Heliyon 10 (2024) e33249

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Enhancing computational thinking in early childhood education with educational robotics: A meta-analysis

Santiago Alonso-García, Antonio-Vicente Rodríguez Fuentes, Magdalena Ramos Navas-Parejo, Juan-José Victoria-Maldonado *

Didactics and School Management, University of Granada, Spain

A R T I C L E I N F O

Keywords:
Computational thinking
Preschool education
Robotics
Technology education
Meta-analysis

A B S T R A C T

This paper deals within a context where technology plays a pivotal role in education. In this sense, it is essential to highlight the emergence of new competencies and skills in education due to technological advancements. Legislative frameworks have been developed to incorporate digital literacy, access to robotics, and computational thinking, between others. Hence, this review and meta-analysis aim at identifying the influence of robotics activities on computational thinking through a PRISMA-guided review. The findings reveal that interventions conducted in early childhood education significantly impact computational thinking. Results also showcase that, despite perceived barriers related to technology accessibility, the presence of legislation and contexts prioritizing these competencies is more relevant than the digital access gap.

1. Introduction

In Spain, the Early Childhood Education phase constitutes the first step into the educational system. Its paramount role within the education framework is underscored by its function as a milestone for subsequent stages. Even with its pivotal importance, this stage receives relatively minimal attention at a curricular level. This is primarily due to the unique characteristics delineated by the [1] Organic Law March 2020 of December 29, which amends Organic Law February 2006 of May 3 on Education, known in Spanish as “Ley Orgánica March 2020 de 29 de diciembre por la que se modifica la Ley Orgánica February 2006 de 3 de mayo de Educación” (henceforth, LOMLOE), which designates this stage, spanning from zero to six years of age, as voluntary.

Early childhood education is marked by significant developmental areas. From birth to six years, critical developments occur, such as: language and motor skills like walking evolve; children transition from reflexive and involuntary actions to conscious and deliberate behaviors; and the foundations of their future personalities start to take shape [2].

Therefore, despite being optional, it is understood as a highly relevant phase in the overall development of an individual. Consequently, based on the LOMLOE, autonomous communities are required to establish legislation setting minimum standards for this stage. In the case of Andalusia, the latest order regulating the curriculum corresponding to Early Childhood Education is the [3] Order of May 30, 2023, in Spanish “Orden de 30 de mayo de 2023”. This decree specifically addresses the needs of diverse learners and individual differences, organizes the evaluation of student learning processes, and sets guidelines for transitioning between cycles and into primary education.

* Corresponding author.
E-mail addresses: salonsog@ugr.es (S. Alonso-García), arfuente@ugr.es (A.-V. Rodríguez Fuentes), magdalena@ugr.es (M. Ramos Navas-Parejo), jvictoria@ugr.es (J.-J. Victoria-Maldonado).

https://doi.org/10.1016/j.heliyon.2024.e33249
Received 11 February 2024; Received in revised form 6 June 2024; Accepted 18 June 2024
Available online 24 June 2024

In this order and following the guidelines established in the LOMLOE, STEM competencies as well as the digital competence are included as key components of the curriculum.

1.1. Technology in education

STEM skills encompass a broad range of developments in early childhood education. This study focuses on exploring technological advancements during this phase. Notably, in traditionally developed curricula for this stage, science and mathematics have received more attention as they are considered more conventional subjects. In contrast, technology and engineering have been less emphasized [4].

Society's digitization and globalization have made technology a fundamental part of the home environment, thus becoming a familiar aspect of students' immediate surroundings [5]. While some studies suggest that the increase in technology usage spurred by COVID-19 might decline in the future [6], others argue that education has recognized technology as a versatile resource with a wide range of applications regardless of the pandemic's impact [7]. Research in favour of integrating technology in education highlights its vital role in promoting students' comprehensive development. Following this premise [8], argue that interacting with technology is essential for acquiring knowledge, attitudes, and values crucial for current and future scenarios.

Another critical area in the discourse on information and communication technology (ICT) is its impact on individuals with special educational needs. Numerous studies have shed light on the significant influence technology can have on people with various disabilities, including autism [9], hearing impairment [10], and dyslexia [11].

However, it is clear that there are some limitations when using such tools. The justification for not using ICT as an educational tool is based on different points. On the one hand, allusion is made of the misuse of technologies, especially social networks, as these in uncontrolled environments tend to be more of a distraction than a learning tool [12]. On the other hand, it is understood that technology can be efficient in some contexts but not for all, so establishing in which contexts it is positive plays a pivotal role. Specifically, regarding language learning, it has been found that ICT and in particular m-learning, is not an efficient tool [13].

Particularly, in the context of Early Childhood Education, technology remains a hotly debated topic that generates rejection due to ethical dilemmas [12], and it is questioned whether or not it should be used during this stage, justifying that there is not enough maturity and development of digital competences for the use of these to be beneficial [14–16].

1.2. Robotics in educational digitization

Amidst the wave of digitalization, educational robotics stands out as a key tool in developing STEM (Science, Technology, Engineering, and Mathematics) and digital competencies. It has proven effective in holistically enhancing various areas, as observed by Ref. [17]. Mathematics, in particular, benefits from the cross-disciplinary impact of robotics. Studies by Refs. [17,18], and [19] underscore its positive effects on math learning, especially in fostering problem-solving skills, which are applicable in mathematical contexts. Likewise [20], recognize the substantial advantages for language learning through robotics interactions. Engaging with programming and robotics requires a deep understanding of language, aiding in the development of complex cognitive sequences. Moreover, the primary appeal of using robotics in Early Childhood Education is its proven impact on computational thinking [21]. Seymour Papert, a pioneer in this field, displayed in 1980 the positive influence of robots on students. Since then, computational thinking has been a growing focus, existing alongside technology but not dependent on it. This form of thinking involves decomposing complex tasks into simpler stages, leading to the completion of more intricate and extensive tasks.

As we can observe, computational thinking is an evolving concept without a precise, universally accepted definition, as it requires a certain level of cognitive development and language understanding. By simplifying complex tasks, students can effectively develop cognitive and linguistic skills [22]. [23] also demonstrate how the development of computational thinking, though initially linked to technology, significantly impacts algorithmic thinking, critical thinking, and problem-solving skills. A significant challenge in researching computational thinking is the lack of instruments for assessing these skills [23]. introduced the Computational Thinking Scales (CTS), but this Likert scale is not yet validated for Early Childhood Education, limiting its applicability.

1.3. Challenges of robotics in early childhood education

The scientific literature presents an alternative perspective, acknowledging that despite technology's numerous benefits, it also introduces significant societal challenges.

A prominent issue is the digital divide, which takes various forms, notably in access to relevant devices. Opinions in the literature vary: some emphasize an access gap, while others note substantial access but with instances of misuse [24]. highlights that COVID-19 showcased that, despite widespread connectivity, the quality of devices and internet connections varies significantly. For example, one individual might have an outdated or budget-friendly phone with slow internet, whereas another might have high-speed internet and a state-of-the-art computer. This disparity leads to unequal access levels, generally favouring those with better resources for achieving superior outcomes.

Additionally, the issue of owning programmable robots is rare, though other free programming alternatives exist [6]. argue that the current focus on the digital divide may be misplaced, as the world's digitization, accelerated by COVID-19, led to technology misuse rather than lack of access.

Additionally, gender disparity, in technology manipulation, draws attention in this context. Some studies reveal significant gender differences in technology usage, while others see these differences as negligible [25]. [26] suggest early childhood initiatives to spark girls' interest in technology, addressing findings by Ref. [27] which indicate lower performance among women in technology fields. Addressing the gender digital divide requires targeted interventions, either integrated into teacher training [28] or implemented directly in classrooms [26]. The goal is to understand usage differences, scrutinize the gender digital divide, and discover effective interventions.

Research has identified robots suitable for interventions in early childhood education, like those described by Ref. [29]. However, the actual effectiveness of these tools remains unclear, as does a standardized protocol for assessing computational thinking. Research varies in their assessment approaches, from qualitative [30] to quantitative [31]. Furthermore, there is no consensus on when and how computational thinking is most effective, with varied findings on age-related abilities with very young children [32,33].

In the scientific literature, several systematic reviews have delved into this subject [34–36]. Additionally, certain facets remain underexplored due to the novelty of the term, with keywords in thesauri lacking precise definitions.

Furthermore, while many reviews highlight interventions within Early Childhood Education, they predominantly only provide descriptions, outlining timelines and tools utilized. Unfortunately, this approach often overlooks critical aspects such as disparities in resource access during this developmental stage and a comprehensive analysis of the outcomes. This *meta*-anylisis aims at exploring the application and impact of educational robotics on computational thinking in early childhood education, addressing several research questions.

R.Q.1. What is the distribution of scientific literature in the WOS and Scopus databases on robotics programming and computational thinking interventions in Early Childhood Education (including years, keywords, and geographical areas)?

R.Q.2. How are these interventions conducted in Early Childhood Education, and what are their contextual characteristics (focusing on socioeconomic factors, study and activity planning, and assessment of computational thinking)?

R.Q.3. To what extent do robotics interventions affect computational thinking levels in Early Childhood Education students?

2. Methods and materials

The methodology for this research follows the 2020 updated PRISMA statement, guiding both systematic reviews and meta-analyses, outlining 27 actions [37].

The research proposal in August 2023 initiated the search in September of the same year. Therefore, the search equation established in September includes only articles published up to that date. In this way, an initial review of key terms was conducted to generate a search equation that included documents focused on the stated objective. The formulated equation was as follows: (kindergarten OR "Early Childhood Education" OR preschool OR "Preschool Education" OR "Preschool Children" OR "Nursery schools") AND ("STEM Education" OR "Engineering Education" OR "STEM Careers" OR "STEAM Education" OR "Technology Education" OR "Computational Thinking" OR "Programming" OR "Coding" OR "robotics" OR "cybernetics")

However, due to the substantial volume of collected documents, it is necessary to conduct an initial filtering using automatic tools within the databases. Thus, filters include the following: belonging to the areas of Education and Educational Research in WOS, or Social Sciences in Scopus; articles published in English and Spanish; articles included in Open Access; and published since 2019. The year 2019 was included and it is chosen as the starting point for its significance in the advancement of robotics. This year marked a major commitment by the European community to this technology, exemplified by pivotal projects like PRO-ACT and INCOBOTICS. Additionally, the European Parliament introduced a comprehensive industrial policy for artificial intelligence and robotics across Europe, underscoring the year's importance. Consequently, 2019 stands as a critical juncture for conducting this research. Despite a noticeable decline in published articles during 2020 and 2021, attributed to the COVID-19 pandemic, the resurgence in publications in 2022 indicates a sustained interest in the field. This uptick suggests that the challenge has not been waning interest but rather the complexities of publishing practical experiences, particularly due to the implementation of blended learning models during the pandemic.

After this initial search, the articles were analysed based on their title, abstract, and methodology to exclude articles according to the criteria outlined in Table 1.

Table 1
Inclusion criteria and justification for article selection.

Inclusion Criteria	Justification
Interventions in Early Childhood Education	This study focuses solely on interventions, so descriptive and theoretical articles are discarded. On another note, it specifically concentrates on Early Childhood Education, rendering interventions aimed at other educational stages irrelevant.
Assesses Computational Thinking	The focus of this research is computational thinking; thus, evaluating other aspects is irrelevant.
Non-experimental/Quasi-experimental Research	Due to the nature of this study and the rigor required for the selected research, initially, studies that include only a single group will be excluded, as they are not suitable for meta-analysis. Furthermore, studies that lack a pre-test or post-test will also be excluded. This is essential to ensure whether the groups were comparable at the start, a key factor in determining the impact of the intervention.
Control Group	In this study, comparing two different interventions would be ineffective. To properly assess an intervention's influence, it must be compared with a control group that does not receive any intervention.
Qualitative Research	For the data analysis, quantitative measures like mean and standard deviation are necessary. Consequently, evaluations based on qualitative research will not be included in the analysis, as they do not provide these specific statistical values.

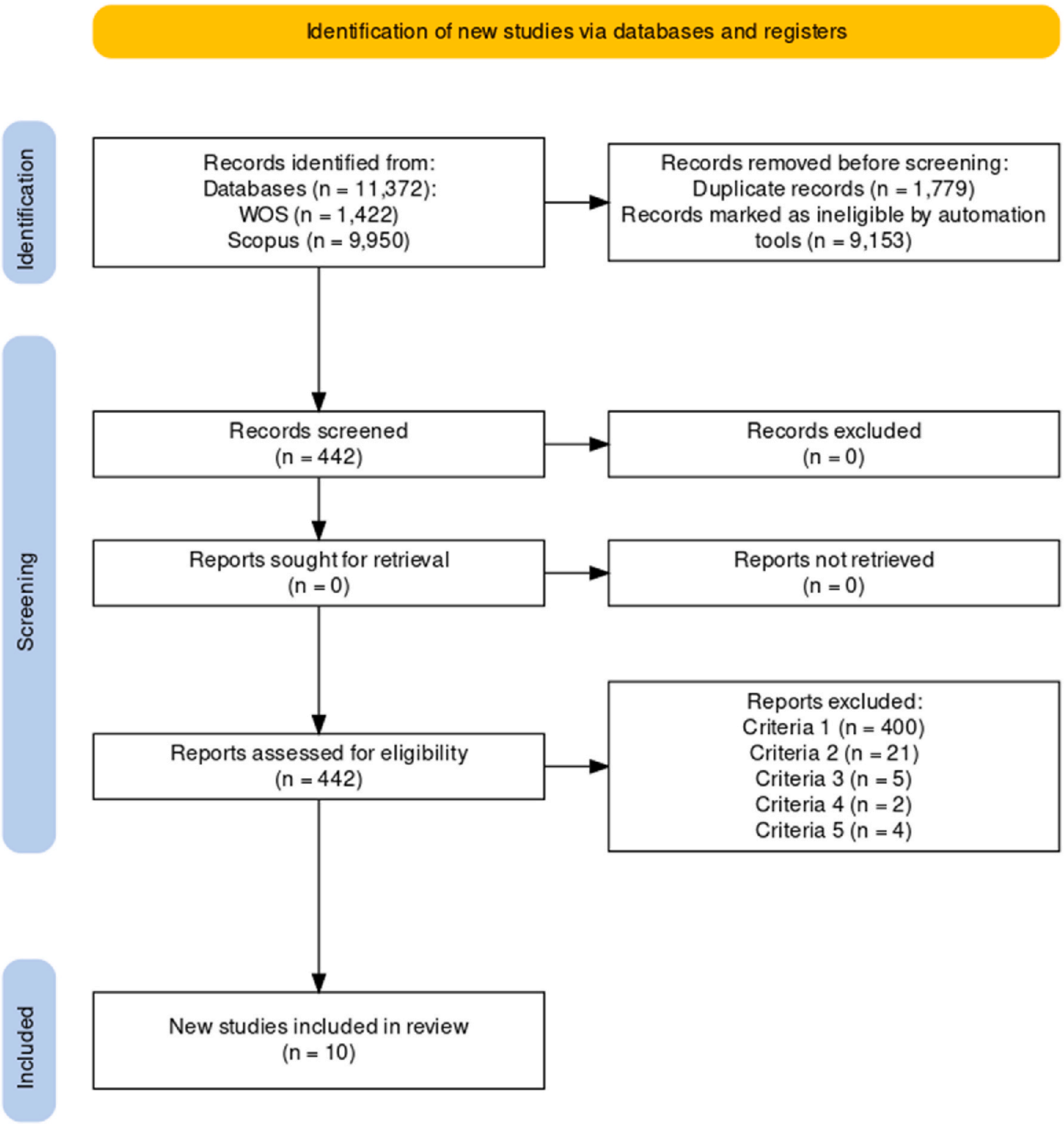

Fig. 1. Prisma flowchart.

After determining the criteria for including documents in this research, Fig. 1 exhibits a flowchart illustrating the selection process. Initially, from a total of 11,372 documents, 10,930 were excluded due to duplication and the automatic filtering mechanisms of the databases. Following the application of these filters, a secondary review was conducted based on the criteria outlined in Table 1. This involved the authors examining the titles, abstracts, and methodologies, which led to the final inclusion of 10 articles, as depicted in Fig. 1.

2.1. Mitigating bias in Article selection

To reduce inclusion bias in this research, a key component of the PRISMA guidelines, it is important to note that all authors were involved in the article screening process. A consensus was reached for the final selection. Initially, 15 articles were considered. After a thorough review based on criterion 4, one additional article was excluded, and based on criterion 5, four more were excluded.

3. Results

With regard to the presentation of the results, it is necessary to specify that they are going to be outlined according to the research questions posed above.

3.1. What is the distribution of scientific literature in the WOS and Scopus databases on robotics programming and computational thinking interventions in early childhood education (including years, keywords, and geographical areas)?

The analysis of the distribution of articles within the WOS and Scopus databases starts by examining the year and continent of the studies' origins. The years 2019 and 2020, marked by the peak of COVID-19, are particularly notable. In Asian countries, curricula often include references to digital development, programming, and computational thinking, with countries like India, China, and Korea being prominent in technological research. This context explains why much of the research originates from these regions.

Identifying relevant articles is challenging due to the inconsistent use of keywords across publications. To address this, we simplified the keyword selection process by focusing on the most common keywords across the articles and the journals they were published in. For example, "Robot Programming" was consolidated under the broader term "Programming." This approach revealed that only six keywords recur across the 10 selected articles, which were published in eight different journals. Notably, the journal "Education and Information Technologies" is a frequent publisher in this field. This analysis provides insight into the key databases' content and the nature of the publications (Fig. 2).

This analysis defines the presence in key databases relevant to the subject and outlines the characteristics of these publications (Fig. 3).

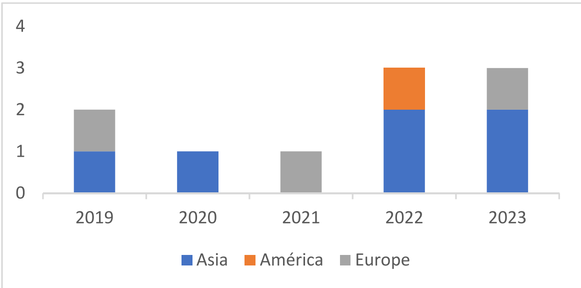

Fig. 2. Distribution of articles by year and continent.

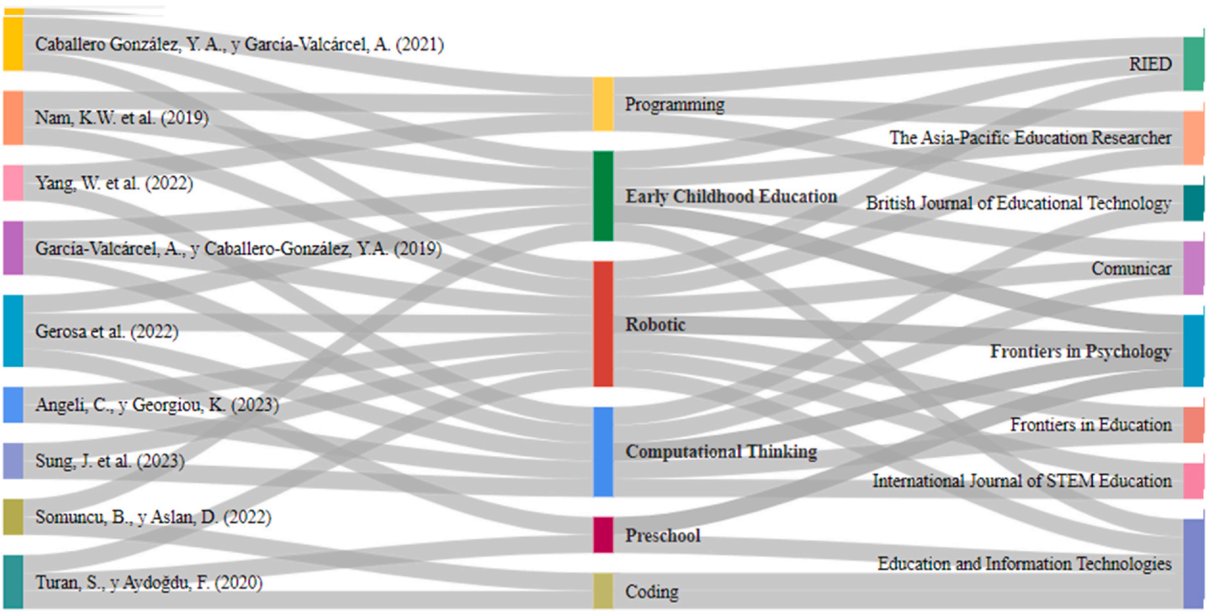

Fig. 3. Relationship between articles, keywords, and journals.

3.2. How are these interventions conducted in early childhood education, and what are their contextual characteristics (focusing on socioeconomic factors, study and activity planning, and assessment of computational thinking)?

To present the data more effectively, this research categorizes information by continent to enhance accessibility. The focus initially is on Asia, as it hosts the majority of research in this area.

Particularly the socio-economic Turkish's context is noticeable, grouped within Asian research for this study, although Turkey shares close political and social ties with Europe. This dual influence is reflected in studies like those by Ref. [18] Somuncu and Aslan (2022) and [38] Turan and Aydoğdu (2020), which focus on robotic interventions in settings where families hold a medium socio-economic status.

Contrastingly, research by Refs. [39–41], and [42] does not detail specific contexts like the former, though it is noted that all students in the cohort involved received programming content.

Regarding intervention methodologies, a consistent three-phase structure is apparent across the included articles. The first phase offers a theoretical introduction to robotics, computational thinking, and programming. The second phase familiarizes students with the tools and robotics through various activities, ensuring they understand the basics and minimize mistakes in the final phase. The third phase evaluates computational thinking through activities and problem-solving activities involving robotic programming.

To conclude the discussion on Asian research, it is important to underline how digital competence is assessed in these studies. Table 2 details the articles and their respective assessment tools or strategies for computational thinking in Asia.

In the American continent, the research is represented by a single article from Uruguay. Due to various constraints in this context, it is challenging to implement interventions [43]. indicate that interventions using these tools are feasible, primarily in high socio-economic contexts, highlighting the significance of economic barriers. To assess computational thinking, activities and problems are segmented into essential subtasks, with each problem allotted 25 min to gauge the total score and level of computational thinking.

Addressing R.Q.2, it is notable that Europe has initiated several projects and programs aimed at developing digital competencies for students and teachers. Tools like DigComp and DigCompEdu have been introduced for managing these competencies. Many countries, including Spain, are beginning to integrate computational thinking into their educational syllabus. This is evidenced in the new legislation in Spain which recognizes computational thinking as a vital skill.

The selected Spanish articles, specifically those by Refs. [44,45], focus on interventions in charter schools with medium socio-economic status [46]. also mention a medium economic level, although they do not specify the type of institution.The methods used for evaluating computational thinking in these European studies are detailed in Table 3.

3.3. To what extent do robotics interventions affect computational thinking levels in early childhood education students?

The analysis employed the standardized mean difference as the outcome measure, applying a random-effects model to the data (see Table 4). The heterogeneity level (tau^2) was determined using the restricted maximum-likelihood estimator. In addition to tau^2

Table 2
Computational thinking assessment in asia.

Reference	Assessment tool/strategy
[39]	The assessment tool used was TACTIC-KUBO
[40]	The assessment tool used was TechCheck-K
[41]	The assessment tool used was TechCheck-K
[42]	To evaluate computational thinking, a variety of activities and problems are used. Each task is broken down into smaller subtasks necessary for solving the problem. Additionally, each problem has a 25-min time limit, with the total score obtained reflecting the level of computational thinking achieved.
[18]	The assessment includes using the Early Mathematical Reasoning Skills instrument. Although it's not specifically designed for computational thinking assessment, it covers many relevant aspects as discussed in the study by Fridberg and Redfors (2021).
[38]	Evaluation is carried out using the Scale for Basic Skills instrument. Despite not being a tool exclusively designed for assessing computational thinking, it encompasses many aspects mentioned in the study by Fridberg and Redfors (2021).

Table 3
Computational thinking assessment in Europe.

Reference	Assessment tool/strategy
[46]Angeli, C., & Georgiou, K. (2023). Investigating the effects of gender and scaffolding in developing preschool children's computational thinking during problem-solving with Bee-Bots. *Frontiers in Education, 7*, 1–12. https://doi.org/10.3389/feduc.2022.757627.	Several activities and problems are executed to evaluate computational thinking. Each task is broken down into smaller ones, necessary subtasks for problem-solving. A time limit of 20 min is set for each problem, which aids in determining the overall score and the level of computational thinking achieved.
[44] Caballero González, Y. A., & García-Valcárcel Muñoz-Repiso, A. (2021). Robots en la educación de la primera infancia: aprender a secuenciar acciones usando robots programables. *RIED-Revista Iberoamericana De Educación a Distancia, 24* [1], 77–94. https://doi.org/10.5944/ried.24.1.27508.	Activities and exercises are conducted. However, it is not specified how these exercises are being assessed.
[45] García-Valcárcel, A., & Caballero-González, Y.A. (2019). Robótica para desarrollar el pensamiento computacional en Educación Infantil. *Comunicar, 27*(59), 63–72. https://doi.org/10.3916/C59-2019-06.	Evaluation is carried out based on the adaptation for the stage of the SSS rubric proposed in the TangibleK program in 2010.

Table 4
Random-effects model.

	Estimate	se	Z	p	CI Lower Bound	CI Upper Bound
Intercept	0.932	0.171	5.45	<0.001	0.597	1.267

Nota. Tau^2 Estimator: Restricted Maximum-Likelihood.

Table 5
Heterogeneity statistics.

Tau	Tau^2	I^2	H^2	R^2	df	Q	p
0.468	0.219 (SE = 0.1366)	80.7 %	5.182	.	9.000	45.934	<0.001

estimation, the Q-test for heterogeneity and the I^2 statistic were reported. If heterogeneity was detected ($tau^2 > 0$), a prediction interval for the true outcomes was provided, regardless of the Q-test results. Studentized residuals and Cook's distances were used to identify potential outliers and influential studies within the model (refer to Table 5). Studies with studentized residuals exceeding a certain threshold were flagged as potential outliers, applying a Bonferroni correction with a two-sided alpha of 0.05 for the number of studies in the meta-analysis. Studies with Cook's distances above a specific threshold were considered influential. Funnel plot asymmetry was assessed using the rank correlation test and regression test, with the standard error of observed outcomes as a predictor.

Ten studies were included in the analysis, showing standardized mean differences ranging from 0.2745 to 1.8272, all positive (100 %) (Fig. 4). The average standardized mean difference, estimated at a\hat{\mu} = 0.9317 (95 % CI: 0.5969 to 1.2666) using a random-effects model, was significantly different from zero ($z = 5.4534$, $p < 0.0001$) This certainly indicates that the effect of robotics on the development of computational thinking is positive as both values are positive.

The Q-test indicated significant heterogeneity in true outcomes ($Q(9) = 45.9340$, $p < 0.0001$, $tau^2 = 0.2190$, $I^2 = 80.7012$ %). The 95 % prediction interval for true outcomes varied from −0.0447 to 1.9082, suggesting variability in study outcomes. An examination of studentized residuals revealed no outliers (all values within ±2.8070). Cook's distances did not highlight any overly influential studies. Neither the rank correlation nor regression tests indicated funnel plot asymmetry ($p = 0.6007$ and $p = 0.9467$, respectively) (Table 6) (Fig. 5).

Statistical analysis shows differences according to the test performed. The Fail-Safe N test shows a certain reliability and therefore no publication bias. However, this test varies according to the method by which it is calculated. Therefore, the publication bias is tested based on the Begg and Mazumdar Rank Correlation Egger's Regression tests, both presenting values above 0.05, which indicates a publication bias in this case towards the publication of articles with positive results.

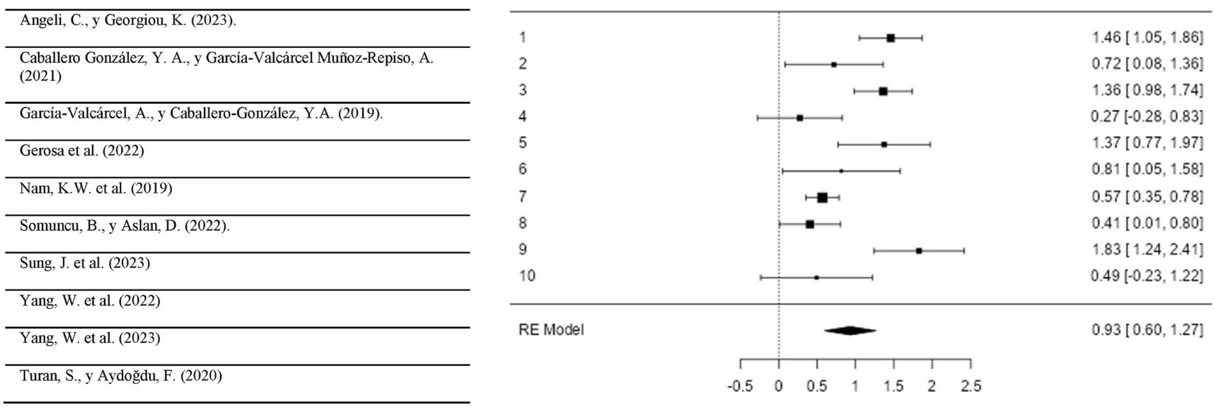

Fig. 4. Forest plot.

Table 6
Publication bias assessment.

Test Name	value	p
Fail-Safe N	537.000	<0.001
Begg and Mazumdar Rank Correlation	0.156	0.601
Egger's Regression	0.067	0.947
Trim and Fill Number of Studies	0.000	.

Nota. Fail-safe N Calculation Using the Rosenthal Approach.

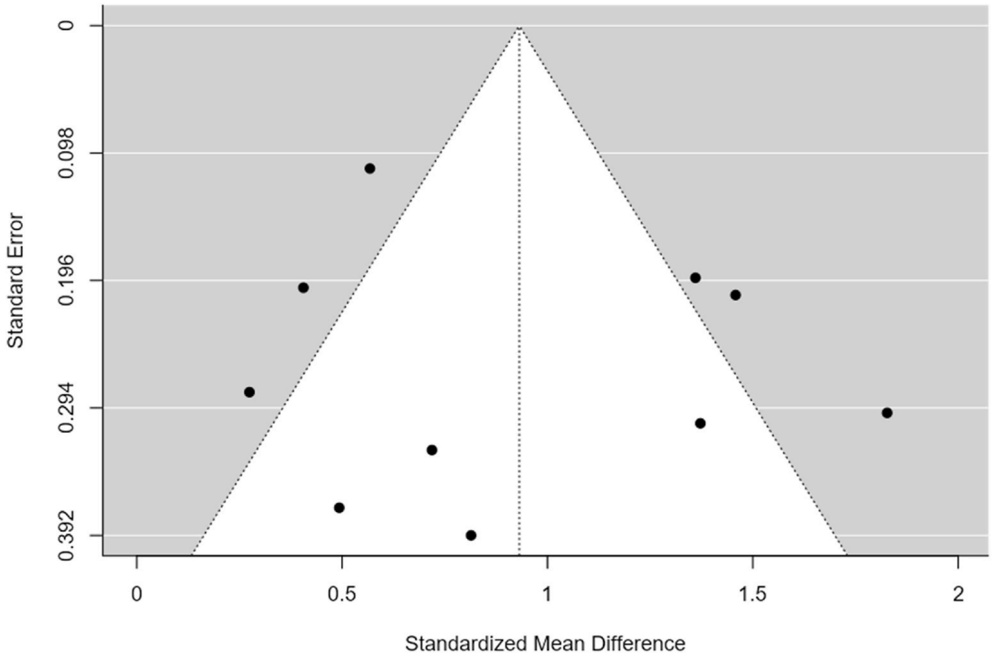

Fig. 5. Funnel plot.

4. Discussion

The principal finding of this meta-analysis is that robotics significantly bolsters computational thinking in students. This conclusion aligns with [22], yet no definitive studies conclusively establish this claim. A notable study in WOS, while similar in theme, does not confirm the impact of interventions on computational thinking. Therefore, this current study aims to ascertain the real influence using various statistical methods.

Educational legislation markedly affects the development of educational practices. A larger number of relevant studies are seen in Asia, especially in China and Korea, due to their emphasis on technology. In contrast, the United States has not prioritized computational thinking and programming, leading to a research gap in this area [47–49].

The accessibility of resources is also crucial [24]. highlighted that device quality impacts knowledge acquisition. Thus, understanding the research contexts to bridge digital access and training gaps is vital.

Additionally, the identification of articles is complicated by the lack of consistent keywords, and the COVID-19 pandemic has influenced research trends, with a decrease in interventions during 2020 and 2021, followed by a resurgence in 2022.

The data suggests that robotics programming enhances computational thinking, a key skill in educational curricula. Interventions are effective across various contexts, and dividing them into theoretical introduction, tool familiarization, and problem-solving phases proves to be an optimal approach.

5. Conclusion

Examining the impact of robotics activities on computational thinking in early childhood education yields profound insights, emphasizing the crucial role of technology integration in educational settings. This study has delved into the consequences of interventions on computational thinking, revealing positive outcomes. Despite concerns about technology accessibility barriers, legislative frameworks promoting digital literacy and computational thinking prove more influential than addressing digital access gaps.

The research underscores the pivotal role of robotics in boosting STEM competencies and digital literacy, particularly in cultivating computational thinking skills. Educational robotics emerges as a potent tool for comprehensive skill development, significantly influencing mathematics learning and language acquisition. The review highlights the transformative potential of computational thinking, involving breaking down complex tasks into simpler stages to attain more intricate goals. While recognizing challenges like the digital divide and gender disparities in technology use, the study proposes interventions to effectively address these issues.

Furthermore, our study accentuates the necessity for additional research to substantiate findings and offer robust evidence supporting the efficacy of robotics in enhancing computational thinking in early childhood education. Examining interventions across different continents provides valuable insights into diverse contexts and approaches, ranging from prioritizing socioeconomic factors to evaluating computational thinking based on geographical locations and socio-economic backgrounds.

The research underscores the importance of structured intervention procedures and clear assessment methods to effectively evaluate the impact of robotics activities on computational thinking. In conclusion, this meta-analysis significantly contributes to understanding how robotics interventions influence computational thinking in early childhood education, emphasizing the need for ongoing research to refine educational practices and outcomes.

Limitations

A theoretical study has been presented which has not focused on working in a specific classroom. This is the main limitation of the research. Initially, research with a pre-test-post-test design was proposed on the same subject to establish the influence of robotics on computational thinking. However, due to the lack of budget and accessibility of knowledge, the present meta-analysis was proposed as a pre-test for future research with the characteristics described above.

Another of the limitations encountered is document management, as the search equation is proposed with more than 11,000 documents at first, so that most of the reference managers were not able to work with such a load. Likewise, despite gender gap being a factor to consider when working with technologies, there has been a lack of in-depth exploration of this theme in the articles ultimately included in the paper. This is a factor that should be further investigated, both in the scientific literature and in future analyses.

Finally, it is worth highlighting the publication bias that exists after the review of the scientific literature, in which it seems that all the results are positive, and it is necessary to see whether this is due to the fact that robotics is an efficient tool or whether only positive results are published.

Future research line

As future research line, it is proposed to carry out another research with the same methodology that focuses only on the Spanish context since 2020. This idea arises from the legislation in force in the country, as, since 2020, these two elements have been included in the curriculum, it would be interesting to see how this legislation has influenced the subject in Spain.

Another future line of research is the intervention with robotics for Early Childhood Education students. This can also be approached from two perspectives: direct intervention with pupils at this stage and training for future teachers at this stage.

Finally, the idea of establishing a single internationally validated instrument to assess computational thinking in any context is proposed, this being a benchmark for comparison between different contexts.

Ethical statement

As a theoretical review of literature from WOS and Scopus, no specific ethical statement is needed, as no human or animal experiments were conducted. However, adherence to PRISMA criteria and involvement of multiple researchers were crucial to prevent bias in article inclusion.

Funding

This work has been funded with public funds by the Vice-Rectorate for Equality, Inclusion, and Sustainability of the University of Granada (Spain), in competitive concurrence in the Call for Grants to Support and Promote Research in the field of Equality, Inclusion, and Social Sustainability in 2022, under the project: Promotion and development of STEM training through robotics and computational thinking in future teachers of Early Childhood Education (LabInRob) (Reference: INV-IGU203-2022).

Data availability

The data presented in this article are openly accessible to the public. All of the articles that were selected for this study are available through open access. It is important to note that these articles are located within the WOS and Scopus databases, ensuring that all the data are readily accessible. This meta-analysis incorporates data from the following articles: [38–46]; and [18].

CRediT authorship contribution statement

Santiago Alonso-García: Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Antonio-Vicente Rodríguez Fuentes:** Writing – review & editing, Writing – original draft, Resources, Methodology, Investigation, Formal analysis, Conceptualization. **Magdalena Ramos Navas-Parejo:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Juan-José Victoria-Maldonado:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Santiago Alonso Garcia reports financial support was provided by University of Granada. This work has been funded with public funds by the Vice-Rectorate for Equality, Inclusion, and Sustainability of the University of Granada (Spain), in competitive concurrence in the Call for Grants to Support and Promote Research in the field of Equality, Inclusion, and Social Sustainability in 2022, under the

project: Promotion and development of STEM training through robotics and computational thinking in future teachers of Early Childhood Education (LabInRob) (Reference: INV-IGU203-2022). If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Ley Orgánica 3/2020, de 29 de diciembre, por la que se modifica la Ley Orgánica 2/2006, de 3 de mayo, de Educación, Boletín Oficial del Estado 340 (de 30 de diciembre de 2020) 122868 a 122953), https://www.boe.es/eli/es/lo/2020/12/29/3.

[2] C.M. Valarezo, S.Z. Celi, B. Rodríguez, V.C. Sánchez, Caracterización general y evolución de la personalidad en la primera infancia, Horizontes Revista de Investigación en Ciencias de la Educación 4 (16) (2020) 469–482.

[3] Orden de 30 de mayo de 2023, por la que se desarrolla el currículo correspondiente a la etapa de Educación Infantil en la Comunidad Autónoma de Andalucía, se regulan determinados aspectos de la atención a la diversidad y a las diferencias individuales, se establece la ordenación de la evaluación del proceso de aprendizaje del alumnado y se determinan los procesos de tránsito entre ciclos y con Educación Primaria. Boletín Oficial de la, vol.104, Junta de Andalucía, de 2 de junio de 2023, 9729-2807, https://juntadeandalucia.es/boja/2023/104/38.

[4] Y. Caballero-Gonzalez, A. García-Valcárcel, Fortaleciendo habilidades de pensamiento computacional en Educación Infantil: Experiencia de aprendizaje mediante interfaces tangible y gráfica, Revista Latinoamericana De Tecnología Educativa - RELATEC 18 (2) (2019) 1–18, https://doi.org/10.17398/1695-288X.18.2.133.

[5] R. Barragán-Sánchez, R. Romero-Tena, M. García-López, Educational robotics to address behavioral problems in early childhood, Educ. Sci. 13 (1) (2022) 1–14, https://doi.org/10.3390/educsci13010022.

[6] M. Villa, M.C. García-Linares, M.T. Cerezo-Rusillo, P.F. Casanova-Arias, COVID 19: Uso y abuso de internet y el teléfono móvil en estudiantes universitarios, International Journal of Developmental and Educational Psychology (IJODAEP) 2 (1) (2021) 107–116, https://doi.org/10.17060/ijodaep.2021.n1.v2.2123.

[7] J.F. Álvarez-Herrero, R. Martínez-Roig, M. Urrea-Solae, Uso de las tecnologías digitales en educación infantil en tiempos de pandemia, Campus Virtuales 10 (2) (2021) 165–174.

[8] R.M. Hernández, A. Rodríguez-Fuentes, N. Roselli, Integración de las TIC a la educación: Una mirada desde el aula universitaria, Hamut'ay 6 (3) (2019) 1–11, https://doi.org/10.21503/hamu.v6i3.1839.

[9] C.D.P. Gallardo-Montes, A. Rodríguez-Fuentes, M.J. Caurcel-Cara, ICT training for educators of Granada for working with people with autism, Heliyon 9 (3) (2023) e13924, https://doi.org/10.1016/j.heliyon.2023.e13924.

[10] A. Rodríguez-Fuentes, L. Alaín-Botaccio, F. García-García, Presentation and evaluation of a digital tool for sign language (Presentación y evaluación de una herramienta digital para la lengua de signos), C&E, Cultura y Educación 34 (3) (2022) 658–688, https://doi.org/10.1080/11356405.2022.2058793.

[11] L. Zuppardo, A. Rodríguez-Fuentes, F. Serrano, Sotfware Lectoescritores contra la Dislexia y Disortografía Sotfware, EduTicInnova 7 (1) (2019) 27–39.

[12] J. Plaza, Evolución del uso de las TIC por parte de los adolescentes en los últimos años: luces y sombras, Aloma: Revista de Psicologia, Ciències de l'Educació i de l'Esport Blanquerna 39 (1) (2021) 39–47, https://doi.org/10.51698/aloma.2021.39.1.39-47.

[13] T.T. Nguyen, H.H. Pham, V.A. Nguyen-Le, C.H. Nguyen, T. Tran, Review of research on predatory scientific publications from Scopus database between 2012 and 2022, J. Sch. Publish. 54 (2) (2023) 175–219, https://doi.org/10.3138/jsp-2022-0045.

[14] J. Boza, M. Torres, Perspectiva sobre la educación inicial y el acceso a las TIC: Revisión crítica de la literatura, Revista de Ciencias Humanísticas y Sociales (ReHuSo) 6 (2) (2021) 47–56.

[15] M.D.M.S. Vera, El desarrollo de la Competencia Digital en el alumnado de Educación Infantil. Edutec, Revista Electrónica De Tecnología Educativa (76) (2021) 126–143.

[16] A.L. Calle-González, D.G. García-Herrera, S.E. Mena-Clerque, Uso de herramientas digitales en Educación Inicial frente a pandemia, CIENCIAMATRIA 7 (13) (2021) 66–84.

[17] M. Canbeldek, N. Isikoglu, Exploring the efects of "productive children: coding and robotics education program" in early childhood education, Education and Information Technologies 28 (2023) 3359–3379, https://doi.org/10.1007/s10639-022-11315-x.

[18] B. Somuncu, D. Aslan, Effect of coding activities on preschool children's mathematical reasoning skills, Education and Information Technologies 27 (2022) 877–890, https://doi.org/10.1007/s10639-021-10618-9.

[19] M. Ricard, M. Estrada, M. Margalef, Idoneidad didáctica en educación infantil: matemáticas con robots Blue-Bot, EDMETIC, Revista de Educación Mediática y TIC 8 (2) (2019) 150–168, https://doi.org/10.21071/edmetic.v8i2.11589.

[20] S. Kewalramani, I. Palaiologou, M. Dardanou, K.-A. Allen, S. Phillipson, Using robotic toys in early childhood education to support children's social and emotional competencies, Australas. J. Early Child. 46 (4) (2021) 355–369, https://doi.org/10.1177/18369391211056668.

[21] S. Papert, Mindstorms: Children, Computers, and Powerful Ideas, Basic Books, 1980.

[22] C.U. Corrie, M.C. Karien, B. Lex, Measurement of executive functioning using a playful robot in kindergarten, Interdisciplinary Journal of Practice, Theory, and Applied Research 4 (36) (2019) 255–273, https://doi.org/10.1080/07380569.2019.1677436.

[23] G. Rodríguez-Abitia, M.S. Ramírez-Montoya, E.O. López-Caudana, J.M. Romero-Rodríguez, Factors for the development of computational thinking in undergraduate students, Campus Virtuales 10 (2) (2021) 153–164.

[24] Á.C. Prince, El autoaprendizaje como proceso para la construcción de conocimientos en tiempos de pandemia, Edição Especial COVID-19 (Publicação Contínua) 2 (2) (2020), https://doi.org/10.54580/r0202.08.

[25] S. Alonso-García, J.J. Victoria-Maldonado, P.J. García-Sempere, F. Lara-Lara, Student evaluation of teacher digitals skills at Granada University, Frontiers in Education 7 (2023) 1–10, https://doi.org/10.3389/feduc.2022.1069245.

[26] S. Jung, K. Lee, A girl's gendered engagement in designing and building robots, Int. J. Technol. Des. Educ. 32 (2022) 2425–2444, https://doi.org/10.1007/s10798-021-09705-2.

[27] R. Çakir, Ö. Korkmaz, Ö. Idil, F.U. Erdoğmuş, The effect of robotic coding education on preschoolers' problem solving and creative thinking skills, Think. Skills Creativ. 40 (2021), https://doi.org/10.1016/j.tsc.2021.100812.

[28] G. Gómez-García, F.J. Hinojo-Lucen, S. Alonso-García, J.M. Romero-Rodríguez, Mobile learning in pre-service teacher education: perceived usefulness of AR technology in primary education, Educ. Sci. 11 (6) (2021) 1–9, https://doi.org/10.3390/educsci11060275.

[29] C.S. González-González, Estado del arte en la enseñanza del pensamiento computacional y la programación en la etapa infantil, Education in the Knowledge Society 20 (17) (2019) 1–15, https://doi.org/10.14201/eks2019_20_a17.

[30] J.F. Álvarez-Herrero, Pensamiento computacional en Educación Infantil, más allá de los robots de suelo, Education in the Knowledge Society 21 (2020) 1–12.

[31] M. Fridbreg, A. y Redfors, Teachers' and children's use of words during early childhood STEM teaching supported by robotics, Int. J. Early Years Educ. (2021) 1–15, https://doi.org/10.1080/09669760.2021.1892599.

[32] M. Terroba, J.M. Ribera, D. Lapresa, M.T. y Anguera, Análisis observacional del desarrollo del pensamiento computacional en Educación Infantil-3 años mediante una propuesta de resolución de problemas con un robot de suelo de direccionalidad programada, Revista de Educación a Distancia (RED) 21 (68) (2021), https://doi.org/10.6018/red.480411.

[33] M. Ruíz, B. y Arteaga, El pensamiento geométrico-espacial y computacional en educación infantil: un estudio de caso con KUBO, Contextos Educativos. Revista De Educación 30 (2022) 41–60, https://doi.org/10.18172/con.5372.

[34] J. Su, Y. Zhong, X. Chen, Technology education in early childhood education: a systematic review, Interact. Learn. Environ. (2023) 1–14, https://doi.org/10.1080/10494820.2022.2160470.

[35] Y. Zeng, W. Yang, A. Bautista, Computational thinking in early childhood education: Reviewing the literature and redeveloping the three-dimensional framework, Educ. Res. Rev. 39 (100520) (2023) 100520, https://doi.org/10.1016/j.edurev.2023.100520.

[36] Y.-H. Ching, Y.-C. Hsu, Educational robotics for developing computational thinking in young learners: a systematic review, TechTrends : For Leaders in Education & Training (2023), https://doi.org/10.1007/s11528-023-00841.
[37] M.J. Page, J.E. McKenzie, P.M. Bossuyt, I. Boutron, T.C. Hoffmann, C.D. Mulrow, L. Shamseer, J.M. Tetzlaff, E.A. Akl, S.E. Brennan, R. Chou, J. Glanville, J. M. Grimshaw, A. Hróbjartsson, M.M. Lalu, T. Li, E.W. Loder, E. Mayo-Wilson, S. McDonald, S. Alonso-Fernández, Declaración PRISMA 2020: una guía actualizada para la publicación de revisiones sistemáticas, Rev. Esp. Cardiol. 74 (9) (2021) 790–799, https://doi.org/10.1016/j.recesp.2021.06.016.
[38] S. Turan, F. Aydoğdu, Effect of coding and robotic education on pre-school children's skills of scientific process, Educ. Inf. Technol. 25 (2020) 4353–4363, https://doi.org/10.1007/s10639-020-10178-4.
[39] W. Yang, D.K.T. Ng, J. Su, The impact of story-inspired programming on preschool children's computational thinking: a multi-group experiment, Think. Skills Creativ. 47 (2023) 1–12, https://doi.org/10.1016/j.tsc.2022.101218.
[40] J. Sung, J.Y. Lee, H.Y. Chun, Short-term effects of a classroom-based STEAM program using robotic kits on children in South Korea, IJ STEM Ed 10 (26) (2023), https://doi.org/10.1186/s40594-023-00417-8.
[41] W. Yang, D.K.T. Ng, H. Gao, Robot programming versus block play in early childhood education: effects on computational thinking, sequencing ability, and self-regulation, Br. J. Educ. Technol. 6 (53) (2022) 1817–1841, https://doi.org/10.1111/bjet.13215.
[42] Y.A. Caballero González, A. García-Valcárcel Muñoz-Repiso, Robots en la educación de la primera infancia: aprender a secuenciar acciones usando robots programables, RIED. Rev. Iberoam. Educ. Distancia 24 (1) (2021) 77–94, https://doi.org/10.5944/ried.24.1.27508.
[43] K.W. Nam, H.J. Kim, S. Lee, Connecting plans to action: the effects of a card-coded robotics curriculum and activities on Korean kindergartners, The Asia-Pacific Education Researcher 28 (2019) 387–397, https://doi.org/10.1007/s40299-019-00438-4.
[44] A. Gerosa, V. Koleszar, G. Tejera, L. Gómez-Sena, A. Carboni, Educational robotics intervention to foster computational thinking in preschoolers: effects of children's task engagement, Frontiers in Psichology 21 (13) (2022) 1–13, https://doi.org/10.3389/fpsyg.2022.904761.
[45] C. Angeli, K. Georgiou, Investigating the effects of gender and scaffolding in developing preschool children's computational thinking during problem-solving with Bee-Bots, Frontiers in Education 7 (2023) 1–12, https://doi.org/10.3389/feduc.2022.757627.
[46] A. García-Valcárcel, Y.A. Caballero-González, Robótica para desarrollar el pensamiento computacional en Educación Infantil, Comunicar 27 (59) (2019) 63–72, https://doi.org/10.3916/C59-2019-06.
[47] D. Silvis, V. Lee, J. Clarke-Midura, J. Shumway, The technical matters: young children debugging (with) tangible coding toys, Information and Learning Sciences 9 (123) (2022) 577–600, https://doi.org/10.1108/ILS-12-2021-0109.
[48] J. Hall, K.I. McCormick, "My Cars don't drive Themselves": preschoolers' guided play experiences with button-operated robots, TechTrends 66 (2022) 510–526, https://doi.org/10.1007/s11528-022-00727-8.
[49] A. Sullivan, M.U. Bers, Investigating the use of robotics to increase girls' interest in engineering during early elementary school, Int. J. Technol. Des. Educ. 29 (2019) 1033–1051, https://doi.org/10.1007/s10798-018-9483-y.