	2	10
51-100	6	1	1	8
> 100	4	1	0	5
Not specified	3	0	0	3
No participants	4	0	0	4
Total	31	7	6	44

with greatest frequency is primary school students ( $n = 13$ ), followed by secondary school students and pre-service teachers ( $n = 7$ ), practicing teachers ( $n = 6$ ), higher education students ( $n = 3$ ), and lastly, early childhood students ( $n = 2$ ), this being the least studied level. Meanwhile, some studies encompass more than one educational level and are classified as mixed ( $n = 2$ ), and some research is focused on the design of robotic prototypes without implementation ( $n = 4$ ).

Regarding the distribution of study participants, it is evident that most of the research focuses on students at some educational level ( $n = 27$ ) and a smaller proportion on teachers, either pre-service or practicing ( $n = 13$ ), with the remainder ( $n = 4$ ) corresponding to studies without participants.

### Sample sizes

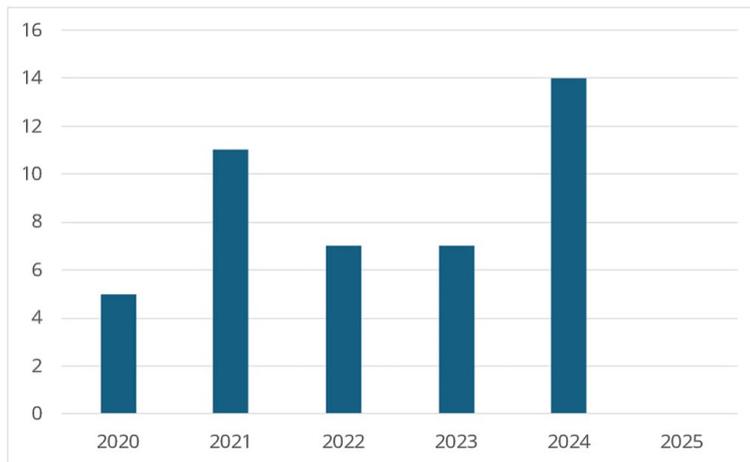
**Table 2** illustrates the analysis of the sample size of each study. The most frequent range is 26 to 50 participants ( $n = 10$ ), and in general, the majority of studies have fewer than 50 participants ( $n = 24$ ). Meanwhile, eight studies work with a sample size of 51 to 100 participants, and 5 studies have more representative samples of greater than 100 participants. Additionally, the sample size of the research studies is analyzed according to the types of study participants, considering three categories: students (early childhood through higher education); pre-service teachers; and practicing teachers. The results of this categorization highlight a scarcity of larger-scale studies focused on pre-service and practicing teachers.

### Methodological approach utilized

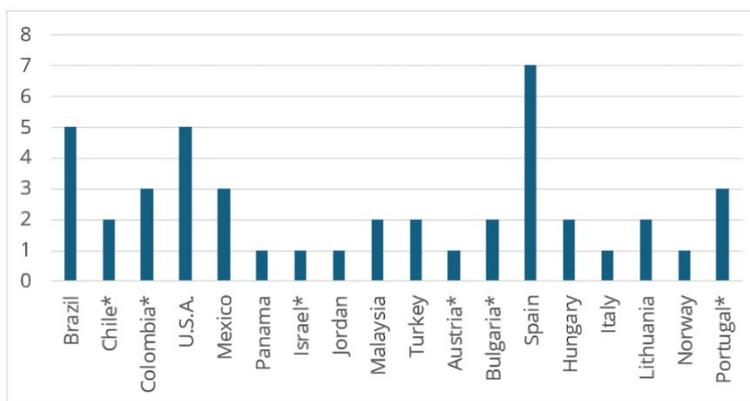
In terms of study type, four of the 44 articles analyzed are theoretical studies, while 40 are empirical studies. Moreover, as illustrated in **Table 3**, the majority of the empirical studies employ a qualitative approach ( $n = 20$ ), most frequently based on case studies ( $n = 5$ ) and action research ( $n = 4$ ). Meanwhile, within the quantitative studies ( $n = 9$ ), the quasi-experimental design predominates ( $n = 5$ ), and the smallest category of empirical studies is mixed method ( $n = 8$ ). In seven studies, it is not possible to identify the research approach used, as it is not explicitly specified.

**Table 3.** Research methodology utilized in the studies analyzed

Methodological approach	Number of articles
Qualitative	20
Quantitative	9
Mixed method	8
Not specified	7
Total	44



**Figure 3.** Distribution of studies according to publication year (the authors' own work)



**Figure 4.** Frequency based on research country of origin (the authors' own work)

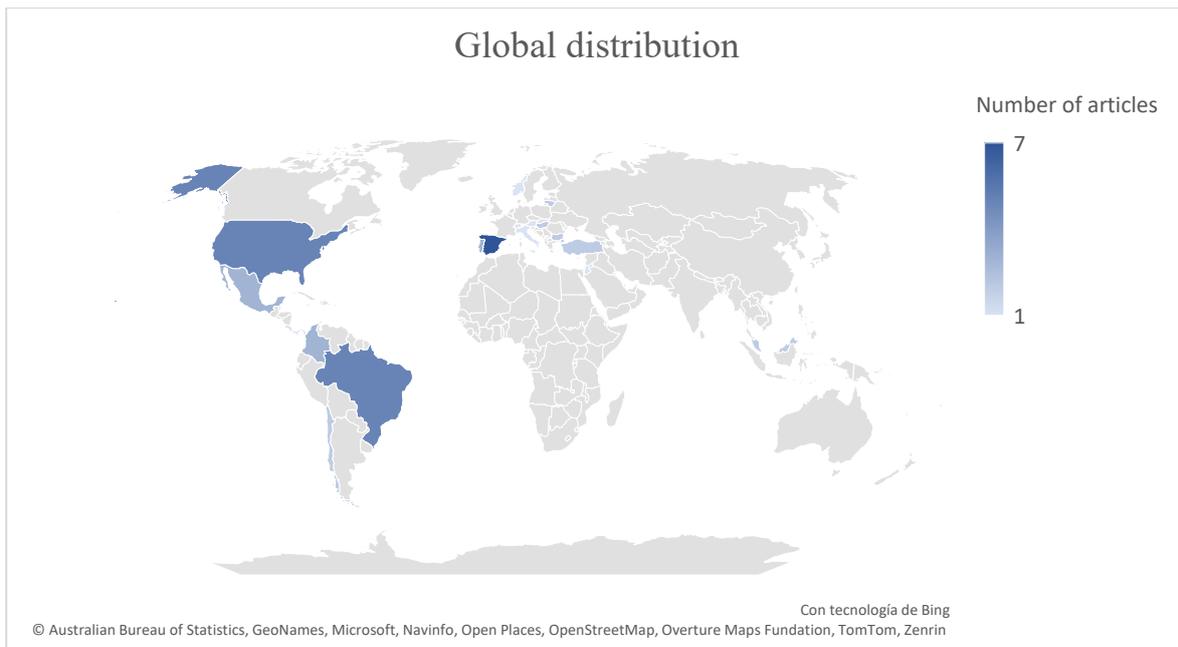
### Year of publication

**Figure 3** displays a highly variable trend in the year of publication of articles related to ER. In 2024, the largest number of articles was published ( $n = 14$ ), followed by 2021 ( $n = 11$ ). Meanwhile, 2025 has not yielded any published studies related to the topic in question, but this is likely due to the date on which the final search was conducted for the review.

### Research country of origin

The results regarding the geographic distribution of research on the use of ER reveal that the majority of studies are concentrated in the Americas ( $n = 19$ ) and Europe ( $n = 18$ ). In particular, countries such as Brazil, the USA, and Spain lead in the quantity of studies (see **Figure 4**), with the latter having the largest number ( $n = 7$ ).

As can be observed in **Figure 5**, a relatively small number of studies have been conducted in Asia ( $n = 6$ ). The continents of Africa and Oceania, meanwhile, do not present any studies related to the topic at hand. Regarding the language of publication, the majority of studies appear in English-language journals ( $n = 32$ ), with smaller numbers in Spanish ( $n = 7$ ) and Portuguese ( $n = 5$ ).



**Figure 5.** Geographic distribution of research country of origin (the authors' own work)

**Table 4.** Classification of research objectives and/or questions in articles analyzed

Categories	n
1. Investigating the effect of a robotics intervention in mathematics education in an exploratory manner.	14
2. Understanding the effect of implementing ER in mathematics education.	5
3. Investigating pre-service or practicing teachers' perceptions on the use of ER in mathematics education.	6
4. Characterizing the knowledge of pre-service or practicing teachers when implementing ER in their practice.	8
5. Designing a methodology or technical tool for implementing ER in mathematics education.	7
6. Not explicitly stated.	4
Total	44

Note. n: Number of articles

## Research Objectives Addressed, Mathematical Domains, and Robot Types

### Research objectives addressed

The research objectives or questions posed by the studies reviewed are organized into five categories that comprise the purposes of the studies (see [Table 4](#)).

The first category refers to studies whose research objective or question is to carry out teaching interventions in mathematics education through the use of ER in an exploratory manner, with the aim of reporting preliminary results. Meanwhile, research in the second category seeks to understand the effects of ER interventions through a broader study type, comparing results using control groups, longitudinal studies, or studies encompassing different educational levels to draw conclusions on the effectiveness of the use of these tools.

The third category includes studies that aim to investigate pre-service or practicing teachers' perceptions about the use of ER in mathematics education. These perceptions are based on interventions carried out previously, or on the experience pre-service teachers have had in their professional practicum. The fourth category includes research on pre-service or practicing teachers that attempts to characterize their knowledge when implementing teaching sequences with students using educational robots; these studies generally seek conclusions on the training or tools that teachers possess to implement ER in an adequate manner.

Lastly, the fifth category encompasses studies that examine the development of a teaching design or technological tool meant to complement the implementation of ER in mathematics education. Some of these studies are theoretical in nature and present a design without implementation, while others include a piloting stage. A final point that should be noted is that a minority of articles do not explicitly indicate the research objective or question.

**Table 5.** Distribution of mathematical domains in studies analyzed

Mathematical domain	n
Numbers	6
Algebra	1
Geometry	21
Statistics/probability	0
Two or more domains	4
Not specified	4
Research without teaching a specific content (or specific domain)	8
Total	44

Note. n: Number of articles

**Table 6.** Robot type utilized in studies analyzed

Robot type	n
Arduino	3
Bee-bot	1
Blue-Bot	1
Fischer-technik	1
LEGO	18
M-bot	2
MindDesigner	1
NAO	2
Pepper	1
Photon	1
Rero-Micro	1
TI-Innovator Rover	1
More than one robot type	7
Not specified	2
Not utilized	2
Total	44

Note. n: Number of articles

### **Mathematical domain prioritized**

In relation to the mathematical domains prioritized for teaching and learning content in the studies reviewed, it is clear that the most common domain is geometry ( $n = 21$ ) (see [Table 5](#)). Other studies are approached from the domains of numbers ( $n = 6$ ) and algebra ( $n = 1$ ), while no studies were encountered in statistics or probability. Moreover, four studies encompass more than one mathematical domain, and four do not specify the content or domain addressed. A further eight studies are not focused on researching the teaching or learning of specific mathematical content using ER, as they are aimed at understanding mathematics teachers' perceptions on the use of these tools or the development of a prototype.

### **Robot types utilized**

Regarding the robot types utilized, specific robot kits are mentioned in 40 articles, and in the remaining four, two do not specify the robot type used while the other two do not utilize specific robotics kits because they are focused on participants' perceptions about implementing these tools. As shown in [Table 6](#), the most commonly used robotics kits are LEGO ( $n = 18$ ), and 7 studies use more than one type of robot in their investigation. Three studies, meanwhile, create their own robots using recycled materials with the support of open-source robots supported on Arduino.

### **Theoretical or Conceptual Perspectives**

This subsection considers the frameworks utilized to support the research reviewed. The articles in question define various concepts associated with the area of study that will be used in the analysis of the results of this research. In the case of the use of theories, the explicit presentation of theoretical constructs or models associated with mathematics education or related fields is considered, applied to the design of teaching proposals or the analysis of results obtained.

**Table 7.** Types of theoretical perspectives utilized in the studies analyzed

Conceptual or theoretical perspectives	n
Learning paths	1
Universal design for learning	1
Information ecology	1
Active learning	1
Inventive learning	1
Spiral approach	1
STEM	1
Octalysis framework	1
PBL	2
OSA	3
TPACK	3
STEAM	5
Total	21

Note. n: Number of articles

**Table 8.** Distribution of disciplines linked with mathematics in the studies analyzed

Discipline	n
STEM	3
Natural Sciences	5
STEAM	5
No links with other disciplines and/or none stated	31
Total	44

Note. n: Number of articles

Twenty-two of the studies are based on a framework related to definitions of concepts associated with the teaching of mathematics using robots. Of these, 21 studies indicate the use of a theoretical perspective, while one work does not explicitly state the use of any of the perspectives mentioned.

In terms of the theoretical constructs or models utilized, the science, technology, engineering, arts, and mathematics (STEAM) perspective is the most frequent (see [Table 7](#)), especially for the design of multidisciplinary teaching proposals. Furthermore, the onto-semiotic approach (OAS) (Godino et al., 2007) and the technological pedagogical content knowledge (TPACK) model (Mishra & Koehler, 2006) are also present in the studies reviewed, mainly used for the analysis of participants' knowledge. Finally, problem-based learning (Barrows & Tamblyn, 1980) is employed in the design of teaching proposals. Additional perspectives are likewise considered in the literature, including, for example, universal design for learning.

### ***Disciplines integrated with mathematics***

In relation to other disciplines linked to the teaching of mathematics using robots, the present study considers those that authors have explicitly stated in their research. As shown in [Table 8](#), the majority of the studies reviewed (n = 31) do not relate mathematics with one or more other disciplines. On the other hand, 13 studies do make this connection, either with STEM, STEAM, or the natural sciences.

## **Challenges and Opportunities**

### ***Learning outcomes of mathematics education***

The articles analyzed have been reviewed in-depth with the aim of uncovering challenges and opportunities for the development of future research from the perspective of mathematics education utilizing ER. Notably, 23 of the articles assert cognitive improvements related to the teaching of mathematical content in comparison to traditional methods. This is especially evidenced in studies that specify how ER leads to greater concept acquisition in students (e.g., Soto-Ardila et al., 2021), with these results persisting for several weeks following the intervention (Ceylan & Aslan, 2024). Nevertheless, these studies also conclude that it is necessary to complement the use of ER tools with adequate teacher participation in order to achieve effective learning (Lopez-Caudana et al., 2020).

### ***Development of mathematical skills in students***

Seventeen of the studies analyzed conclude that interventions based on ER serve a dual purpose for mathematical learning. This is demonstrated by the parallel development of certain skills, including critical and analytical thinking, logic, creativity, and problem-solving (Kim et al., 2021; Ybarra & Soares, 2022). Additionally, ER fosters a better understanding of spatial relationships (Aslan et al., 2024), and it contributes to the development of CT (Ceylan & Aslan, 2024; De la Hoz Serrano et al., 2024; Muñoz et al., 2020), visualization, and multiple representations (Körei & Szilágyi, 2024).

### ***Improvements in student attitudes in the classroom***

Meanwhile, in 23 of the 44 studies analyzed, the investigators explicitly state how certain student behaviors in the classroom have improved with the implementation of ER to teach specific content. For example, da Silveira Guimarães et al. (2021) indicate that the course becomes more attractive when working with content that is joined with the digital culture of children and youth; in addition, an increase in students' interest, participation, and motivation regarding classroom activities has been reported with ER (Amador-Terrón et al., 2022). There is also evidence of a greater level of attention in general within the course (da Silva & da Costa Barbosa, 2021), along with increased self-efficacy (Daher, 2022), reduction of anxiety (Gomes et al., 2023), and improvements in collaborative work among peers (Ortega et al., 2021).

### ***Teacher perspectives on the use of educational robotics***

Sixteen articles demonstrate how pre-service or practicing teachers who participate in ER-based activities develop a better attitude and willingness to implement these technologies in the future practice. Likewise, their perceptions improve regarding the benefits these tools offer for students' learning and skill development (Castro et al., 2023; Bento-Miguens et al., 2024).

Conversely, 18 studies report difficulties or obstacles for teachers when implementing ER. In these cases, authors mention that the lack of knowledge or experience on the part of teachers in incorporating these tools constrains their practice and performance; it is therefore necessary to train teachers with methods and strategies to implement ER properly (Casler-Failing & Collins, 2022). By the same token, teachers' preparation is an important factor to consider in that the more prepared and comfortable they are with these tools, the better they will be able to plan and adapt their teaching strategies (Lopez-Caudana et al., 2020). Indeed, some teachers recognize that activities utilizing ER require extensive planning and design (Amador-Terrón et al., 2022); in addition, some express concern about their lessons becoming ludic activities without underlying mathematical learning (Reyes et al., 2021).

### ***Limitations and difficulties reported in studies***

In 27 studies, another type of limitation recognized is that is associated with the number of participants, suggesting that other types of sampling methods should be considered for participant selection (Kim et al., 2021). In this sense, it is further proposed that research in this area should be extended to other institution types, educational levels, degree programs, and countries and regions (De la Hoz et al., 2024). Additionally, it is important that longitudinal studies be conducted to corroborate the results obtained in the long term (Arshad et al., 2020). On another note, the use of only one type of robot can also limit the results obtained, as the programming language can vary from one kit to the next, with some being highly specific and tailored to certain school levels (Castro et al., 2023). In a broader sense, some authors call attention to the need to incorporate control groups to distinguish and compare results, with the aim of generalizing the findings obtained (Bento-Miguens et al., 2024; De la Hoz Serrano et al., 2024).

On the other hand, 11 studies report weaknesses in the robotic tools themselves in terms of the possibility of classroom implementation, which include the following: being limited to acting as an assistance tool solely for the teacher, together with the high cost of robotics kits, does not allow enough students to work with the robots (da Silveira Guimarães et al., 2021); not all establishments can have teachers trained in the use of these tools or count on adequate laboratories or technical infrastructure (Bento-Miguens et al., 2024; Szilágyi et al., 2024); and lastly, the high number of students in some classrooms and limited space constrains the development of collaborative work with ER (Seckel et al., 2021).

### **Learning inequalities in the classroom**

In a significant number of studies ( $n = 14$ ), ER is presented as a relatively new classroom support tool that needs to be researched further, emphasizing teaching practices and questioning whether they respond effectively to the diversity of students present in today's classrooms (Lengua-Cantero et al., 2022). Some articles state that robots have a positive impact on the development of cognitive capacities in children with learning disorders such as autism spectrum disorder (ASD) and dyscalculia (Arshad et al., 2020; Lengua-Cantero et al., 2022). Likewise, authors report the ER allows for the reduction of inequalities for students in rural schools related to digital literacy and knowledge (Castro et al., 2023). It is also suggested that the use of ER could reduce gender gaps, fostering favorable attitudes toward science, mathematics, and technology, especially among women (De la Hoz et al., 2024; Plangg & Fuchs, 2022).

### **Tensions and Contradictory Results Reported**

Regarding the actual impact of ER in mathematics education, some studies have demonstrated contradictory results regarding mathematical learning achieved when compared with traditional methods. Although a large number of studies affirm favorable cognitive results when using these types of tools (e.g., Arshad et al. 2020; Aslan et al. 2024; Castañeda-Miranda et al. 2021; Gomes et al. 2023; Varaman et al. 2024), others show no significant differences between teaching using robotics and regular classes (e.g., Castro et al. 2023; Daher, 2022; Sáez-López & Buceta-Otero, 2023). Likewise, another contradiction has emerged regarding the duration that these interventions should have; authors such as Amador-Terrón et al. (2022) and De la Hoz Serrano et al. (2024) conclude the longitudinal studies would allow for more significant results, while others state that brief interventions have shown favorable results with students and pre-service teachers (Silva et al., 2024; Vitalle & Iacono, 2024). Meanwhile, numerous tensions have been reported in the studies analyzed, principally in relation to challenges in the implementation of ER by teachers (Al-Nawaiseh et al. 2024), the high cost of these tools (da Silveira Guimarães et al., 2021), and the limited validity of findings stemming from methodological designs (Casler-Failing & Collins, 2022).

## **DISCUSSION AND CONCLUSIONS**

This study presents the current state of research on mathematics education using ER based on the analysis of a selection of 44 articles published since 2020. The results reveal ER to be an emerging and important area of study within mathematics education, a conclusion reached through the study of bibliometric characteristics, the revision of research questions and/or objectives, the analysis of the theoretical and/or conceptual perspectives with which research has been developed, and the identification of the main challenges and opportunities recognized by researchers regarding this area.

Regarding the first research question, the results indicate that although studies on ER are distributed across all educational levels, early childhood and higher education are the least explored in terms of this type of tool. Likewise, there are few studies focused on pre-service or practicing teachers; it is necessary to investigate these subjects further in order to offer a comparison with the limited results obtained thus far (Sala-Sebastià et al., 2023). Apart from that issue, in the majority of studies analyzed, the sample sizes are relatively small, with convenience sampling and quasi-experimental designs predominating (Kim et al., 2021). Therefore, in future research, participant numbers could be increased, and different sampling methods and more thorough methodological designs could be considered.

As demonstrated, an increase in the number of publications can be observed to date in the period analyzed, with a maximum of 14 in 2024; this tendency underlines the potential of continued research related to ER in mathematics education in the future. In terms of where these studies have originated, the analysis reveals that Spain ( $n = 7$ ), the USA ( $n = 5$ ), and Brazil ( $n = 5$ ) predominate. In general, there is relatively scarce representation from the Southern Hemisphere, pointing to a need to generate more research in this region. Meanwhile, regarding the methodologies utilized, qualitative approaches prevail, and while this is beneficial in terms of gaining a deeper understanding of the study area, it is necessary to be able to expand research to include mixed or quantitative methods in order to obtain results on a larger scale.

Regarding the second research question, the analysis highlights that nearly a third of the studies (14) are centered on investigating the effects of interventions that use educational robots in mathematics education. The majority of these studies are exploratory in character and most note positive results; however, some report that no meaningful improvements have been demonstrated compared to traditional methods (Sáez-López & Buceta-Otero, 2023). Future research could include more studies that address the teaching of specific mathematical content using ER, as well as examining whether initial results are maintained over time (De la Hoz Serrano et al., 2024).

In terms of the predominant mathematical domains present in the research, in almost half of the articles analyzed ( $n = 21$ ), contents related to geometry are addressed, followed by numbers. This could be due to the fact that these ER tools are notably tangible and easy to observe for students. It follows that pre-service teachers report that the same contents are the most adaptable for utilizing ER (Amador-Terrón et al., 2022). In future research, ER could be studied further in relation to algebra, or in relation to statistics or probability; likewise, more research could be conducted focusing on more than one mathematical domain.

Meanwhile, regarding the question of robot types, although a great variety of robotics kits are available on the market, the most common by far in the articles studied are LEGO robots ( $n = 18$ ), which are relatively expensive, making it difficult to work with a large number of them (Körei & Szilágyi, 2024; Soto-Ardila et al., 2020). Moreover, it is necessary to implement ER interventions with multiple robot types in order to compare results (Casler-Failing & Collins, 2022). Some of the other studies reviewed, for their part, highlight the development of low-cost robots built using recycled parts and open-source hardware including Arduino (da Silva & da Costa Barbosa, 2021; da Silveira Guimarães et al., 2021). Considering these different possibilities, it is important to develop future research to explore the potential of open-source robotics kits in mathematics education in greater depth, in comparison with other commercial kits.

The third research question examines the theoretical and conceptual perspectives used by researchers to analyze the results obtained when implementing ER. In this respect, half of the articles reviewed utilize definitions of concepts associated with the use of robots in mathematics education, and 21 studies employ at least one theoretical perspective, with the most frequently used being STEAM, followed by the OSA and the TPACK model. Some authors emphasize the importance of developing learning sequences with ER grounded in theories of learning (Aslan et al., 2024), and the importance of employing theoretical frameworks specific to the field of mathematics education is also underscored (Sala-Sebastià et al., 2023). This leaves ample room for future research considering diverse theories or perspectives that could enrich the design of ER proposals and their outcomes.

Regarding interdisciplinary integration in the studies analyzed, a limited number of such proposals is evident, as the majority of studies (31) do not connect mathematics teaching with other disciplines. This is inconsistent with the potential that ER possesses to incorporate integrated STEM or STEAM approaches (Eguchi, 2014; Körei & Szilágyi, 2024). At the same time, these results coincide with the class designs proposed by mathematics teachers in training when developing tasks that do not promote the representation or writing of algorithms and have a limited interdisciplinary approach to incorporating this type of support tool (Sala-Sebastià et al., 2023). Therefore, future research should consider teaching designs that incorporate interdisciplinarity in order to enrich proposals for the incorporation of ER and take greater advantage of the potential offered by robotics in mathematics education.

Addressing the fourth research question, the main challenges that authors posit relate to difficulties associated with the high cost of these tools, large class sizes, and limited resources available at educational establishments, together with often inadequate infrastructure. For example, Ortega et al. (2021) assert the need to research the development of other types of lower-cost robots while maintaining the essential characteristics for their correct usage and easy handling by students. Considering this challenge, future studies could explore the use or development of robotics tools that are more accessible for the educational community.

Likewise, some authors report difficulties related to the training that teachers have, both as pre-service teachers and in continuing education, to incorporate ER tools into their teaching practices; specific factors including lack of knowledge, experience, and time available are most frequently cited. Researchers conclude that pre-service teachers should receive more training in the use of this type of technology during their degree

programs in order to facilitate greater implementation in the classroom (Casler-Failing, 2021). In this vein, further research could investigate how training programs or capacitation in ER influence pre-service teachers' future practices. Moreover, researchers affirm that the results obtained in such studies should be corroborated through the use of more than one robot type and consider different programming languages; they also identify the need for longitudinal studies, incorporation of control groups, and comparison of results at different educational levels.

On the other hand, among the opportunities afforded by the use of ER in mathematics education, its potential to improve students' attitudes in class stands out in terms of both increased interest and greater participation and motivation (Daher, 2022; Ortega et al., 2021). Moreover, authors conclude that interventions supported by this type of tool promote the development of mathematical skills or competencies in students, such as critical thinking, creativity, problem-solving, visualization, spatial reasoning, and CT (De la Hoz Serrano et al., 2024; Ybarra & Soares, 2022). These results are promising, though it should be noted that the majority of these studies are preliminary, based on small sample sizes, and framed within exploratory contexts. Accordingly, future studies could investigate how ER facilitates the development of these mathematical abilities through larger-scale studies, and with a focus on the specific mathematical abilities.

By the same token, researchers state that pre-service and practicing teachers who participate in activities involving ER may develop a better attitude and greater disposition toward implementing it, as well as building positive perceptions about its potential in mathematics teaching and skills development (Castro et al., 2023). In addition, ER has been demonstrated to be a valuable assistance tool in the classroom, producing positive results in the development of cognitive abilities among students with learning disorders, for example, dyscalculia or ASD (Arshad et al., 2020; Lengua-Cantero et al., 2022). Likewise, it could be a tool that helps to reduce gender differences and encourage positive attitudes toward science, mathematics, and technology, especially among women (De la Hoz et al., 2024). The latter should be explored further to provide more empirical evidence to deepen and consolidate existing results, also considering the sociocultural contexts of the participants.

### Concluding Observations

The digital era in which we live increasingly promotes the integration of contemporary technologies into the classroom. In this respect, various studies have focused on reviewing the scientific literature related to the impact of programming and robotics on teaching and learning mathematics at the primary school level (Ortiz, 2023; Seckel et al., 2023). The present study seeks to broaden the scope of this work by focusing on all educational levels and including pre-service and practicing teachers in order to provide an extensive and complete account of the current state of the use of ER in mathematics education. In this manner, the analysis of the 44 selected articles has highlighted the importance of integrating educational robots in the teaching and learning of mathematics for improving various factors related to students' attitudes during classes (Amador-Terrón et al., 2022; da Silveira Guimarães et al., 2021). Moreover, ER possesses a dual purpose, on the one hand for students' learning, as it fosters the development of certain mathematical competencies or skills (Ceylan & Aslan, 2024; Kim et al., 2021), and on the other hand for the practices of pre-service and in-service teachers, among whom it promotes positive perceptions about its own use and potential benefits for pupils (Bento-Miguens et al., 2024; Sáez-López & Buceta-Otero, 2023).

However, in spite of the latter, further research is still needed in other aspects of ER where current studies have produced contradictory results, such as the impact of ER on the cognitive development of students to improve learning outcomes for mathematical content when compared to traditional methods. Likewise, some researchers point to promising results from short periods of intervention (Kim et al., 2021), while others indicate that students exposed to ER during a greater number of sessions obtained more meaningful results (Lopez-Caudana et al., 2020).

While the findings exhibited are promising, these tools are not considered a definitive solution to the problems that comprise this field of study; rather, ER represents an assistance tool for teachers, who in turn require the training necessary to take full advantage of its potential in cognitive, skills, and interdisciplinary development with their students, with the aim of enriching mathematical learning.

## Limitations

Finally, the limitations of the present study relate to two aspects: first, the searches were limited to journals indexed in the WoS and Scopus databases, excluding research related to this area of interest published in other journals and databases. In light of this limitation, future reviews could consider additional sources, as well as other source types including book chapters and conference proceedings in mathematics education. Second, other ways of coding could be considered for the information presented in the studies analyzed, including categories focused on how robots are integrated with mathematics and the duration of interventions using robotics. However, this study provides a reliable account of the scientific development realized thus far in research on mathematics education using ER, which is presented as a contribution to the research community in mathematics education.

**Author contributions:** **MI-C:** conceptualization, data curation, resources, formal analysis, writing – original draft, writing – review & editing, visualization; **CH-R:** writing – review & editing, supervision, visualization, conceptualization, methodology, resources, formal analysis. Both authors agreed with the results and conclusions. Both authors approved the final version of the article.

**Funding:** This study was funded by National Research and Development Agency of Chile, under the Fondo Nacional de Desarrollo Científico y Tecnológico de Iniciación 2023, Folio 11230523. Furthermore, Marcelo Ibáñez-Carrasco expresses his gratitude to the Beca de Magíster Nacional, Folio 22250730.

**Ethics declaration:** This study was approved by the Institutional Review Board at Universidad Católica del Maule on 28 April 2025 with approval number 54/2025.

**AI statement:** The authors stated that no generative artificial intelligence tools will be used during the preparation of this manuscript.

**Declaration of interest:** The authors declared no competing interest.

**Data availability:** Data generated or analyzed during this study are available from the authors on request.

## REFERENCES

- Al-Nawaiseh, S. J., Tabieh, A. A. S., Maqableh, W. F., Altawalbeh, M., & Ahmad, F. B. (2024). The effectiveness of using educational robots in enhancing engineering mathematics skills among students in basic school. *International Journal of Education and Practice*, 12(3), 906-921. <https://doi.org/10.18488/61.v12i3.3768>
- Amador-Terrón, S., Carvalho, J. L., & Melo, L. (2022). Teaching mathematics with the support of robotics: The opinion of future primary school teachers. *Prisma Social*, 38, 114-136.
- Arshad, N. I., Hashim, A. S., Mohd Ariffin, M., Mohd Aszemi, N., Low, H. M., & Norman, A. A. (2020). Robots as assistive technology tools to enhance cognitive abilities and Foster valuable learning experiences among young children with autism spectrum disorder. *IEEE Access*, 8, 116279-116291. <https://doi.org/10.1109/ACCESS.2020.3001629>
- Aslan, D., Dağaynası, S., & Ceylan, M. (2024). Technology and geometry: Fostering young children's geometrical concepts through a research-based robotic coding program. *Education and Information Technologies*, 29(17), 22699-22721. <https://doi.org/10.1007/s10639-024-12747-3>
- Athanasiou, L., Mikropoulos, T. A., & Mavridis, D. (2019). Robotics interventions for improving educational outcomes—A meta-analysis. In M. Tsitouridou, J. Diniz, & T. Mikropoulos (Eds.), *Technology and innovation in learning, teaching and education* (pp. 91-102). Springer. [https://doi.org/10.1007/978-3-030-20954-4\\_7](https://doi.org/10.1007/978-3-030-20954-4_7)
- Barrows, H. S., & Tamblyn, R. M. (1980). *Problem-based learning: An approach to medical education*. Springer.
- Bento-Miguens, A. L., Nunes Piedade, J. M., dos Santos, R. J. B., & Oliva, T. L. (2024). Meaningful learning in mathematics: A study on motivation for learning and development of computational thinking using educational robotics. *Educational Media International*, 61(1-2), 4-15. <https://doi.org/10.1080/09523987.2024.2357472>
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77-101. <https://doi.org/10.1191/1478088706qp0630a>
- Brennan, K., & Resnick, M. (2012). New frameworks for studying and assessing the development of computational thinking. In *Proceedings of the American Educational Research Association Meeting*.
- Bulut, M., & Borromeo Ferri, R. (2023). A systematic literature review on augmented reality in mathematics education. *European Journal of Science and Mathematics Education*, 11(3), 556-572. <https://doi.org/10.30935/scimath/13124>

- Carreira, S., & Jacinto, H. (2019). A model of mathematical problem solving with technology: The case of Marco solving-and-expressing two geometry problems. In P. Liljedahl, & M. Santos-Trigo (Eds.), *Mathematical problem solving. ICME-13 monographs* (pp. 41-62). Springer. [https://doi.org/10.1007/978-3-030-10472-6\\_3](https://doi.org/10.1007/978-3-030-10472-6_3)
- Cascales, A., Carrillo, M. E., & Redondo, A. M. (2017). ABP y tecnología en educación infantil [PBL and technology in early childhood education]. *Pixel-Bit. Revista de Medios y Educación*, 50, 201-210. <https://doi.org/10.12795/pixelbit.2017.i50.14>
- Casler-Failing, S. (2021). Learning to teach mathematics with robots: Developing the 'T' in technological pedagogical content knowledge. *Research in Learning Technology*, 29. <https://doi.org/10.25304/rlt.v29.2555>
- Casler-Failing, S., & Collins, R. M. (2022). Learning with robots: Teaching and supporting productive struggle in a math methods course. *International Journal for Technology in Mathematics Education*, 29(1), 49-58. [https://doi.org/10.1564/tme\\_v29.1.05](https://doi.org/10.1564/tme_v29.1.05)
- Castañeda-Miranda, V. H., Luque-Vega, L. F., Lopez-Neri, E., Nava-Pintor, J. A., Guerrero-Osuna, H. A., & Ornelas-Vargas, G. (2021). Two-dimensional cartesian coordinate system educational toolkit: 2D-CACSET. *Sensors*, 21(18), Article 6304. <https://doi.org/10.3390/s21186304>
- Castro, A., Medina, J., Aguilera, C. A., Ramirez, M., & Aguilera, C. (2023). Robotics education in STEM units: Breaking down barriers in rural multigrade schools. *Sensors*, 23(1), Article 387. <https://doi.org/10.3390/s23010387>
- Ceylan, M., & Aslan, D. (2024). The effect of learning trajectories-based coding education program on preschoolers' mathematical measurement skills. *Education and Information Technologies*, 29(7), 7737-7757. <https://doi.org/10.1007/s10639-023-12107-7>
- Clements, D. H., & Meredith, J. S. (1992). Research on logo: Effects and efficacy. *Journal of Computing in Childhood Education*, 4, 263-290.
- Coad, L. (2016). The M in STEM what is it really? *The Australian Mathematics Teacher*, 72(2), 3-6.
- Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed method approaches* (5th ed.). SAGE.
- da Silva, M. P., & da Costa Barbosa, F. (2021). Matemática e física em experiências de robótica livre: Explorando o sensor ultrassônico [Mathematics and physics in free robotics experiments: Exploring the ultrasonic sensor.]. *Texto Livre*, 14(3), Article e29629. <https://doi.org/10.35699/1983-3652.2021.29629>
- da Silveira Guimarães, D., da Silva, É. A., & da Costa Barbosa, F. (2021). Explorando a matemática e a física com o robô seguidor de linha na perspectiva da robótica livre [Exploring mathematics and physics with the line-following robot from the perspective of free robotics.]. *Texto Livre*, 14(1), Article e24895. <https://doi.org/10.35699/1983-3652.2021.24895>
- Daher, W. (2022). Students' motivation to learn mathematics in the robotics environment. *Computers in the Schools*, 39(3), 230-251. <https://doi.org/10.1080/07380569.2022.2071227>
- Davide, H. (2021). *Pensamento computacional dos alunos no final do 1º ciclo do ensino básico* [Computational thinking of students at the end of the first cycle of basic education] [Master's thesis, Universidade de Lisboa].
- De la Hoz Serrano, A., Melo Niño, L. V., Álvarez Murillo, A., Martín Tardío, M. Á., Cañada Cañada, F., & Cubero Juárez, J. (2024). Analysis of gender issues in computational thinking approach in science and mathematics learning in higher education. *European Journal of Investigation in Health, Psychology and Education*, 14(11), 2865-2882. <https://doi.org/10.3390/ejihpe14110188>
- De la Hoz, A., Melo, L., Cañada, F., & Cubero, J. (2024). Educational robotics for science and mathematics teaching: Analysis of pre-service teachers' perceptions and self-confidence. *Heliyon*, 10(21), Article e40032. <https://doi.org/10.1016/j.heliyon.2024.e40032>
- Dong, W., Li, Y., Sun, L., & Yiran, L. (2023) Developing pre-service teachers' computational thinking: A systematic literature review. *International Journal of Technology and Design Education*, 34, 191-227. <https://doi.org/10.1007/s10798-023-09811-3>
- Eguchi, A. (2014). Robotics as a learning tool for educational transformation. In D. Alimisis, G. Granosik, & M. Moro (Eds.), *Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics & 5th International Conference Robotics in Education* (pp. 27-34). Academic Press.

- European Commission. (2022). Guidelines for teachers and educators on tackling disinformation and promoting digital literacy through education and training. *European Union*. <https://education.ec.europa.eu/node/2263>
- Evripidou, S., Georgiou, K., Doitsidis, L., Amanatiadis, A. A., Zinonos, Z., & Chatzichristofis, S. A. (2020). Educational robotics: Platforms, competitions and expected learning outcomes. *IEEE Access*, 8, 219534-219562. <https://doi.org/10.1109/ACCESS.2020.3042555>
- Feurzeig, W., & Papert, S. A. (2011). Programming-languages as a conceptual framework for teaching mathematics. *Interactive Learning Environments*, 19(5), 487-501. <https://doi.org/10.1080/10494820903520040>
- Fuchs, K., & Caba, H. (2016). Algorithmic/solution-oriented thinking: A core strategy in practical computer science in schools. *Schule Aktiv, (Special issue of the BMB)*, 6-8.
- Godino, J. D., Batanero, C., & Font, V. (2007). The onto-semiotic approach to research in mathematics education. *ZDM Mathematics Education*, 39, 127-135. <https://doi.org/10.1007/s11858-006-0004-1>
- Gomes, C., Gomes, H., Figueiredo, M., Lucas, A., & Menezes, L. (2023). MindMaths: Learning mathematics in the early years through computational thinking and robotics. *IE Comunicaciones: Revista Iberoamericana de Informática Educativa*, 37, 14-22.
- González-Calero, J., Cózar, R., Villena, R., & Merino, J. (2019). The development of mental rotation abilities through robotics-based instruction: An experience mediated by gender. *British Journal of Educational Technology*, 50(6), 3198-3213. <https://doi.org/10.1111/bjet.12726>
- Goos, M., Carreira, S., & Namukasa, I. K. (2023). Mathematics and interdisciplinary STEM education: Recent developments and future directions. *ZDM Mathematics Education*, 55, 1199-1217. <https://doi.org/10.1007/s11858-023-01533-z>
- Hsu, Y.-C., Irie, N., & Ching, Y. H. (2019). Computational thinking educational policy initiatives (CTEPI) across the globe. *TechTrends*, 63, 260-270. <https://doi.org/10.1007/s11528-019-00384-4>
- Kim, Y. R., Park, M. S., & Tjoe, H. (2021). Discovering concepts of geometry through robotics coding activities. *International Journal of Education in Mathematics, Science and Technology*, 9(3), 406-425. <https://doi.org/10.46328/ijemst.1205>
- Körei, A., & Szilágyi, S. (2024). Discovering epitrochoid curves with STEAM-based learning methods. *Annales Mathematicae et Informaticae*, 60, 205-217. <https://doi.org/10.33039/ami.2024.04.001>
- Kuckartz, U., & Rädiker, S. (2023). *Qualitative content analysis: Methods, practice and software*. SAGE.
- Lai, C., Wang, Q., & Huang, X. (2023). The evolution of the association between teacher technology integration and its influencing factors over time. *Journal of Research on Technology in Education*, 55(4), 727-747. <https://doi.org/10.1080/15391523.2022.2030266>
- Lee, J., Joswick, C., & Pole, K. (2023). Classroom play and activities to support computational thinking development in early childhood. *Early Childhood Education Journal*, 51(3), 457-468. <https://doi.org/10.1007/s10643-022-01319-0>
- Lengua-Cantero, C., de Jesús Acosta Meza, D., Angelica Garcia Medina, M., & Ruiz Escorcia, R. R. (2022). Pensamiento computacional: Programación y robótica para disminuir la discalculia [Computational thinking: Programming and robotics to reduce dyscalculia]. *RISTI: Revista Ibérica de Sistemas e Tecnologías de Informação*, 50, 282-295.
- Lopez-Caudana, E., Ramirez-Montoya, M. S., Martínez-Pérez, S., & Rodríguez-Abitia, G. (2020). Using robotics to enhance active learning in mathematics: A multi-scenario study. *Mathematics*, 8(12), Article 2163. <https://doi.org/10.3390/math8122163>
- Lye, S. Y., & Koh, J. H. L. (2014). Review on teaching and learning of computational thinking through programming: What is next for K-12? *Computers in Human Behavior*, 41, 51-61. <https://doi.org/10.1016/j.chb.2014.09.012>
- Miller, J. (2019). STEM education in the primary years to support mathematical thinking: Using coding to identify mathematical structures and patterns. *ZDM Mathematics Education*, 51, 915-927. <https://doi.org/10.1007/s11858-019-01096-y>
- Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, 108(6), 1017-1054. <https://doi.org/10.1111/j.1467-9620.2006.00684.x>

- Muñoz, L., Villarreal, V., Morales, I., Gonzalez, J., & Nielsen, M. (2020). Developing an interactive environment through the teaching of mathematics with small robots. *Sensors*, 20(7), Article 1935. <https://doi.org/10.3390/s20071935>
- OECD. (2022). *Mending the education divide*. OECD Publishing. <https://doi.org/10.1787/92b75874-en>
- Ortega, G. C., Téllez, A. F., Guarnizo, J. G., & Camacho, É. C. (2021). Educational environment for primary school using commercial robotic system. *Electrical and Electronic Engineering*, 26(1), 41-61. <https://doi.org/10.14483/23448393.16721>
- Ortiz, I. R. (2023). La robótica en el área de matemáticas en educación primaria. Una revisión sistemática [Robotics in the area of mathematics in primary education. A systematic review]. *EduTec. Revista Electrónica de Tecnología Educativa*, 84, 1-17. <https://doi.org/10.21556/edutec.2023.84.2889>
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., ... Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, 372, Article n71. <https://doi.org/10.1136/bmj.n71>
- Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. Basic Books Inc.
- Plangg, S., & Fuchs, K. J. (2022). A gender-related analysis of a robots' math class. *International Journal for Technology in Mathematics Education*, 29(3), 143-163. [https://doi.org/10.1564/tme\\_v29.3.03](https://doi.org/10.1564/tme_v29.3.03)
- Rahman, S. M. M. (2021). Assessing and benchmarking learning outcomes of robotics-enabled STEM education. *Education Sciences*, 11(2), Article 84. <https://doi.org/10.3390/educsci11020084>
- Reyes, G. E. B., López, E., Ponce, P., & Mazón, N. (2021). Role assignment analysis of an assistive robotic platform in a high school mathematics class, through a gamification and usability evaluation. *International Journal of Social Robotics*, 13(5), 1063-1078. <https://doi.org/10.1007/s12369-020-00698-x>
- Sáez-López, J.-M., & Buceta-Otero, D. R. (2023). The M bot robot for learning Cartesian coordinates in secondary education. *Pixel-Bit. Revista de Medios y Educacion*, 66, 271-301. <https://doi.org/10.12795/pixelbit.95617>
- Sala-Sebastià, G., Breda, A., Seckel, M. J., Farsani, D., & Alsina, À. (2023). Didactic-mathematical-computational knowledge of future teachers when solving and designing robotics problems. *Axioms*, 12(2), Article 119. <https://doi.org/10.3390/axioms12020119>
- Scaradozzi, D., Screpanti, L., & Cesaretti, L. (2019). Towards a definition of educational robotics: A classification of tools, experiences and assessments. In L. Daniela (Ed.), *Smart learning with educational robotics* (pp. 63-92). Springer. [https://doi.org/10.1007/978-3-030-19913-5\\_3](https://doi.org/10.1007/978-3-030-19913-5_3)
- Seckel, M. J., Breda, A., Font, V., & Vásquez, C. (2021). Primary school teachers' conceptions about the use of robotics in mathematics. *Mathematics*, 9(24), Article 3186. <https://doi.org/10.3390/math9243186>
- Seckel, M. J., Salinas, C., Font, V., & Sala-Sebastià, G. (2023). Guidelines to develop computational thinking using the Bee-bot robot from the literature. *Education and Information Technologies*, 28(12), 16127-16151. <https://doi.org/10.1007/s10639-023-11843-0>
- Shankar, R., Ploger, D., Nemeth, A., & Hecht, S. A. (2013). Robotics: Enhancing pre-college mathematics learning with real-world examples. In *Proceedings of the 20<sup>th</sup> ASEE Annual Conference and Exposition*. <https://doi.org/10.18260/1-2--22435>
- Silva, R., Costa, C., Freitas, Y., Martins, F., & Cebrián-De-La-Serna, M. (2024). Educational robotics and primary school mathematics teaching: An analysis of pre-service teachers didactic-mathematical knowledge. *Eurasia Journal of Mathematics, Science and Technology Education*, 20(10), Article em2515. <https://doi.org/10.29333/ejmste/15199>
- Soto-Ardila, L. M., Carrasco, A. C., Niño, L. M., & González, R. L. (2020). Opiniones de los futuros maestros de primaria sobre el uso de la robótica educativa para la enseñanza de las matemáticas [Opinions of future primary school teachers on the use of educational robotics for teaching mathematics]. *New Trends in Qualitative Research*, 2, 675-686. <https://doi.org/10.36367/ntqr.2.2020.675-686>
- Soto-Ardila, L. M., Niño, L. M., & Carrasco, A. C. (2021). Robótica educativa para enseñar matemáticas: Opiniones de los estudiantes del grado en educación primaria [Educational robotics for teaching mathematics: Opinions of students in the primary education degree]. *New Trends in Qualitative Research*, 7, 211-219. <https://doi.org/10.36367/ntqr.7.2021.211-219>

- Sung, W., Ahn, J., & Black, J.B. (2017). Introducing computational thinking to Young learners: Practicing computational perspectives through embodiment in mathematics education. *Tech Know Learn*, 22, 443-463. <https://doi.org/10.1007/s10758-017-9328-x>
- Szilágyi, S., Körei, A., & Vaičiulyté, I. (2024). An innovative STEAM-based method for teaching cycloidal curves in engineering higher education. *Education Sciences*, 14(10), Article 1087. <https://doi.org/10.3390/educsci14101087>
- Tzagkaraki, E., Papadakis, S., & Kalogiannakis, M. (2021). Exploring the use of educational robotics in primary school and its possible place in the curricula. In M. Malvezzi, D. Alimisis, & M. Moro (Eds.), *Education in & with robotics to foster 21st-century skills* (pp. 216-229). Springer. [https://doi.org/10.1007/978-3-030-77022-8\\_19](https://doi.org/10.1007/978-3-030-77022-8_19)
- Varaman, P., Kumar, J. A., Rabu, S. N. A., & Osman, S. (2024). The effect of educational robots on primary schools' mathematics learning achievement, interest, and attitude. *Journal of Educators Online*, 21(2). <https://doi.org/10.9743/JEO.2024.21.2.17>
- Vitale, A., & Iacono, U. D. (2024). Using social robots as inclusive educational technology for mathematics learning through storytelling. *European Public & Social Innovation Review*, 9, 1-17. <https://doi.org/10.31637/epsir-2024-672>
- Voogt, J., Fisser, P., Good, J., Mishra, P., & Yadav, A. (2015). Computational thinking in compulsory education: Towards an agenda for research and practice. *Education and Information Technologies*, 20(4), 715-728. <https://doi.org/10.1007/s10639-015-9412-6>
- Wei, C. W., & Hung, L. L. (2011). A joyful classroom learning system with robot learning companion for children to learn mathematics multiplication. *Turkish Online Journal of Educational Technology*, 10, 11-23.
- Wing, J. (2006). Computational thinking. *Communications of the ACM*, 49(3), 33-35. <https://doi.org/10.1145/1118178.1118215>
- Ybarra, L. A. C., & Soares, M. (2022). A robótica e o pensamento computacional na educação: Uma proposta de avaliação da aprendizagem baseada em projetos [Robotics and computational thinking in education: A proposal for project-based learning assessment]. *Dialogia*, 40, Article e21524. <https://doi.org/10.5585/40.2022.21524>
- You, H. S., Chacko, S. M., & Kapila, V. (2021). Examining the effectiveness of a professional development program: Integration of educational robotics into science and mathematics curricula. *Journal of Science Education and Technology*, 30(4), 567-581. <https://doi.org/10.1007/s10956-021-09903-6>
- Zhang, L., & Nouri, J. (2019). A systematic review of learning computational thinking through scratch in K-9. *Computers & Education*, 141, Article 103607. <https://doi.org/10.1016/j.compedu.2019.103607>

