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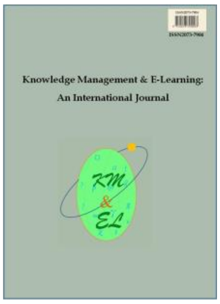
Irene Trapero-González
José-María Romero-Rodríguez
Francisco-Domingo Fernández-Martín
Santiago Alonso-García
University of Granada, Granada, Spain



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Educational robotics and STEM competence in early childhood education: Systematic review and meta-analysis of programmes and outcomes

Irene Trapero-González

Faculty of Education Sciences
University of Granada, Granada, Spain
E-mail: irenetrapero@correo.ugr.es

José-María Romero-Rodríguez*

Faculty of Education Sciences
University of Granada, Granada, Spain
E-mail: romejo@ugr.es

Francisco-Domingo Fernández-Martín

Faculty of Education Sciences
University of Granada, Granada, Spain
E-mail: fdfernan@ugr.es

Santiago Alonso-García

Faculty of Education Sciences
University of Granada, Granada, Spain
E-mail: salonsog@ugr.es

*Corresponding author

Abstract: Educational robotics is presented as a resource increasingly present in the early childhood education stage, allowing the development of STEM competences in a practical and motivating way. Due to the evolution of its use in the classroom, the aim of this paper was to analyse and evaluate research on robotics applied to early childhood education. To do so, we used a systematic literature review methodology based on The Campbell Collaboration, analysing a total of 15 scientific papers that met the inclusion and exclusion criteria. Among the results, different robotics resources are shown, among which Bee-Bot stands out, most STEM competences are worked on, except engineering, and almost all the results of the programmes are significant, with gains in the experimental groups. For its part, the meta-analysis collected 13 papers and showed significant results in STEM competences by the experimental group versus the control group. Finally, the use of educational robotics improves STEM competences, which is why it is necessary to use it in classrooms from an early age, as it will help to promote their comprehensive development from an early age through a more practical and motivating education for students.

Keywords: Early childhood education; Meta-analysis; Robotics; STEM;

Systematic review

Biographical notes: Irene Trapero-González is a doctoral candidate of the Faculty of Education Sciences at the University of Granada. Her research interests include educational robotics and STEM competence in initial teacher education. She works as an early childhood education teacher in the municipal school of Molvízar (Granada, Spain).

Dr. José-María Romero-Rodríguez is a teaching and research staff attached to the Department of Didactics and School Organisation at the University of Granada (Spain). He carries out his research work within the AREA research group. Author of more than 100 scientific articles of impact (JCR and Scopus) on the use of Information and Communication Technologies (ICT) for the improvement of teaching and learning and on the risks associated with the problematic use of the Internet.

Dr. Francisco-Domingo Fernández-Martín is a Full university lecturer, attached to the Department of Developmental and Educational Psychology at the University of Granada. He has been teaching in higher education at the same time implementing several innovation and research projects tied to the improvement of the quality of education. He has a lot of experience in implementing public program evaluations, research studies and assessments in the education field with a particular focus on topics of keywords.

Dr. Santiago Alonso-García is a Full university lecturer in the Department of Didactics and School Organisation and Vicedean of Students, Employment and Employability in the Faculty of Education Sciences at the University of Granada. His lines of research are linked to learning with technology. He is the director of the research group Laboratorio de Innovación en Educación (LabInEd).

1. Introduction

Educational robotics is a discipline that combines concepts of robotics and education, using robots as pedagogical tools to engage students in hands-on, collaborative activities that help develop STEM (Science, Technology, Engineering and Mathematics) competences in a tangible and concrete way (Sun & Zhou, 2023; Wu et al., 2023). In doing so, they can construct meaningful knowledge, allowing them to apply it to real-life situations (García et al., 2022), in a practical and playful way unlike traditional education (Casado-Fernández & Checa-Romero, 2020; Ferrada et al., 2020; Theodoropoulou et al., 2023). In this sense, robotics involves the study and application of scientific principles in the creation and programming of robots, develops technical skills through the design and construction of robots, and programming develops mathematical, logical and problem-solving skills.

Regarding the use of robotics in early childhood education, in recent years there has been an increase in the use of robotics kits that allow experimentation with mechanics, electronics and programming. These robotics projects in the classroom are based on projects that in most cases arise from the pupils' own interests (González-Cervera et al., 2021).

Through their use, students can learn skills linked to logical thinking, problem-solving, and mathematical and scientific concepts in a much more visual and practical way, thus helping them to understand problems (Çakır et al., 2021; Raposo-Rivas et al., 2022; Schina et al., 2021). Its incorporation in classrooms fosters motivation for any learning at this educational stage (Papadakis, 2022), provided it is integrated in an appropriate way and adapted to the level and needs of the students. In this way, it has become an increasingly popular tool in the classroom, as it is not only an effective way to teach technical skills but can also help students develop social and emotional skills (Barragán-Sánchez et al., 2023).

Integration in the classroom offers several benefits, as the use of robotics fosters the development of problem-solving skills (Campos & Muñoz, 2023). Among the possible benefits of robotics in the early childhood education stage, some of the most outstanding ones can be presented (Chernobrovkin et al., 2020; Garcés et al., 2021; Kerimbayev et al., 2023; Papadakis, 2020; Rodrigo-Parra, 2021): (i) STEM competences development: Educational robotics can help children develop skills in areas such as science, technology, engineering and mathematics. By working with robots, children can learn concepts such as programming, electronics and mechanics; (ii) Encouraging creativity and imagination: the use of robotics in the classroom encourages pupils' creativity by allowing them to experiment and try out new activities; (iii) Promotion of teamwork and collaboration: the different projects based on robotics are usually focused on working in small or large groups, thus stimulating communication, collaboration and teamwork as a common goal. Likewise, from an early age, the aim is to break down gender stereotypes related to these skills and combat inequalities.

Along the same lines, different experiences have arisen that work on STEM education in the early childhood education classroom, among which the following stand out: Ruíz and Arteaga (2022) used the educational robot KUBO as a tool to introduce early childhood education students to computational thinking and programming. The aim of the activity was to develop logical thinking, problem-solving and spatial orientation skills in the students; Alsina and Acosta (2022), worked on the learning of repetition patterns using the project work methodology, the manipulation of materials and the use of the Cubetto programmable robot; Romero-Tena and Romero-González (2020), presented a didactic sequence designed for two groups of students, with the aim of evaluating the effectiveness of the use of the Bee-bot robot in learning repetition patterns; Diago et al. (2018), conducted an exploratory study on the strategies used by students in mathematical problem solving using the Bee-bot robot. The aim of the study was to address problem-solving instruction through appropriate teaching sequences and to analyse students' performances during problem-solving. Recio Caride (2019), based her experience on the integration of robotics and computational thinking in early childhood education, her aim was to share the experiences and practices carried out over five school years with two groups of early childhood education, with the intention of showing the benefits that these practices can bring to students from the age of three.

On the other hand, some previous reviews in this field highlighted: (i) that educational robotics can be a catalyst to improve learning, although there are documented cases where no substantial improvement in the educational process has been observed (Benitti, 2012); (ii) the studies reviewed mainly used educational robotics as a complementary tool to support the teaching of other subjects or the focus on STEM education (Jung & Won, 2018).

Based on these considerations and given the growing importance of the use of robotics as a powerful educational resource in early childhood education, the general objective of the systematic review was to analyse and evaluate research on robotics applied to early childhood education. This review followed the international standards established by The Campbell Collaboration (2021), establishing the following specific objectives: (a) identify the main characteristics of the research work that has been carried out on educational robotics programmes with pupils aged 0-6 years for the development of STEM competences; (b) describe the most relevant characteristics of educational robotics programmes, as well as their empirical evidence on STEM competence; and (c) issue relevant conclusions and recommendations for future practices and studies in this area. Research questions were posed as research questions:

RQ1: What are the most salient features of the studies (geographical and temporal distribution, type of publication, sample selection procedure and group configuration, sample characteristics, standardised test and methodological designs) on robotics in early childhood education?

RQ2: What are the most relevant characteristics of robotics programmes in early childhood education (duration, environment in which they are developed, intervention procedures, practices, strategies, techniques, resources, and activities)?

RQ3: What are the results of the implementation of robotics programmes in early childhood education in relation to STEM competence?

2. Method

The systematic review of the literature was carried out under the international standards established by The Campbell Collaboration (2021), an entity recognised for its work in the elaboration of critical analyses and exhaustive meta-analyses in fields such as education (Sánchez et al., 2022). A search protocol was also developed for the systematic review, which is published and open access in DIGIBUG: Institutional Repository of the University of Granada (Trapero-González, 2023).

The search was conducted during April and May 2023 and a review of all articles published up to that time was carried out.

2.1. Search strategies

Firstly, a primary search was carried out using the Web of Science, ProQuest and Scopus databases due to their high recognition through their impact indexes: Journal Citation Reports (JCR) and Scimago Journal & Country Rank (SJR). Secondly, a complementary search was conducted by accessing other resources and websites of relevant networks and institutions and contacting experts in the field. In addition, hand searches were conducted to ensure the inclusion of both published and unpublished studies in the systematic review.

Next, to select the appropriate search terms, the Education Resources Information Center (ERIC) Thesaurus was used, taking into consideration the inclusion and exclusion criteria established for the review. In addition, the search strategy was adapted to each of the platforms and databases to ensure an effective search in each of them.

In all those platforms and databases with advanced search functions, search terms were classified into two main categories: independent variables (educational robotics programmes in early childhood education) and dependent variables (STEM competences), in both English and Spanish. These categories were combined using the Boolean operator “AND”, while within each category the Boolean operator “OR” was used to include the search terms and their synonyms. This facilitated the search and selection of relevant studies for the systematic review, ensuring the inclusion of all studies related to the variables of interest. Thus, the search equation used for each of the databases is shown in Table 1.

Table 1
Search equations according to each database

Database	Equation
Web of Science and Scopus	(Robotics OR Robots) AND (intervention* OR program* OR practice* OR train* OR initiative* OR action* OR project*) AND (STEM OR "Science, Technology, Engineering and Mathematics" OR Science OR Technology OR Engineering OR Mathematics) AND (Prekindergarten* OR Kindergarten* OR "Preschool Education" OR "Early Childhood Education" OR "Childhood Education")
ProQuest	(Robotics OR Robots) AND (intervention* OR program* OR practice* OR train* OR initiative* OR action* OR project*) AND (STEM OR "Science, Technology, Engineering and Mathematics" OR Science OR Technology OR Engineering OR Mathematics) AND (Prekindergarten* OR Kindergarten* OR "Preschool Education" OR "Early Childhood Education" OR "Childhood Education"). In addition, internal filters were added: early childhood education OR preschool education OR kindergarten OR preschool children OR elementary school students OR elementary schools

2.2. Inclusion and exclusion criteria

Inclusion and exclusion criteria were established based on the definition or operational characteristics of the independent and dependent variables. Subsequently, the methodological designs, the participant population and the geographical, cultural and temporal restrictions were determined in order to specify the inclusion and exclusion criteria.

On the one hand, the independent variable was linked to educational robotics programmes in early childhood education, which refers to those educational interventions that use robotics material to improve STEM competence and are aimed at students aged 0-6 years (Terroba et al., 2021).

On the other hand, as dependent variables, educational robotics programmes are those that promote the development of a set of STEM (i.e., science, technology, engineering and mathematics) competencies and skills in participating students (Gerosa et al., 2022).

Ultimately, these variables were measured in quantitative terms, using standardised tests, questionnaires, inventories or scales.

In relation to the research designs, studies using experimental and quasi-experimental methodological designs with comparison groups were chosen for inclusion in the review. The target population was early childhood education pupils aged zero to six years. No geographical or temporal restrictions were imposed, although the studies included in the review were required to be written in English or Spanish.

2.3. Data collection and analysis

For the management and documentation of the search process, it was decided to use the RefWorks tool. Through this tool, it was possible to carry out an exhaustive follow-up of the studies selected in the search process.

This process of selecting the studies found was implemented through the following actions: (i) First level, those studies that appeared duplicated in the different databases used were eliminated; (ii) Second level, the title and abstract of each study were analysed to discard studies that did not meet the proposed inclusion criteria; (iii) At the third level, the full versions of each of the studies selected at the second level were read to determine whether they finally met the inclusion criteria. All of this was captured in an Excel template to streamline data collection and analysis.

Once the final selection of studies had been made, information was extracted from each of them, taking into account the inclusion criteria set out in the review: a) contextual characteristics (reference, country and type of publication); (b) methodological characteristics (sample selection procedure and clustering, methodological design and data analysis); (c) sample characteristics (size, age, gender, cycle); (d) assessment instruments used to measure the dependent variables (standardised tests, tests, questionnaires, inventories, scales); (e) characteristics of educational robotics programmes (environment in which it is developed, components, duration, procedures, practices, strategies, techniques and resources); (f) dependent variables, in this case STEM; and (g) results and conclusions obtained.

The approach adopted for data analysis was a narrative content analysis of the data extracted from the studies included in the systematic review (Dochy, 2006). The aim was to identify common results of the studies and characteristics of the educational robotics programmes used and their impact on STEM competence.

The meta-analysis was carried out using the standardized mean difference as the outcome measure (Viechtbauer, 2010). A random effects model was applied to the data set, as presented in Table 2. To assess the level of heterogeneity (τ^2). Alongside the τ^2 estimation, we also conducted the Q-test to evaluate heterogeneity and calculated the I^2 statistic. In instances where any degree of heterogeneity was observed ($\tau^2 > 0$, irrespective of the Q-test results), we established a prediction interval aimed at the accurate estimation of true outcomes (refer to Table 3). To identify potential outliers or influential studies within the model, we relied on studentized residuals and Cook’s distances. Studies with studentized residuals exceeding the threshold of the $100 \times \left(1 - \frac{0.05}{2k}\right)$ percentile from a standard normal distribution were considered as possible outliers. Notably, we adopted a Bonferroni correction with a two-sided alpha level of .05 to accommodate the 13 studies included in the meta-analysis. For identifying influential studies, those with Cook’s distances surpassing the median plus six times the interquartile range of Cook’s distances were singled out. To ascertain funnel plot asymmetry, we employed the rank correlation test and the regression test, utilizing the standard error of the observed outcomes as a predictor (see Fig. 1). The analysis was carried out with the Jamovi programme, version 2.3.

Table 2
Random-effects model

	Estimate	SE	*Z*	*p*	CI Lower Bound	CI Upper Bound
Intercept	1.01	.185	5.43	< .001	.643	1.369

Table 3
Heterogeneity statistics

τ	τ^2	I^2	H^2	R^2	*df*	*Q*	*p*
.777	.604 (SE = .2226)	90.37%	10.380	.	19.000	210.167	< .001

Note. τ^2 estimator: Restricted maximum-likelihood.

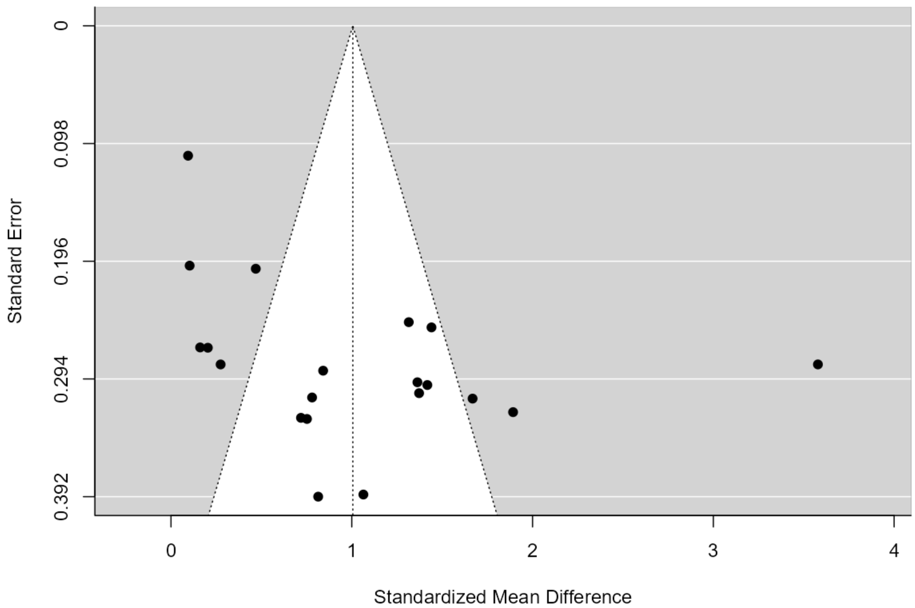

Fig. 1. Funnel plot

3. Results

After the initial search, 972 studies were identified: 870 in the primary search and 102 in the supplementary search. Subsequently, after eliminating duplicate studies and studies related to other topics (first level of selection), 98 studies were excluded. We excluded 491 studies as they did not meet the inclusion criteria and then examined the title and abstract of 383 studies (second level of screening). Finally, after reading the full text of 18 studies (third level of screening), two of them were eliminated due to lack of access to full text and one of them was eliminated, leaving a total of 15 studies that met the inclusion criteria for the systematic review, while for the meta-analysis 13 studies collected the relevant data for the meta-analysis (see Fig. 2).

The 15 studies selected correspond to 14 journal articles and one conference proceedings published between 2013-2023. The year with the highest concentration of publications was 2022 with five studies. The language used for the publications was English (N = 14) and Spanish (N = 1). The countries where the research was carried out were as follows: Turkey (N = 5); South Korea (N = 3); Spain (N = 2); Israel (N = 2); USA (N = 1); China (N = 1) and Uruguay (N = 1).

The sample selection process was random (*N* = 4) and non-random, i.e., by convenience (*N* = 11). Specifically, a total of 1273 participants (M = 84.86) were examined in these studies, ranging from 27 to 450 participants per study. The gender distribution of the participants in the different studies was variable, always including boys (52.52%) and girls (47.48%). The ages ranged from three to seven years (M = 5.15; SD = 0.61), who were in the second cycle of the infant education stage.

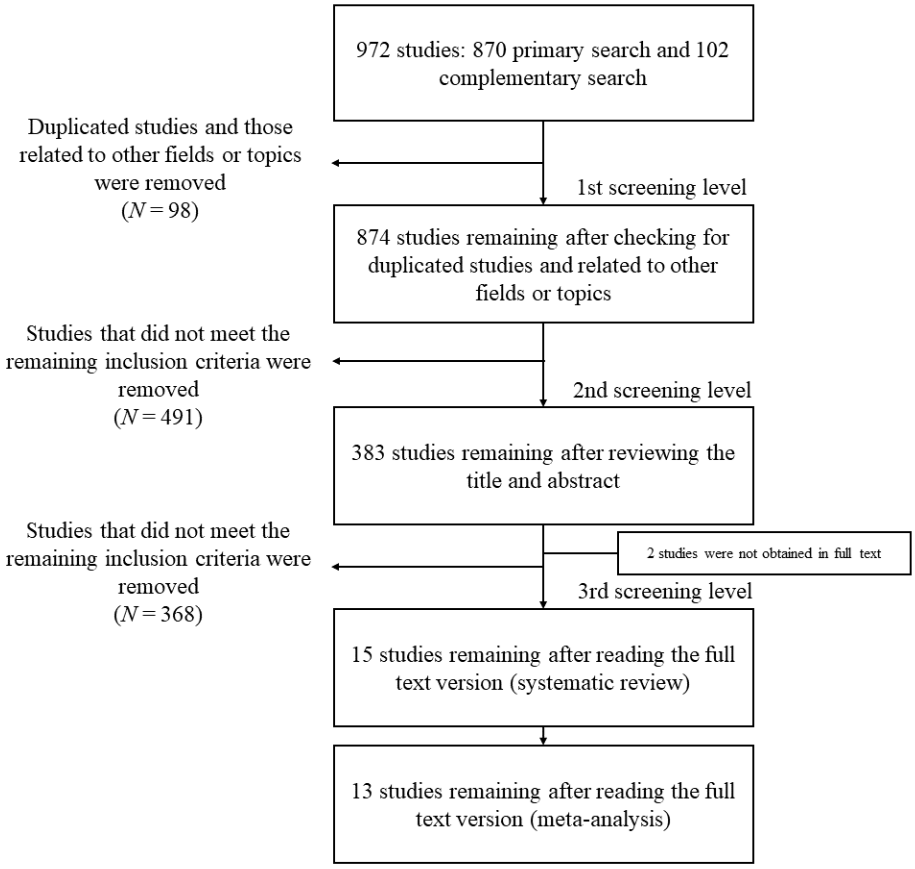

Fig. 2. Flowchart

The methodological designs adopted by the different studies were quasi-experimental (*N* = 11) and experimental (*N* = 4), all of them with experimental and control groups and pretest and posttest measures. The group configuration procedures were carried out by means of random (*N* = 10) and non-random (*N* = 5) assignments. All selected studies conducted different data analyses: *t*-test; Kolmogorov-Smirnov test for normality; Mann-Whitney U test; Wilcoxon's W; ANCOVA; ANOVA; ShapiroWilks test; Linear mixed-effects models; Post-hoc Tukey tests; Cohen's D; Levene's statistical test. The evaluation instruments used were: Test of Early Language Development (TELD-3); Torrance Tests of Creative Thinking (TTCT); Evaluation Instrument for the Early Mathematical Reasoning Skills (EIEMRS); Problem-Solving Skills Scale (PSSS); Head-Toes-Knees-Shoulders (HTKS); "*SSS*" Rubric; Child Self-Regulation and Behavior Questionnaire (CSBQ); Problem-Solving Performance Instrument (PSPI); Ad hoc set of 15 illustrated stories with four cards per story; Scale for Preschool Students' Basic Skills

(SPSBS); TONI Test of Nonverbal Intelligence (TTNI); Illinois Test of Psycholinguistic Abilities (ITPA); Spatial-Vocabulary Test (SVT); Visual-Spatial Memory Test (VSMT); Mental Rotation Test (MRT); Test of Visual-Perceptual Skills (non-motor) – revised (TVPS); Colored Progressive Matrices Test (CPM); Tablet-based Version of Raven's Colored Progressive Matrices (TVRCPM); Adapted Questionnaire based on Yune Tran's CT Questionnaire (CT-Yune Tran); Creative Problem-Solving Ability (CPSA); TechCheck; Picture Sequencing Task (PST); Evaluation Instrument for the Early Mathematical Reasoning Skills (EIEMRS); Ad hoc rubric; Creative Thinking Abilities Test (CTAT).

With regard to the main characteristics of robotics programmes in early childhood education (Table 4), the following programmes were implemented: The development of the productive children coding and robotics education program (PCP) (Canbeldek & Isikoglu, 2023); TangibleK robotics (García-Valcárcel & Caballero-González, 2019); Educational Programming Language (EPL) (Un & Kim, 2020); Coding education programme (Somuncu & Aslan, 2022). On the other hand, some studies did not implement a specific programme (Brainin et al., 2022; Brainin et al., 2021; Caballero-González & García-Valcárcel, 2021; Çakır et al., 2021; Çiftci & Bildiren, 2019; Gerosa et al., 2022; Kazakoff et al., 2013; Nam et al., 2019; Sung et al., 2023; Turan & Aydoğdu, 2020; Yang et al., 2022).

With regard to the duration of the programmes analysed, they range from one to nine weeks. Moreover, these programmes have been implemented entirely in urban centres and incorporate the following STEM competences: mathematics (N = 12); science (N = 5); technology (N = 7).

Table 4
Characteristics of educational robotics programmes

Programme	Duration	STEM	Robotics resource	Procedure
PCP (Canbeldek & Isikoglu, 2023)	2 times a week for 9 weeks	Mathematics; Science	Matatalab; Bee-Bot; Doc	It consists of three basic activities: unplugged coding, robotics and block coding. The children were asked to use the robots, individually or in small groups, to code certain tasks that they planned themselves.
TangibleK Robotics (García-Valcárcel & Caballero-González, 2019)	7 sessions of 4 hours each	Mathematics	TangibleK	Six programming sessions. Each session integrated robotics activities into the curriculum to enhance logical-mathematical skills. During the development of the activities, students worked in small groups (4–5 members) in a collaborative way.
Ad-hoc programme (Sung et al., 2023)	5 weeks	Mathematics; Science	Kibo	62 STEAM activities were carried out to learn to recognise coding symbols, principles of operation and commands, repetition and robot movement conditions
Ad-hoc programme (Nam et al., 2019)	8 weeks	Mathematics	Turtle-Bot	Participation in two stages of activities and applications consisting of four and eight activities. In the foundation phase, four or five children made up a group and shared ideas about how to operate the Turtle Bot. In the application phase, the researcher grouped them into small groups within the treatment group.
Ad-hoc programme (Kazakoff et al., 2013)	1 week	Science; Technology	Lego WeDo	The children used LEGO Education WeDoTM Robotics Construction Sets, with the hybrid tangible-graphic software CHERP, and various art materials to build and programme their robots.

Ad-hoc programme (Turan & Aydoğdu, 2020)	8 weeks, two days per week, one hour per day	Technology; Mathematics; Science	Kibo	The programme for the children in the study aimed at understanding technology in everyday life with visual materials, basic programming concepts, number use and prediction activities, space/time relationships, introduction of a robot kit and installation to visually grasp the concepts of science and physics.
Ad-hoc programme (Brainin et al., 2022)	10 sessions of 30 minutes each	Mathematics	Bee-Bot	Spatial skills were fostered by teaching basic spatial language concepts. The two intervention groups (robot/no robot) participating in the study attended sessions with the same basic spatial intervention programme, similar in content and structure, with or without a robot.
Ad-hoc programme (Brainin et al., 2021)	10 sessions of 30 minutes each	Mathematics	Bee-Bot	The teaching and practice of the concepts in the two intervention groups were delivered to two children in each session by a teacher once a week. During Sessions 1 to 7, the children learned and practised the following spatial concepts: front, back, inside, outside, right, left, in front, around, between, near, and far. During Sessions 8 to 10, the integrative practice of the concepts was carried out using maps that promote spatial learning.
Ad-hoc programme (Çiftci & Bildiren, 2019)	8 weeks. Two teaching hours per week	Technology	Code.org	The course was designed around a game-based drag-and-drop method. The lesson began with the teacher directing the children to the section they would be working on and the tasks they were to complete. They were then shown how to log on to the code.org website and complete these tasks themselves. Students completed these tasks with the help of computer-based guides and teacher support.
Ad-hoc programme (Gerosa et al., 2022)	11 sessions of 30 minutes each; 5 sessions per week	Mathematics; Technology	RoboTito	The introductory session was presented by the group coordinator where he talked to the children about the general rules of the workshop and the idea of playing with a robot to solve different situations. Then, the children worked with the previous instructions given by the teacher: spatial concepts, determining the configuration of cards on the mat, planning and creating sequential movements, incorporating distracting objects, pre-established wrong configuration and establishing the steps to reach the goal.
EPL (Un & Kim, 2020)	13 sessions	Mathematics; Technology	Robot ad hoc	Materials from the Internet were used for the purpose of assembling block robots and EPL programming activities. The instructional media and activity instructions given to the children were carefully chosen after being evaluated by robotics and programming education professionals and early childhood education professionals for content validity.
Ad-hoc programme (Yang et al., 2022)	6 weeks	Mathematics	Matatalab	The intervention programme for the coding classes is a curriculum designed around the functions of the Matatalab screenless robot. Each activity involved 20-30 children simultaneously, with 4–5 children per group in small-group activities. A total of seven robot kits were provided for use during the collective research activities. Each week, teachers conducted one or two large group learning activities to programme robots or build blocks with their children.
Coding education programme (Somuncu & Aslan, 2022)	4 days a week for 5 weeks	Mathematics	Bee-Bot	The programme was prepared by the researchers with the purpose of supporting children's mathematical reasoning skills. Twenty mathematical activities were planned, the first four of which are composed of unplugged coding activities, while the following ones used Bee-Bot. Each programming education activity addresses a different mathematical reasoning skill.
Ad-hoc programme (Caballero-González & García-Valcárcel, 2021)	6 sessions. 24 hours in total	Technology	Bee-Bot	The assessments (pre-test and post-test) were based on programming challenges called Solve-It. The challenges consisted of constructing programming sequences to get the Bee-Bot robot to move to a specific point marked on a mat. Five challenges were planned for each assessment. The students worked collaboratively in small groups (3–4 students) in their everyday classroom.
Ad-hoc programme (Çakır et al., 2021)	4 weeks and a total of 32 teaching hours were taught	Mathematics; Science; Technology	Lego WeDo	The programme was divided into: (i) a presentation of the Robotic Education Kit, and Glowingsnail Coding Platform and Activity; (ii) a reminder of the Robotic Education Kit, and Cooling Fan and Moovings Satellite Coding Platform and Activities; (iii) motion Sensor based Spaceship Activity; (iv) "*Let's build our own frog*" activity.

Finally, the observed standardized mean differences displayed a range from .0945 to 3.5785, with a predominant majority of estimates showing positive values (100% occurrence). The random-effects model yielded an estimated average standardized mean difference of 1.0058 (95% CI [.6426, 1.3689]), clearly indicating a significant deviation from zero (z = 5.4278, p < .0001). The outcomes' heterogeneity was evident based on the Q-test results, revealing substantial heterogeneity ($Q(19)$ = 210.1667, p < .0001, τ^2 = .6040, I^2 = 90.3657%). Delving into the prediction interval for the true outcomes (95% CI [-.5601, 2.5716]), it's noteworthy that despite the positive estimation of the average outcome, potential negative true outcomes were indicated in select studies. In the context of this model, scrutiny of studentized residuals spotlighted one study (García-Valcárcel & Caballero-González, 2019) with values exceeding ± 3.0233, potentially classifying it as an outlier. Similarly, Cook's distances identified the same study as exerting a disproportionate level of influence. However, both the rank correlation and regression tests did not uncover any signs of asymmetry within the funnel plot (p = .1284 and p = .1432, respectively). The overall effect size had a large effect (Cohen's d = 1.01). The observed difference between groups was substantial in terms of within-data variability.

The forest plot configuration shows the 13 studies that collected mean and standard deviation data for the control and experimental groups in each study (see Fig. 3). Some studies were divided according to the construct that was measured (e.g. all three measures of the Brainin et al., 2022 study were considered). All constructs were linked to STEM competence, hence the relevance of adding them to the meta-analysis.

4. Discussion

Specifically, based on the studies analysed (RQ1), it can be seen that the use of educational robotics increased significantly in 2022. Moreover, the use of this resource is being carried out in different parts of the world as shown in the studies analysed, which affirms that STEM competences are being worked on in the early childhood education stage with robotics, becoming an increasingly popular tool in the classroom, as it is not only used to teach technical skills but also as a tool to foster social and emotional skills (Barragán-Sánchez et al., 2023). Likewise, this implementation of robotics in the classroom is being applied in the second cycle of infant education, which covers ages three to six. In terms of the participants in the studies analysed, the distinction in the percentage by sex is very similar (52.52% boys and 47.48% girls), which accentuates benefits such as breaking gender stereotypes related to these skills and combating inequalities in collaborative work (Chernobrovkin et al., 2020; Garcés et al., 2021; Kerimbayev et al., 2023; Papadakis, 2020).

Regarding the characteristics of the programmes (RQ2), despite the claims made by authors such as González-Cervera et al. (2021) regarding robotics projects, it is important to note that the studies analyzed do not always take into account the individual interests of students as a determining factor in their approach. In this sense, the projects used have been used for the convenience of the researcher to obtain specific results and benefits. In turn, some of the studies collected (Brainin et al., 2022; Caballero-González & García-Valcárcel, 2021; Canbeldek & Isikoglu, 2023; García-Valcárcel & Caballero-González, 2019; Nam et al., 2019; Yang et al., 2022) work with robotics resources in a collaborative way. This links to the importance of collaborative robots for learning enhancement (Rodrigo-Parra, 2021).

In terms of the most commonly used robot, Bee-bot stands out because its programming is simple for students in the early childhood education stage, it favours collaborative work and concepts such as laterality, logical thinking or the creation of mats with contents that arise from the students' interests can be worked on (Diago et al., 2018; Romero-Tena & Romero-González, 2020).

As regards the significance of the programmes used in the different studies (RQ3), the results are significant in most of the programmes applied which are linked to STEM competences. In this respect, only three competences have been worked on in the studies analysed, with the engineering competence being more complex in its development at such early stages. However, the areas linked to mathematics have been those that have had the greatest development and significance in early childhood education students.

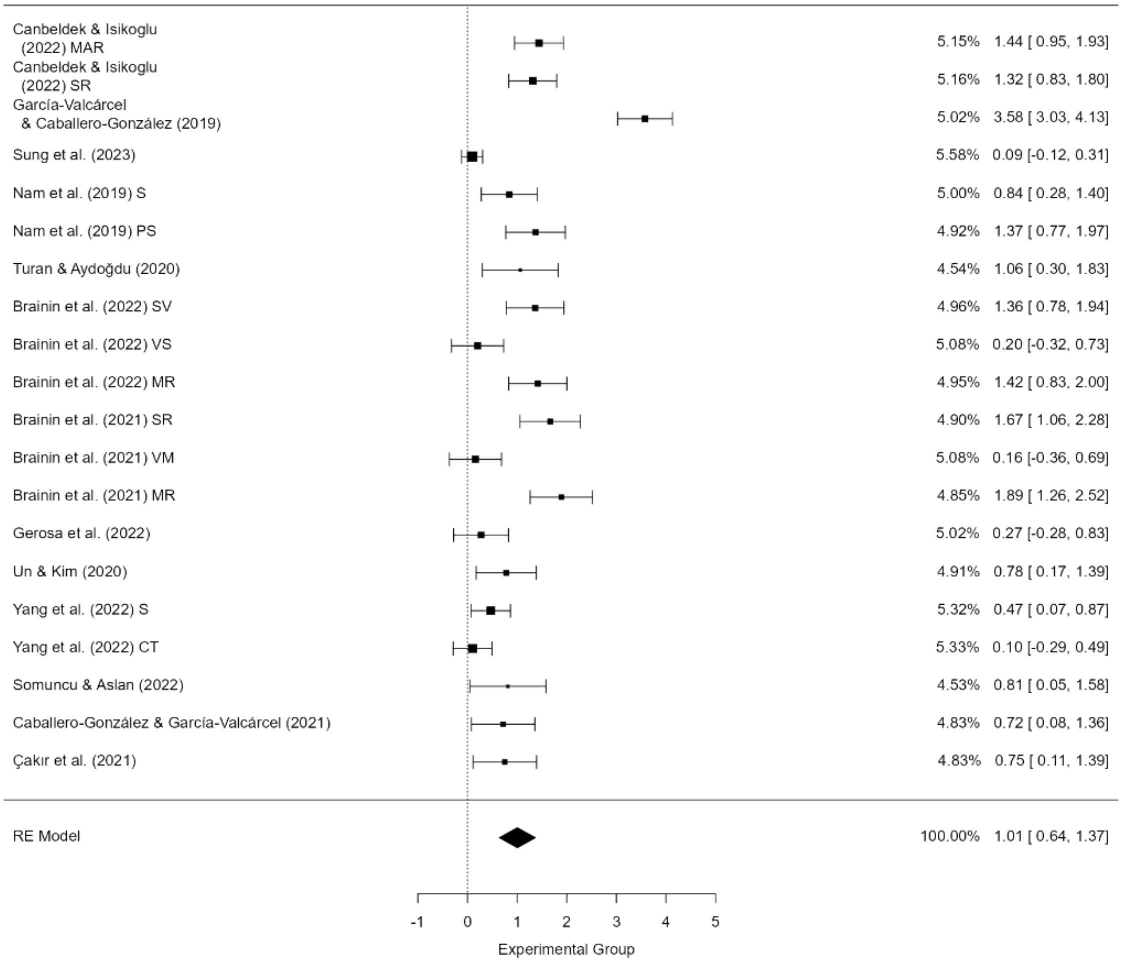

Fig. 3. Forest plot. MAR = Mathematical Reasoning; SR = Spatial Relaion; S = Sequencing; PS = Problem-Solving; SV = Spatial Vocabulary; VS = Visual-spatial Memory; MR = Mental Rotation; VM = Visual Memory; CT = Computational thinking.

5. Conclusion

By means of this systematic review, a series of documents have been studied to provide information on different programmes and their results, in which educational robotics is used to improve STEM competences, thus providing answers to the research questions posed.

In this regard, with respect to the first research question, the results obtained show that South Korea, Spain, Israel, Turkey, the USA, Uruguay and China are the countries where evidence has been found of the use of educational robotics programmes for the early childhood education stage to promote STEM competences. Specifically, the study consists of 14 articles and one conference proceedings published between 2013 and 2023, characterised by the selection of experimental and quasi-experimental methodological designs, with comparison groups, mostly randomly configured. As far as the second research question is concerned, all these programmes have been developed in urban schools and implemented by teachers themselves or external staff. These programmes have a variable duration of intervention and are mainly aimed at developing mathematics, science and technology skills. To do so, they have used resources such as TangibleK, Kibo, Turtle-Bot, Lego WeDo, Bee-bot, Code.org, RoboTito and Matatalab through a wide range of practices and activities. The third research question relates to the effectiveness of these robotics programmes in early childhood education in relation to STEM competence, with 15 of the results being significant and five non-significant.

Certainly, this systematic review with meta-analysis may encounter some limitations such as: (i) The evolution of the field of study: Research on educational robotics and STEM competence in early childhood education is constantly evolving. It is possible that there is literature published after the review date that has not been included; (ii) Generalisability of results: The programmes and results examined may be specific to particular countries, educational institutions or population groups, limiting the applicability of findings to other settings; (iii) Biases of included studies: Some studies may have methodological limitations or biases that may affect the validity of their results; (iv) The scope of the review: It is important to recognise that a systematic review is limited by the availability of relevant papers and studies. If specific papers or studies were not accessible, important information may have been omitted that could affect the findings and conclusions of the paper; (v) Although the results are positive in favour of educational robotics programs to improve STEM competence, the data should be interpreted with caution due to the small number of studies.

Even so, the practical implications of this work are linked to the importance of developing robotics programmes in early childhood education to favour the development of students at this educational stage, so the results of this systematic review can provide teachers with valuable information on the implementation of educational robotics and STEM competence in early childhood education. It would also help them to develop more effective and appropriate programmes to promote learning in these areas. In addition, it may help in the selection of the most appropriate resources and materials. This includes the identification of technological tools, robotics kits and teaching materials that have been shown to be effective in improving student learning and motivation. Also, future lines of research may emerge in which an evaluation of the long-term impact on the cognitive, academic and socio-emotional development of children in early childhood education is conducted, providing a deeper understanding of the benefits of educational robotics in early childhood education. In the same vein, it would be interesting to investigate how educational robotics and STEM competence can be adapted and applied effectively in different cultural and socio-economic contexts and thus explore curricular adaptations to cater for the diversity of learners. On the other hand, the training and professional development of educators in this field is critical for successful implementation. Investigating the most effective approaches to training teachers and promoting their competence in these areas would be a valuable line of research.

In short, the use of educational robotics improves STEM competences, which is why it is necessary to use it in classrooms from an early age, as it will help to promote their comprehensive development from an early age through a more practical and motivating education for students.

Author Statement

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ORCID

Irene Trapero-González https://orcid.org/0009-0006-8459-6711

José-María Romero-Rodríguez https://orcid.org/0000-0002-9284-8919

Francisco-Domingo Fernández-Martín https://orcid.org/0000-0003-1272-1131

Santiago Alonso-García https://orcid.org/0000-0002-9525-709X

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