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Integrating computational thinking in children aged 3 to 6: challenges and opportunities in early childhood education

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Computational thinking (CT) has emerged as a crucial skill in 21st-century education. Although most research has focused on education levels beyond primary school, this article reviews the impact of its integration in early childhood education, specifically for children aged 3–6 years old. Through a systematic review of 84 studies published in Scopus and Web of Science between 2013 and 2023, pedagogical strategies and technological tools used to develop CT in early childhood are explored. The findings reveal that while CT fosters key cognitive and motor skills, the lack of appropriate materials and teacher training hinders effective implementation. The article highlights the need for continuous teacher training programs and the comprehensive inclusion of CT in early childhood curricula. Furthermore, it identifies a lack of consistent assessment tools that measure the long-term effects of these interventions on child development.

KEYWORDS

computational thinking, early childhood education, educational robotics, cognitive development, teacher training

Introduction

Computational thinking (CT) has become established as an essential competency in the contemporary digital society. Wing (2011) described it as "the new literacy of the twenty-first century," highlighting its relevance in both educational and professional environments. In early childhood education, particularly between the ages of three and six, CT not only lays the foundation for logical reasoning and problem-solving but also fosters key dispositions such as curiosity, creativity, and perseverance (Bers, 2018).

However, the effective integration of CT into early childhood education faces several challenges. One of the most prominent is the prevailing tendency in educational strategies to prioritize the use of digital tools such as robots and apps while neglecting approaches more appropriate for young children's development, such as unplugged or play-based activities (Brackmann et al., 2017; Akiba, 2022).

Another significant challenge is the lack of conceptual clarity in defining and evaluating CT outcomes. Many educational interventions do not adequately distinguish between cognitive skills, such as abstraction or sequencing, and learning dispositions, such as persistence or curiosity (Sun et al., 2021). This distinction is crucial, as both dimensions are essential to understanding the full impact of CT in early childhood education (Liu et al., 2023).

Furthermore, there is a disconnect between CT initiatives and the developmental characteristics of young children. Although digital tools can be valuable resources for exploration and creativity, their use must be mediated by pedagogical strategies that respond to children's social, emotional, and cognitive needs (Limón, 2022). Otherwise, implementing tools such as robots or screens from a utilitarian perspective may lead to student disengagement and limit the development of critical competencies for digital citizenship (Akiba, 2022; Artecona et al., 2016).

In this context, it is necessary to reconsider how CT is introduced in early childhood education and to explore pedagogical approaches that integrate both technical and human dimensions. Understanding CT not merely as a set of analytical tools but as a pedagogical framework that supports exploration, autonomy, and engagement opens the path toward more inclusive and transformative educational practices (OECD, 2020; Bers, 2018).

The role of computational thinking in cognitive development

Diverse academic disciplines use computational thinking as a fundamental cognitive process for problem-solving, providing students with practical experience in addressing real-world challenges and encouraging engagement with computer science (Master et al., 2023). Computational thinking embodies a form of analytical reasoning that closely resembles mathematical reasoning (e.g., problem-solving), engineering reasoning (process design and assessment), and scientific reasoning (systematic analysis).

Wing (2006) asserts that computational thinking "is a fundamental skill for everyone, not just for computer scientists. To reading, writing, and arithmetic, we should add computational thinking to every child's analytical ability." (p. 33). The International Society for Technology in Education (ISTE) and the Computer Science Teachers Association (CSTA) have articulated an operational definition of computational thinking as a problem-solving methodology encompassing algorithmic problem formulation, logical data organization, abstraction as a representational mechanism, automation, resource and time efficiency, and solution generalization. Furthermore, elements such as confidence, persistence, tolerance for uncertainty, and communication are emphasized (Gerosa et al., 2022).

Consequently, computational thinking extends beyond just technical programming abilities; it is regarded as a cross-disciplinary cognitive process that may be incorporated into diverse fields of education. This strategy fosters the development of coding skills in early childhood, specifically in children aged 3–6, by employing strategies that enhance logical and sequential thinking. Prior studies indicate that preschoolers may acquire fundamental programming principles through the use of visual tools and interactive resources, fostering the development of algorithmic thinking in a natural and joyful manner (Bers, 2018).

Computational thinking enhances functional skills in domains such as literacy and mathematics (Clements and Sarama, 2018). The incorporation of computational thinking in early childhood education has demonstrated efficacy in enhancing numerical comprehension and mathematical problem-solving via logical sequences and repetitive patterns, which are essential concepts in programming and mathematics (Relkin et al., 2020).

From this viewpoint, computational thinking represents a method for systematically assessing, formulating, and resolving problems. This approach involves deconstructing big issues into smaller components, recognizing commonalities, formulating sequential solutions, and employing fundamental ideas such as assessment, pattern recognition, abstraction, and algorithm development. The early development of thinking, crucial in the 21st century, is critical for fostering pupils' cognitive progress.

In addition to its recognition as a cognitive process that underpins analytical reasoning and problem-solving, computational thinking is increasingly conceptualized as a pedagogical framework that supports the design of developmentally appropriate, inquiry-based, and engaging learning environments in early childhood (Bers, 2018; Clarke-Midura et al., 2023). This dual perspective enhances its relevance in educational contexts, allowing it to function not only as a transferable cognitive competency but also as a structuring element for curricular innovation and interdisciplinary learning.

Computational thinking in early childhood education

Early childhood computational thinking is a crucial cognitive process aimed at cultivating problem-solving abilities and digital capabilities from a young age. Computational thinking transcends its role as a programming tool; it is a cognitive process that facilitates problem structuring, idea organization, and strategy development for resolution. The incorporation of digital solutions in early childhood education promotes children's ability to create and implement such solutions, enhancing creativity and knowledge construction, thereby equipping them to traverse a digitized society (Pugnali et al., 2017; Relkin et al., 2020). This method not only includes programming education but also cultivates the capacity to deconstruct intricate problems into manageable components, recognize commonalities, and formulate sequential solutions, thereby fostering analytical and algorithmic reasoning from a young age (Kanaki and Kalogiannakis, 2022).

Clarke-Midura et al. (2023) emphasize the groundbreaking contributions of Papert in the 1970s and 1980s, who utilized the "cybernetic" turtle within the LOGO environment as an educational tool to cultivate mathematical reasoning in youngsters through engagement with "thinking objects." Papert developed these items not merely to teach mathematics but also to involve children in essential elements of computational thinking, such as sequencing and debugging. This methodology has profoundly impacted contemporary research on imparting computational thinking in early childhood education.

Bers presents seven significant concepts for advancing early childhood computer education, derived from the Papert foundations: algorithms, modularity, control structures, representation, hardware and software, design processes, and debugging (Sullivan and Umashi Bers, 2018, p. 17). These concepts not only enhance technical abilities but also solidify computational thinking as a cognitive process that fosters the development of logical reasoning and systematic problem-solving from an early age.

Understanding that computational thinking in early infancy extends beyond computer science is crucial, since it fosters numerous abilities vital for all citizens (Caballero-González and García-Valcárcel, 2020). Education equips children for future technological applications such as coding and robotics, hence fostering broader and more equitable access to the digital skills essential for the future (Lu and Fletcher, 2009, as quoted by Bezuidenhout, 2021).

Developed nations regard computational thinking as the foundation of the emerging technology society, whilst poor nations perceive it as the optimal means to bridge educational disparities Basogain et al. (2016). Educators are progressively acknowledging the significance of this skill in education, while research remains insufficient about the methods to teach and cultivate computational thinking in young children outside conventional systems (Li and Yang, 2023).

Previous literature on early childhood computational thinking has predominantly examined the integration and impact of computational thinking within STEAM and STEM disciplines, alongside the utilization of technology as a programming instrument to augment 21st-century skills via robotics (Hu et al., 2024; Hu, 2024; Martins et al., 2023; Rich et al., 2024; Silva et al., 2023; Su and Yang, 2023; Zeng et al., 2023; Zhang and Crawford, 2023). This review focuses on the development of learning through computational thinking in children aged 3–6 years. For this purpose, the following general question was posed: what dimensions or concepts of learning are affected by CT? In this context, three specific questions guide the results presented: (1) What are the primary educational needs? (RQ1) (2) How does computational thinking affect the overall learning progress and cognitive development of early childhood education students? (RQ2) (3) What specific tools and practices have been employed to promote computational thinking in early childhood education, and what criteria are used to assess their effectiveness? (RQ3).

These questions seek to go beyond its function as a tool for introducing programming concepts or developing specific cognitive skills. Computational thinking can also be understood as a pedagogical framework that organizes young children's interaction with learning tasks. When intentionally integrated into the curriculum, computational thinking encourages educators to design activities that promote logical reasoning, creativity, collaboration, and iterative problem-solving. This broader perspective aligns with constructionist approaches (Papert, 1980; Bers, 2018), which position computational thinking not only as a content to be taught, but as a fundamental perspective for structuring early learning experiences.

Methodology

Research on the development of computational thinking in early childhood has gained traction in the academic community, so it is important to review this field's application to get a more in-depth understanding of how early childhood uses and appropriates computer thought.

This systematic review aims to track the development of computational thinking research in early childhood education. Recognizing this as the foundation of emotional and cognitive well-being across the lifespan, as well as one of the most advantageous investments a nation can undertake, given its promotion of holistic development, gender equality, and social cohesion (UNESCO, 2024).

While numerous studies have confirmed the efficacy of computational thinking in education, with some even extending its application to early childhood education, the obstacles, or strategies for incorporating computational thinking into preschool curricula remain unclear. We highlight the need to reveal how computational thinking achieves learning and how to integrate it into the early childhood curriculum.

This review has specific objectives. (1) Identify educational needs that have enabled the use of computational thinking in preschool education. (2) Recognize the importance of computational thinking within the learning process of preschool students. (3) Examine the tools and strategies used in preschool education to develop computational thinking. The findings will enable the academic community to deepen the teaching of early childhood computatnal thinking within the scope of learning achievements, providing a more analytical look at the use of tools used to develop computational thought in young children.

Method

This systematic review used the guidelines set out in the PRISMA statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (see Figure 1). The recognized method establishes each step, leading to the development of a review protocol for the literature search process, eligibility criteria, and data extraction.

Data search process

In February and March 2024, we selected two multidisciplinary and high-impact academic databases Scopus and Web of Science (WoS) to carry out the literature search for this systematic review. These platforms were chosen for their comprehensive indexing of peer-reviewed journals in the fields of education, technology, and early childhood studies. Subsequently, a search string was constructed using a combination of controlled vocabulary and free-text terms to capture literature related to computational thinking, early childhood, preschool education, and kindergarten. The search terms were iteratively refined to ensure alignment with the study's scope and objectives. Publications from the year 2024 were excluded to maintain consistency, as the searches were conducted prior to the completion of that publication year.

We combine several terms to refine the search and obtain more precise results. We used the following search equations: Scopus (TITLE-ABS-KEY ("computational thinking") OR TITLE-ABS-KEY ("robot") OR TITLE-ABS-KEY ("coding") OR TITLE-ABS-KEY ("robotics") OR TITLE-ABS-KEY ("programming") AND TITLE-ABS-KEY ("early childhood") OR TITLE-ABS-KEY ("young child*") OR TITLE-ABS-KEY ("preschool*") OR TITLE-ABS-KEY ("kindergarten*") OR TITLE-ABS-KEY ("pre-k*") OR

FIGURE 1
PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses). Own creation.

TITLE-ABS-KEY ("childcare") OR TITLE-ABS-KEY ("child care") OR TITLE-ABS-KEY ("day care")) WoS ("computational thinking" OR"robot" OR "coding" OR "robotics" OR "programming") AND ("early childhood"OR "young child*" OR "preschool*" OR "kindergarten*" OR "pre-k*" OR "childcare" OR "child care" OR "day care"). In March 2024, researchers analyzed and accessed peer-reviewed articles published between 2013 and 2023.

The search string was designed to balance sensitivity and specificity, ensuring the inclusion of a comprehensive set of studies while minimizing irrelevant results. The terms "computational thinking," "coding," "robotics," "robot," and "programming" were selected to capture both the conceptual dimensions of Computational Thinking (CT) and its most frequent pedagogical applications in early childhood contexts. These terms are commonly used in the literature and have been employed in previous systematic reviews addressing similar topics. At the same time, the inclusion of population-specific terms such as "early childhood," "young child," "preschool," "kindergarten," "pre-k," "child care," and "day care" made it possible to identify studies explicitly focused on learners aged 3–6.

Eligibility criteria

Figure 1 displays the results of the PRISMA analysis, which indicated that a total of 10,196 articles were searched. A total of 9,620 papers were eliminated by automated filtering based on criteria such as publication year 2013–2023, topic (e.g., unrelated to education or computational thinking), keywords, and publication stage.

During the eligibility assessment phase, a total of 72 studies were excluded for various reasons, including lack of alignment with the school cycle or age (n = 28), absence of relation to computational thinking (n = 18), being systematic reviews (n = 7), focusing on teacher training in specific tools (n = 16), and duplicate records in the abstracts (n = 3) (see Table 1).

TABLE 1 Inclusion and exclusion criteria for articles.

Inclusion criteria	Exclusion criteria
Studies published between 2013 and 2023.	Studies unrelated to computational thinking.
Peer-reviewed journal articles.	Studies exclusively focused on technical training in specific digital tools, without addressing broader aspects of computational thinking integration.
Research involving children in early childhood education (preschool, kindergarten, pre-K, child care, day care).	Studies not aligned with the early childhood educational cycle or target age group.
Studies related to computational thinking, robotics, coding, or programming.	Systematic reviews or meta-analyses.
	Duplicate records (especially in abstracts).
	Studies that are not related to education

Data extraction

To ensure the rigor and reliability of the data extraction and coding process, two researchers independently coded all the selected studies using a structured coding framework that included the following analytical dimensions: educational needs, learning dimensions affected by computational thinking, tools and strategies employed, and methodological approaches.

The coding framework was developed iteratively based on the objectives of the review and theoretical references related to computational thinking in early childhood education. Discrepancies between the two independent coders were systematically discussed in consensus meetings. In cases where agreement could not be immediately achieved, a third researcher acted as an arbitrator to finalize the coding decisions.

This process of double independent coding followed by consensus and arbitration ensured the reliability of the classification. A detailed description of the coding categories, subcategories, and the criteria supporting their construction (see Tables 1, 2).

This rigorous process contributed to increasing the credibility, trustworthiness, and replicability of the systematic review.

Data analysis procedure

Computational Thinking has emerged as a critical area of study and has been widely explored across diverse educational contexts. For this review, a total of 84 relevant studies published between 2013 and 2023 were identified. This body of literature is considered sufficiently comprehensive to provide a thorough overview of the implementation and application of CT in early childhood education. These studies were systematically examined to extract and categorize the most salient elements.

The analytical process employed a coding strategy grounded in a predefined framework encompassing four key analytical categories: (1) the identified problem or challenge, (2) the educational needs addressed, (3) the tools and strategies implemented, and (4) the methodological design adopted in each study (see Tables 1, 3).

Each article was manually reviewed and coded using a structured coding matrix, which was developed iteratively and validated by the three authors to ensure inter-coder reliability. This process enabled the classification of recurring themes and patterns across the selected studies. Consistency in the coding procedure was achieved through cross-validation and double-checking of entries, allowing for a robust synthesis of findings. The adopted analytical approach provided a nuanced understanding of the pedagogical, technological, and contextual dimensions shaping the use of CT in early childhood education.

Results

The results presented in this section emerge from a comprehensive examination of the 84 texts selected following the application of the previously outlined inclusion and exclusion criteria. These studies facilitate the identification of the demands and effects that computational thinking has exerted on the social and cognitive development of children within early childhood education settings. Furthermore, given that the integration of computational thinking in early childhood education has been the subject of numerous investigations aimed at elucidating its effects, the initial focus will be an analysis of publication trends during the review period. This analysis will illustrate the increasing scholarly interest in this area, alongside the geographical distribution of the conducted studies, thereby providing a more nuanced understanding of the review's findings.

Subsequently, the findings of the systematic review are presented, structured according to the three research questions (RQ1, RQ2, RQ3) formulated to guide this study. A meticulous examination of the selected studies allowed for the identification of the educational needs that underpinned the integration of computational thinking (RQ1), the cognitive and learning outcomes associated with its implementation (RQ2), and the specific tools, strategies, and evaluation criteria employed (RQ3).

These papers illustrate how CT enhances foundational skills in early childhood including problem solving, abstraction, and logical sequencing while shaping social and cognitive development (RQ2). As shown in Table 2, the results are organized into three key dimensions: (1) the educational demands driving CT integration (RQ1), (2) the pedagogical tools and tactics employed in classrooms (RQ3), and (3) the observed learning outcomes (RQ2). This structure provides a grounded perspective on the influence of CT, highlighting both its potential for curricular incorporation and the challenges identified in different contexts.

Descriptive statistical analysis of the selected studies

Publication trends

The systematic analysis of 84 studies reveals exponential growth in computational thinking (CT) research for early childhood education, directly informing our understanding of evolving pedagogical needs (RQ1) and implementation strategies (RQ3). As Figure 2 demonstrates, after limited output during 2013–2018 (1–3 articles/year), scholarly interest surged from 2019 (10 articles) onward, peaking in 2022–2023 (21 and 22 articles respectively). This trajectory mirrors increasing attention to both cognitive impacts (RQ2) and technological integration (RQ3) in early CT education.

Geographic distribution of research output

Figure 3 evidences crucial geographic disparities in contextualizing both educational needs (RQ1) and applicability of findings (RQ2 and RQ3). The United States (18) and Spain (17) account for 40% of the publications, while Germany, Australia, Brazil and China account for another 47%. The remaining 13% come from countries in the early stages of research, such as Costa Rica, India and Uruguay, highlighting the need to adapt strategies to diverse contexts (RQ1) and develop accessible tools (RQ3). This uneven distribution poses challenges for generalizing results on cognitive development (RQ2) and suggests opportunities for comparative research.

Concepts related to computational thinking

Computational thinking (CT) involves core computer science principles: breaking down problems, recognizing patterns, abstracting relevant information, and creating algorithms to solve problems (Wing, 2006). These are considered essential 21st-century skills, similar to reading, writing, and arithmetic (Wing, 2011). This review includes studies showing that CT skills can be developed in young children. Activities can help them systematically define problems, organize information, identify patterns, and plan solutions.

For example, Acosta et al. (2023), Angerami et al. (2022), and da Silva Ticon et al. (2022) demonstrate teaching CT using physical

TABLE 2 **Summary of the 84 articles included in the systematic review.**

Article	Problem situation raised in the study	Educational needs	Tools and strategies to promote computational thinking in early childhood
Acosta et al., 2023	The study raises the need to understand how children aged 3–5 years learn and justify patterns of repetition in technological contexts, given the scarcity of research that connects computational thinking and algebraic thinking in early childhood education. It seeks to show how the use of resources such as robots and digital games can favor mathematical representation and justification in early stages of development	Learning dimensions.	Apps
Akiba, 2022	The article discusses the lack of effective integration between "unplugged" and "plugged" activities in the teaching of computational thinking and coding in early childhood education. Although children are increasingly exposed to digital tools, many teachers are not tech-savvy, which limits the use of resources such as ScratchJr or TangibleK. In addition, it is not clear whether "unplugged" activities actually develop skills that are transferable to digital contexts. The study proposes the need for accessible hybrid approaches that enable teachers to facilitate meaningful digital experiences without requiring high levels of technological literacy.	Lack of teacher training	Connected and disconnected
Almousa and Alghowinem, 2023	The study raises the question of a lack of personalized, autonomous educational tools to support literacy learning in children ages 3–5. It highlights the need to tailor content, assessments, and feedback based on the child's individual behavior and responses.	Learning dimensions.	Educational robotics
Álvarez-Herrero, 2021	The study addresses the lack of systematic criteria for selecting floor robots in Early Childhood Education, which hinders an adequate pedagogical implementation. It proposes and validates an instrument that helps to analyze its characteristics and educational potential in a planned way.	Lack of CT educational tools in the first place	Robotica educativa
Angeli and Georgiou, 2023	The study addresses how gender and scaffolding affect the development of computational thinking in preschool children when solving problems with Bee-Bots, given the scant empirical evidence on these factors in early childhood education.	Early childhood programming	Educational robotics
Angerami et al., 2022	The study raises the lack of empirical research on the learning that 5 and 6-year-old children develop when using programming toys, highlighting the need to understand how these tools enhance computational thinking through playful and meaningful experiences	Early childhood programming	Educational robotics
Aranda et al., 2019	The study raises the need to assess how educational robotics, through the use of the Blue-Bot robot, can promote spatial orientation and mathematical processes in Early Childhood Education, in the absence of planned and contextualized didactic proposals in traditional schools.	Learning dimensions.	Educational robotics
Barman and Kjällander, 2022	The study addresses the difficulties in integrating educational digital tools such as mathematics games in early childhood education, highlighting the need to align their use with the curriculum, ensure meaningful play and support teachers with low digital competence.	Lack of CT educational tools in the first place	Apps

(Continued)

TABLE 2 (Continued)

Article	Problem situation raised in the study	Educational needs	Tools and strategies to promote computational thinking in early childhood
Berciano-Alcaraz et al., 2022	The study analyzes the cognitive and technical difficulties faced by 3-year-olds when using educational robots, given the lack of research on their early computational literacy and how they develop computational thinking in specific playful and didactic contexts.	Early childhood programming	Educational robotics
Bers and Sullivan, 2019	The study addresses the need to investigate whether the existence of state computer science standards in the United States increases young children's exposure to fundamental computer science ideas, especially through the use of languages such as ScratchJr.	Early childhood programming	Apps
Bers et al., 2019	The study addresses the difficulty of integrating programming and computational thinking in formal early childhood education, highlighting the need for appropriate pedagogical approaches for teachers and proposing the use of KIBO robotics as an effective playful and educational tool	Early childhood programming	Robotica educativa
Betelin et al., 2021	The study addresses the need to introduce programming into preschool education through text-free environments, adapted to child development. It proposes a methodology based on the programmed control of real objects, avoiding the use of screens in young children.	Early childhood programming	Connected and disconnected activities
Bezuidenhout, 2021	The article addresses the lack of a specific conceptual framework to develop teaching materials that promote STEM literacy in early education, especially through dialogic reading, in the context of the new South African digital skills curriculum for the first grades	Lack of CT educational tools in the first place	Apps
Caballero-González and Muñoz-Repiso, 2019	The study raises the need to integrate innovative educational proposals that strengthen computational thinking from early childhood education, analyzing how tangible and graphic interfaces can impact learning, given the scarce empirical evidence in real classroom contexts	Early childhood programming	Educational robotics
Caballero-González and García-Valcárcel, 2020	The study addresses the lack of empirical research that evaluates the impact of educational robotics programs on the development of computational thinking in elementary school, exploring how activities with Bee-Bot strengthen skills such as sequencing, abstraction and debugging in children aged 6–7 years.	Early childhood programming	Educational robotics
Caballero-González and Muñoz-Repiso, 2021	The study addresses the need to assess whether activities with programmable robots can develop computational thinking, specifically sequencing, in children in early childhood education, and whether there are learning differences according to sex, in an early educational context.	Early childhood programming	Educational robotics
Campos and Rodríguez Muñoz, 2023	The study addresses the lack of didactic proposals that integrate educational robotics with language learning in Early Childhood Education, especially to develop lexical relationships, highlighting the need for contextualized activities that promote linguistic competences and skills of the 21st century.	Learning dimensions.	Educational robotics

(Continued)

TABLE 2 (Continued)

Article	Problem situation raised in the study	Educational needs	Tools and strategies to promote computational thinking in early childhood
Clarke-Midura et al., 2023	The study addresses the lack of adequate formative assessments for computational thinking in early childhood education, proposing an approach based on observable errors as indicators of opportunities for knowledge improvement, integrated into the design of tasks through the Evidence-Centered Design framework	Lack of CT educational tools in the first place	Educational robotics
Clarke-Midura et al., 2021	The study addresses the lack of understanding about how young children use and change spatial frames of reference (egocentric and allocentric) when programming with coding toys, considering their imprecise coordination and the influence of these changes on computational learning.	Lack of CT educational tools in the first place	Educational robotics
Critten et al., 2022	The study addresses the lack of research on the feasibility of teaching programming and computational thinking to children aged 2–4 years through guided play activities, considering their limited cognitive, linguistic and motor skills at such early stages.	Early childhood programming	Educational robotics
de Haas et al., 2020	The impact of different types of robot feedback on children's participation and learning increases in second language learning.	Learning dimensions.	Educational robotics
Demir-Lira et al., 2020	The study addresses the paucity of empirical evidence on the effectiveness of social robots as tutors in teaching vocabulary in a second language, exploring how different types of scaffolding (gestures and visual cues on screen) affect children's learning.	Learning dimensions.	Educational robotics
Dufranc et al., 2020	The study addresses the lack of specific didactic frameworks and integrated materials to implement STEM education with robotics in early childhood education, especially for children from 4 to 8 years old, making it difficult for teachers without specialized training to apply them	Lack of CT educational tools in the first place	Educational robotics
Fridberg et al., 2023	The research question addressed in the article is how the self-efficacy of in-service preschool teachers in STEM disciplines and their experiences of robotics-supported STEM teaching can be described after implementing botSTEM practices.	Lack of teacher training	Educational robotics
García-Fuentes, 2022	The study analyzes how the Spanish digital press represents educational robotics and computational thinking in childhood, evidencing its growing presence but also the lack of information on effective methodologies for its implementation in educational and domestic contexts.	Lack of CT educational tools in the first place	Educational robotics
Gerosa et al., 2022	The study addresses the need to evaluate how children's attentional and motivational participation during educational robotics activities influences the development of computational thinking, given the scarce empirical evidence on these factors in early childhood education interventions.	Early childhood programming	Educational robotics
Hollenstein et al., 2022	The study addresses the lack of research on how guided symbolic play can foster digital problem-solving skills in early childhood education, exploring its potential for children to understand digital transformation processes and develop key competencies of the 21st century.	Learning dimensions.	Apps

(Continued)

TABLE 2 (Continued)

Article	Problem situation raised in the study	Educational needs	Tools and strategies to promote computational thinking in early childhood
Jack et al., 2019	The study addresses the absence of a curriculum framework in Malaysia to teach tangible programming to preschoolers, despite its potential to develop computational thinking from an early age and overcome barriers to access in rural contexts or with non-specialized teachers.	Lack of CT educational tools in the first place	Lack of PC educational tools in the first place
Kanaki and Kalogiannakis, 2022	The study addresses the lack of research on how age influences the development of algorithmic thinking in the early years of primary education, highlighting the need for appropriate assessment tools to tailor the teaching of computational thinking to each stage.	Learning dimensions.	Apps
Kewalramani et al., 2020	The study explores how the use of robotic toys and electronic blocks (littleBits) in early childhood education can foster 21st century skills, such as design thinking, creativity and problem-solving, integrating STEM in a playful and collaborative way.	Early childhood programming	Educational robotics
Kim et al., 2021	The study addresses the integration of culturally and linguistically diverse children into American schools, where they face low expectations and stereotypes. A humanoid robot was designed to mediate collaborative and positive interactions, fostering inclusion and learning in a kindergarten classroom.	Learning dimensions	Educational robotics
Kim and Tscholl, 2021	The study addresses the lack of research on how social robots can facilitate bodily learning experiences in childhood, from the perspective of embodied cognition, by exploring how children interact physically, emotionally, and socially with robots during educational activities.	Lack of CT educational tools in the first place	Educational robotics
Kourti et al., 2023	The study explores Computational Thinking (CT) in preschool children in Greece, assessing their ability to develop CT skills using Scratch Jr. In addition, it examines the perceptions of parents and teachers about the use of technology and the introduction of CT in early childhood education.	Early childhood programming	Apps
Kory Westlund et al., 2017	The study addresses whether young children use the same non-verbal social cues (such as gaze direction and body orientation) to learn new words when interacting with a social robot, compared to a human interlocutor.	Early childhood programming	Educational robotics
Lavigne et al., 2023	The study investigates how digital resources and hands-on activities at home can foster computational thinking in preschoolers and improve parents' understanding and confidence in supporting this learning through co-participation in media	Early childhood programming	Educational robotics
Leung, 2023	The study addresses the challenges faced by early childhood education teachers in Hong Kong when implementing STEM education, especially due to their low training, lack of resources, and the challenge of transforming their pedagogical strategies toward more child-centered approaches.	Lack of teacher training	Teacher perception
Liu et al., 2023	The study investigates how robotics education (RE) affects the cognitive skills and processes of children aged 6–8 years, using cognitive assessments, eye tracking, and interviews, to understand its benefits in STEM learning and cognitive development.	Learning dimensions.	Educational robotics

(Continued)

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TABLE 2 (Continued)

Article	Problem situation raised in the study	Educational needs	Tools and strategies to promote computational thinking in early childhood
Martin et al., 2020	The study addresses whether certain characteristics of a humanoid robot, such as its apparent autonomy and friendly expressiveness, influence young children's willingness to help it, given previous evidence that children display prosocial behaviors even toward robots.	Lack of CT educational tools in the first place	Educational robotics
Manches and Plowman, 2017	The paper addresses the lack of consensus on computer education for young children, highlighting the proliferation of programming tools without a clear pedagogy. It proposes to build on previous research (Logo, computational thinking, and STEM) to inform and debate its implementation in early childhood.	Lack of CT educational tools in the first place	Educational robotics
Masarwa et al., 2023	The study addresses the scarcity of research on "unplugged" activities to develop computational thinking in early childhood education, considering the limitations of teachers with digital technologies and the need for accessible environments, adapted to the classroom and coherent with child development.	Early childhood programming	Apps
Master et al., 2023	The study examines gender stereotypes and motivation in elementary school children toward computational thinking. It is observed that boys tend to favor their own gender in stereotypes of interest and ability, but there are no gender differences in their personal motivation.	Early childhood programming	Educational robotics
Miguel, 2023	The article addresses how to promote computational thinking in early childhood education through the use of digital and non-digital technologies. The need to transform children from passive users to active thinkers, capable of solving everyday problems, is raised.	Early childhood programming	Connected and disconnected activities
Misirli and Komis, 2023	The study investigates the debugging process in 526 preschoolers (4–6 years old) by programming a tangible robot, analyzing how they identify and correct errors, the types of mistakes they make, and the strategies they develop to debug effectively.	Learning dimensions.	Educational robotics
Mohanarajah and Sritharan, 2022	The lack of studies reporting on developmental trends of pretend play behaviors in typically developing preschoolers and their impact on early identification of developmental deviations.	Lack of CT educational tools in the first place	Connected and disconnected activities
Moltó and Martínez, 2022	The study analyzes whether the implementation of educational robotics, specifically the KUBO robot, favors the learning of geometric and spatial notions in children aged 3–4 years, using Van Hiele's model to assess its impact on cognitive and spatial development.	Learning dimensions.	Educational robotics
Monteiro et al., 2021	The study analyzes how to integrate computational thinking, programming, and robotics in preschool education (3–6 years) from an interdisciplinary perspective, exploring their impact on the development of digital, personal, and social competencies, and on early literacy.	Lack of teacher training	Teacher perception
Montuori et al., 2023	The study evaluates the impact of a combined intervention of unplugged programming and educational robotics on computational thinking and cognitive skills of preschoolers, analyzing near and far transfer effects on coding skills, executive and visuospatial functions.	Learning dimensions.	Connected and disconnected activities

(Continued)

TABLE 2 (Continued)

Article	Problem situation raised in the study	Educational needs	Tools and strategies to promote computational thinking in early childhood
Muñoz-Repiso and Caballero-González, 2019	The study addresses the need to empirically evaluate the impact of educational robotics activities on the development of computational thinking in early childhood education, given the growing demand for digital literacy from an early age and the scarcity of research in this field.	Early childhood programming	Educational robotics
Nacher et al., 2016	The paper analyzes the lack of research on the relationship between play, learning, and technology in early childhood education, highlighting the underutilization of emerging technologies such as interactive surfaces and robots, and proposes future challenges for their effective integration.	Early childhood programming	Connected and disconnected activities
Nores et al., 2022	The study explores the relationship between quality ratings in preschool classrooms (CLASS) and counts of activities, content and pedagogical strategies (EduSnap). It seeks to understand how teachers' decisions about the structure of the day and content influence interactions and observed quality.	Learning dimensions.	Educational robotics
Odgaard, 2022	The challenges and considerations related to the implementation of computational thinking and computer science education in preschools, including the risks of poorly informed approaches and empirical examination of problem-solving activities in Danish preschools.	Early childhood programming	Educational robotics
Odgaard, 2023	The exploration of computational empowerment in early childhood educational activities with computational thinking, focusing on the power relations and forms of empowerment experienced by children in kindergarten.	Early childhood programming	Educational robotics
Otterborn et al., 2020	The study addresses the lack of knowledge about how early childhood teachers in Sweden implement coding activities in their pedagogical practice, in a context where the curriculum demands digital literacy but does not specify clear guidelines on teaching coding.	Lack of teacher training	Connected and disconnected activities
Papadakis, 2020	The article addresses the need to guide the educational community on the selection and proper implementation of robots and robotics kits in early childhood and early primary education, given the growing commercial offer and the lack of clear pedagogical criteria.	Lack of CT educational tools in the first place	Educational robotics
Papadakis, 2022	The study addresses the challenge of promoting computational thinking and coding skills in young children through mobile applications. Although there are many "educational" apps, few are properly designed to promote these skills in an effective and playful way	Lack of CT educational tools in the first place	Apps
Pérez-Suay et al., 2023	The study evaluates a didactic sequence that uses programmable educational robots to develop computational thinking (CT) and mathematical problem-solving skills in preschool children. The relationship between the level of elaboration of the numerical sequence and the success in the proposed tasks is analyzed.	Learning dimensions.	Educational robotics

(Continued)

TABLE 2 (Continued)

Article	Problem situation raised in the study	Educational needs	Tools and strategies to promote computational thinking in early childhood
Pila et al., 2019	The study evaluates the effectiveness of two tablet apps, Daisy the Dinosaur and Kodable, in teaching basic programming skills to young children (4–6 years old). It analyzes whether children can learn coding concepts and whether factors such as gender and the attractiveness of Apps influence their learning.	Early childhood programming	Apps
Pinto and Osório, 2019	The study addresses the need to understand how children learn to program in early childhood education through computational thinking, programming, and robotics activities, given the paucity of research that integrates these experiences with the appropriate curricular areas and pedagogical approaches for this stage.	Early childhood programming	Educational robotics
Presser et al., 2023	The study addresses the lack of appropriate tools and approaches to teach data collection and analysis (DCA) skills in preschool children. It seeks to integrate mathematics and computational thinking through an intervention that includes curricular research and a digital application to promote problem-solving skills.	Early childhood programming	Apps
Pugnali et al., 2017	The study addresses how the choice of the technological interface – tangible (KIBO) or graphic (ScratchJr) – influences the development of computational thinking and positive socio-emotional behaviors in young children, in the absence of comparative empirical evidence in early educational contexts	Early childhood programming	Connected and disconnected activities
Ramírez-Benavides et al., 2016	The study addresses the lack of appropriate programming tools for preschoolers (4–6 years) who cannot read or write. The aim is to develop an intuitive mobile application that allows them to program robots and promote 21st century skills.	Early childhood programming	Apps
Scherer et al., 2019	The "problem" or "problem question" of the article is whether learning computer programming improves cognitive skills such as creativity, reasoning, and mathematical skills.	Learning dimensions.	Educational robotics
Sjödahl and Eckert, 2023	The study addresses the lack of understanding about how young children manifest computational thinking, especially with regard to abstraction and decomposition practices, and proposes to analyze these actions in visual programming contexts to make their learning processes observable.	Early childhood programming	Apps
Silvis et al., 2022	The study explores how children develop an ethic of care toward robots when interacting with them in programming environments. It examines the responsibilities that children assume when robots fail and how they establish affective relationships with these technologies.	Early childhood programming	Educational robotics
Somuncu and Aslan, 2022	The study addresses the lack of research on the effect of coding activities on mathematical reasoning skills in preschool children. It seeks to determine if these activities improve these skills compared to regular programs.	Learning dimensions.	Educational robotics
Sullivan and Bers, 2012	The study addresses the gender gap in STEM fields, where men outnumber women. It investigates whether gender stereotypes affect the performance of boys and girls in robotics and programming tasks from early education.	Lack of teacher training	Educational robotics

(Continued)

TABLE 2 (Continued)

Article	Problem situation raised in the study	Educational needs	Tools and strategies to promote computational thinking in early childhood
Sullivan and Bers, 2016	The study addresses the gender gap in STEM, especially in robotics and programming, where men outnumber women. The aim is to identify whether gender stereotypes affect the performance of boys and girls in robotics and programming tasks from an early age.	Early childhood programming	Educational robotics
Sullivan and Umashi Bers, 2018	The study addresses the lack of research on how teacher gender influences girls' performance in programming tasks in early primary education, exploring whether having female instructors improves their performance and reduces gender differences	Lack of teacher training	Educational robotics
Sung, 2022	The study addresses the lack of validated tools to measure computational thinking (CT) in young children, especially in South Korea. The aim is to verify the applicability of two measurements, Bebras Cards and TACTIC-KIBO, to assess TC in children aged 5–6 years.	Early childhood programming	Connected and disconnected activities
Sung et al., 2023	The study addresses the low inclusion of engineering and technology content in early childhood education in South Korea and the lack of evidence on the effects of STEAM programs with robotics on the cognitive, social and computational development of young children.	Early childhood programming	Educational robotics
Tadeu and Brigas, 2022	The study addresses the need to introduce computational thinking in early childhood education, highlighting the lack of preparation of schools and teachers to implement these skills. It focuses on strategies and tools to develop computational thinking in young children, without relying exclusively on technology	Early childhood programming	Educational robotics
Terroba et al., 2021	The study addresses the difficulty of developing computational thinking in 3-year-olds by solving problems with a programmable floor robot. The children's ability to organize spatially and self-evaluate solutions is analyzed, highlighting the importance of teacher intervention.	Early childhood programming	Educational robotics
da Silva Ticon et al., 2022	The study addresses the resistance to methodological innovations in Early Childhood Education (IE) to develop Computational Thinking (CP), despite its importance in the 21st century. Propose connected and unconnected activities to promote CP in young children.	Early childhood programming	Connected and disconnected activities
Tolksdorf et al., 2021	The study addresses the ethical and procedural challenges of implementing social robots in kindergartens. It focuses on how child-robot interaction affects the institutional environment, trust, inclusion, and the roles of caregivers and parents.	Learning dimensions.	Educational robotics
Torres et al., 2018	The study raises the need to introduce educational robotics in Early Childhood Education to promote the development of basic spatial notions, evaluating whether the use of the Roamer robot improves spatial orientation in young children, given the key role of these skills in early learning and digital literacy.	Learning dimensions.	Educational robotics

(Continued)

TABLE 2 (Continued)

Article	Problem situation raised in the study	Educational needs	Tools and strategies to promote computational thinking in early childhood
Unahalekhaka and Bers, 2022	The study addresses the lack of rigorous and appropriate rubrics for evaluating programming projects in young children, specifically with ScratchJr. The aim is to develop a valid and reliable tool that measures both coding and design concepts in creative projects.	Lack of CT educational tools in the first place	Apps
Urlings et al., 2019	The study raises the difficulty of validly and attractively assessing executive functions (working memory, inhibitory control and cognitive flexibility) in kindergarten children, proposing the use of playful robots as an alternative to traditional tests that are not suitable for this age.	Learning dimensions.	Educational robotics
van den Berghe et al., 2021	The study investigates how individual differences in language learning skills moderate the effects of using social robots in teaching second language vocabulary to young children, comparing their effectiveness to tablet use.	Learning dimensions.	Educational robotics
Vogt and Hollenstein, 2021	The study addresses the lack of approaches in early childhood education to explore digital transformation through symbolic play, limiting the development of digital competencies and 21st century skills needed for children's futures.	Early childhood programming	Apps
Welch et al., 2022	The study addresses the difficulty of 5–6 year olds to understand and conceptualize a dynamic linear unit in programming activities with robots, identifying preconceptions and challenges in the measurement and use of iterative units.	Learning dimensions.	Connected and disconnected activities
Yang et al., 2022	The study raises the need to empirically compare the effects of programming with robots versus block play, both common practices in early childhood education, to determine which is more effective in the development of computational thinking, sequencing and self-regulation, given that there is little research that rigorously analyzes these differences.	Early childhood programming	Connected and disconnected activities
Zeng et al., 2023	The study raises the paucity of research examining the content knowledge (CK) and pedagogical knowledge (PK) of early childhood education teachers in the teaching of programming and computational thinking. This lack of understanding limits the design of effective training that strengthens their teaching practice in a key area for preparing children for the challenges of the twenty-first century.	Lack of teacher training	Connected and disconnected activities
Zuo et al., 2023	The study highlights the low presence of robotics courses in kindergartens in China and the lack of systematic curricula and adequate materials for their implementation. Against this backdrop, it proposes to develop children's robotics courses integrating artificial intelligence technologies and an automatic document classification system based on the Vector Space Model (VSM), in order to facilitate the creation of relevant pedagogical content and improve the quality of teaching at this educational stage.	Learning dimensions.	Educational robotics
Чернобровкин et al., 2020	The study addresses the lack of systematic equipment and materials in educational robotics for preschoolers. The need to integrate android robotic devices, such as "Robonova-1", to improve communication, social adaptation and parental competence in early childhood education is highlighted	Lack of CT educational tools in the first place	Educational robotics

TABLE 3 Methodologies pertinent to study in computational thinking.

Approach	Methodology and instruments	Article
Qualitative	Interviews and/or questionnaires	Leung, 2023; Almousa and Alghowinem, 2023; Sullivan and Bers, 2013; Zuo et al., 2023; Fridberg et al., 2023
	Video recorded observations	Angerami et al., 2022; Hollenstein et al., 2022
	Direct observation	Almousa and Alghowinem, 2023; Pérez-Suay et al., 2023; da Silva Ticon et al., 2022; Terroba et al., 2021; Torres et al., 2018
Quantitative	Pre-test and post-test	Jack et al., 2019; Muñoz-Repiso and Caballero-González, 2019; Montuori et al., 2023; Sung, 2022; Yang et al., 2022; Somuncu and Aslan, 2022
	Videos	Odgaard, 2023
	Evaluation rubric	Unahalekhaka and Bers, 2022
Mixed	Interviews and/or questionnaires	Fridberg et al., 2023; Pugnali et al., 2017; Ramírez-Benavides et al., 2016; Misirli and Komis, 2023; Campos and Rodríguez Muñoz, 2023
	Interviews and/or questionnaires	Bers and Sullivan, 2019; Acosta et al., 2023
	Pre-test and post-test	Sung et al., 2023; Lavigne et al., 2023; Liu et al., 2023; Angeli and Georgiou, 2023

robotics and coding, allowing children to practice logical ordering and sequencing. Similarly, Gerosa et al. (2022) and Pérez-Suay et al. (2023) highlight how tasks like troubleshooting or modifying commands improve logical analysis and automated problem-solving. These approaches foster computational reasoning, adaptive thinking, and creativity.

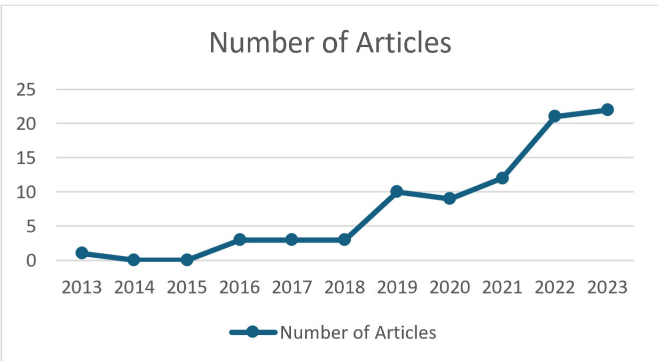
The reviewed studies (see Table 2) show CT as a versatile skill that improves learning across subjects like computer science, mathematics, science, and language. Sullivan and Bers (2016) emphasize this versatility, a point supported by Pila et al. (2019) and Lavigne et al. (2023), whose studies show programming activities boosting mathematical reasoning through pattern exploration. Furthermore, Kim and Tscholl (2021) found that CT also enhances socio-emotional skills by encouraging collaboration and group problem-solving.

Overall, this review confirms that CT is widely integrated into early education. Traditional CT concepts have been successfully applied in classrooms with positive results. Table 4 summarizes the main concepts from the reviewed papers and how they relate to actual classroom practices.

Identification of educational requirements for the use of computational thinking

The analysis focused on the specific educational needs in early childhood that prompted the use of computational thinking. Results show that 28.6% of the research used computational thinking to address educational objectives related to challenges in developing cognitive, social, and communication skills. Integrating computational thinking aims to enhance mathematical problem-solving, develop spatial skills and executive functions, facilitate language acquisition, and improve social interactions (see Table 5).

Conversely, studies recognized a need to improve the development of computational thinking skills in young children. To adapt programming and robotics activities to the cognitive and physical capabilities of preschool-aged children, 39% of the research focused on developing and implementing suitable and accessible tools, methodologies, and digital technologies for young children. The goal was for students to understand basic programming principles effectively and clearly, while also maintaining their motivation and interest (see Table 6). Most studies focused on using software tools such as robotic kits and programming applications, neglecting the opportunity to incorporate computational thinking from various viewpoints specific to the teacher and the students' experiences.



Year	Number of Articles
2013	1
2014	0
2015	0
2016	3
2017	3
2018	3
2019	10
2020	9
2021	12
2022	21
2023	22

FIGURE 2
Total number of articles by year. Own creation.

10.3389/feduc.2025.1535135

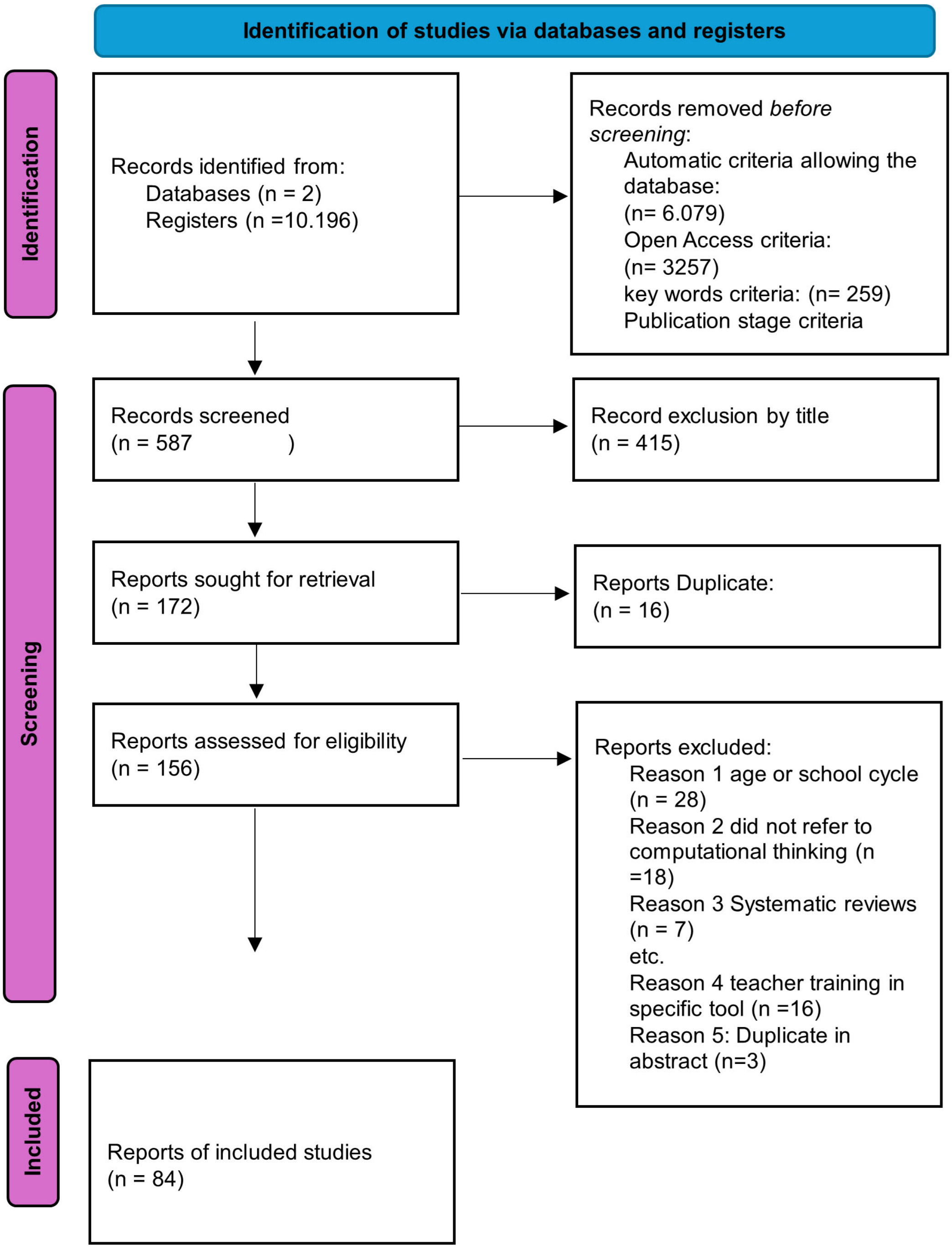


FIGURE 3
Heat map. Own creation.

Research indicates that 17% of studies highlight several educational necessities for developing and assessing computational thinking in early childhood. These include: the absence or inadequacy of appropriate materials and technical equipment; fragmented teaching materials that hinder coherent robotics implementation; and a lack of formative and evaluative tools for assessing coding in child development. The authors agree on the importance of having methodologiest and tools that promote scientific literacy and computational thinking from an early age (see Table 7).

Moreover, the absence of confidence and education among educators obstructs the incorporation of computational thinking in early children, thereby generating a pressing requirement for purposefully crafted and simply available materials that may be seamlessly included into the preschool classroom. Merely 8% of the research demonstrate this scenario, wherein they admit that preschool teachers frequently lack the training and specialized skills to include computational thinking into the instruction. Why is it crucial to develop training frameworks and competencies for thorough teacher training? (see Table 8).

TABLE 4 Concepts related to computational thinking.

Concepts	Definition	Article
Coding	Assignment of symbols interpreted as essential modern technological literacy.	Akiba, 2022; Martin et al., 2020; Master et al., 2023; Pila et al., 2019
Robotics	It reinforces spatial learning and children's irreversible thinking.	Berciano-Alcaraz et al., 2022; Bers and Sullivan, 2019; Dufranc et al., 2020; Papadakis, 2020; Pugnali et al., 2017; Urlings et al., 2019
Programming	Develops problem-solving skills, creativity, and is a new form of literacy.	Pila et al., 2019; Ramírez-Benavides et al., 2016; Scherer et al., 2019; Tadeu and Brigas, 2022; Zeng et al., 2023
Abstraction	Process of abstracting the essential in problems.	Kourti et al., 2023; Zeng et al., 2023
Algorithm	Sequential steps to solve problems.	Kanaki and Kalogiannakis, 2022; Kourti et al., 2023
Deconstruction of the problem	Breaking down problems into smaller parts makes it easier to find solutions.	Kourti et al., 2023
Debugging	Identify and solve defects in software programs efficiently.	Misirli and Komis, 2023; Zeng et al., 2023
Inductive reasoning	Rules derived from patterns in observed concrete cases.	Alsina, 2023
Deductive reasoning	Validate conjectures with extensive reasoning and logical analysis.	Alsina, 2023
Algebraic thinking	Exploring patterns promotes effective generalization and early mathematical development.	Acosta et al., 2023
Programming skills	Create, modify, evaluate code; understand programming; essential computational thinking.	Scherer et al., 2019
Decomposition	Breaking down complex problems into simple segments makes it easier to find solutions.	Clarke-Midura et al., 2023; Zeng et al., 2023
Algorithmic thinking	Development and use of ordered sequences for program execution.	Clarke-Midura et al., 2023
Spatial thinking	Reasoning about locations, orientations, and spatial relationships.	Clarke-Midura et al., 2023
Self-regulation	Executive functioning helps with behavior control, emotional management, and decision-making.	Kim and Tscholl, 2021
21st Century skills	Techniques, communication, creativity, critical thinking, collaboration.	Hollenstein et al., 2022
Problem solving	It requires reasoning, identification, planning, and evaluation.	Aranda et al., 2019; Hollenstein et al., 2022

Methodologies pertinent to study in computational thinking

The analysis categorized the research based on their methodology as qualitative (33.3%), quantitative (28.5%), and mixed (35.7%). The predominant approaches employed are case studies, which aim to examine the specific circumstances and characteristics of various groups (see Table 3). In relation to data collection instruments, observation (see Table 3), and some combinations of instruments such as interviews and surveys are relevant (Pila et al., 2019; Sullivan and Bers, 2016, Unahalekhaka and Bers, 2022). Following that, Table 3 presents the recorded results pertaining to the employed approaches and instruments.

Computational thinking development artifacts

A synthesis of the reviewed literature highlights that robotic and digital tools are not simply devices used in isolation, but rather pedagogical mediators that facilitate meaningful interaction with the fundamental aspects of computational thinking in early childhood. When intentionally integrated, they foster cognitive, motor, linguistic, and socioemotional development through embodied and interactive learning experiences.

Tools such as Blue Bot, Bee Bot, and KIBO serve as tangible interfaces that translate abstract computational concepts into physically manipulable actions. Their programmable functions encourage sequencing, logical reasoning, spatial orientation, and collaborative problem-solving (Aranda et al., 2019; Fridberg et al., 2023; Jack et al., 2019; Pugnali et al., 2017). These tools have proven particularly effective in promoting engagement and immediate feedback, thereby reducing passive waiting times and maintaining children's motivation (Bharatharaj et al., 2023; Odgaard, 2022). For example, KIBO encourages fine motor coordination and teamwork through block programming, while Blue Bot facilitates mathematical exploration and spatial perception.

Social robots further expand the pedagogical scope by supporting language development and social interaction. Their ability to simulate conversational exchanges has shown promise in enhancing second language acquisition and reinforcing sociobehavioral norms (Almousa and Alghowinem, 2023; Kim and Tscholl, 2021; Kory Westlund et al., 2017). In this context, Bee Bot, beyond being a simple programmable toy, becomes a flexible learning companion that adapts to diverse curricular content and promotes inclusive practices

TABLE 5 Articles on educational needs around the dimensions.

Article	Educational needs	Tools and strategies to promote computational thinking in early childhood
Acosta et al., 2023	Learning dimensions.	Apps
Almousa and Alghowinem, 2023	Learning dimensions.	Educational robotics
Aranda et al., 2019	Learning dimensions.	Educational robotics
Campos and Rodríguez Muñoz, 2023	Learning dimensions.	Educational robotics
de Haas et al., 2020	Learning dimensions.	Educational robotics
Demir-Lira et al., 2020	Learning dimensions.	Educational robotics
Hollenstein et al., 2022	Learning dimensions.	Apps
Kanaki and Kalogiannakis, 2022	Learning dimensions.	Apps
Kim et al., 2021	Learning dimensions	Educational robotics
Liu et al., 2023	Learning dimensions.	Educational robotics
Misirli and Komis, 2023	Learning dimensions.	Educational robotics
Moltó and Martínez, 2022	Learning dimensions.	Educational robotics
Montuori et al., 2023	Learning dimensions.	Connected and disconnected activities
Nores et al., 2022	Learning dimensions.	Educational robotics
Pérez-Suay et al., 2023	Learning dimensions.	Educational robotics
Scherer et al., 2019	Learning dimensions.	Educational robotics
Somuncu and Aslan, 2022	Learning dimensions.	Educational robotics
Tolksdorf et al., 2021	Learning dimensions.	Educational robotics
Torres et al., 2018	Learning dimensions.	Educational robotics
Urlings et al., 2019	Learning dimensions.	Educational robotics
van den Berghe et al., 2021	Learning dimensions.	Educational robotics
Welch et al., 2022	Learning dimensions.	Connected and disconnected activities
Zuo et al., 2023	Learning dimensions.	Educational robotics

(Angeli and Georgiou, 2023; Caballero-González and García-Valcárcel, 2020; Caballero-González and Muñoz-Repiso, 2021).

Digital programs such as Scratch Jr. complement these tangible experiences by offering a visual programming environment that encourages symbolic thinking and creative expression without requiring literacy or typing skills. This approach allows students to experiment with algorithmic structures through storytelling and animation, fostering both computational fluency and narrative competence (Bers and Sullivan, 2019; Pugnali et al., 2017; Sullivan and Bers, 2013).

Across all studies, a common implication is that the educational potential of these tools lies not in their technological sophistication, but in how they are integrated into developmentally appropriate pedagogical practices. When implemented with intentional scaffolding, these artifacts contribute not only to the acquisition of programming skills, but also to broader competencies such as persistence, collaboration, abstraction, and creativity (Bezuidenhout, 2021; Clarke-Midura et al., 2021; Hollenstein et al., 2022; Lavigne et al., 2023; Yang et al., 2022).

Knowledge acquired via the use of computational thinking

Academic research emphasizes the positive impact of educational robotics on analytical skills, creativity, and problem-solving capabilities. (Álvarez-Herrero, 2021). In their recent publications, Papadakis (2022) and Чернобровкин et al., (2020) highlight the significance of cultivating digital abilities in children of preschool age. These skills encompass computational thinking and educational robotics, and involve proficiencies in sequencing, coding, and problem-solving.

The researchers in their study tackle the many obstacles associated with incorporating robots into the classroom curriculum, particularly in the context of early childhood education. (Su and Zhong, 2022).

Computational activities enhanced problem solving and mathematical reasoning (Somuncu and Aslan, 2022), while students innovative solutions to challenges demonstrated creativity development (Álvarez-Herrero, 2021; Kewalramani et al., 2020). Robotics and programming particularly fostered teamwork through collaborative problem solving (Clarke-Midura et al., 2021).

One of the goals of computational thinking in Early Childhood Education is to diversify learning activities, since research demonstrates the beneficial effects on cognitive, computational, and social development. Through the use of physical robots, children enhance their fine motor abilities and spatial conceptual understanding. (Montuori et al., 2023). The cultivation of computational thinking in education serves not only to enhance students' academic achievements but also to facilitate their adjustment to a dynamic society that places growing importance on digital and technological proficiency.

Discussion

The analysis conducted on the 84 reviewed articles allowed for the identification of the aspects that motivate the integration of computational thinking in early education, the contributions that its integration makes to the different dimensions of child development, as well as the main challenges and difficulties encountered in its integration into early childhood education. Based on the findings obtained, several key points can be highlighted in relation to the objectives and research questions posed.

The examined research identified the varied educational needs that drive the incorporation of computational thinking into early childhood education, facilitating the development of both the child's dimensions and age-appropriate learning. A significant

TABLE 6 Articles on educational needs around early childhood programming.

Article	Educational needs	Tools and strategies to promote computational thinking in early childhood
Angeli and Georgiou, 2023	Early childhood programming	Educational robotics
Angerami et al., 2022	Early childhood programming	Educational robotics
Berciano-Alcaraz et al., 2022	Early childhood programming	Educational robotics
Bers and Sullivan, 2019	Early childhood programming	Apps
Bers et al., 2019	Early childhood programming	Robotica educativa
Betelin et al., 2021	Early childhood programming	Connected and disconnected activities
Caballero-González and Muñoz-Repiso, 2019	Early childhood programming	Educational robotics
Caballero-González and García-Valcárcel, 2020	Early childhood programming	Educational robotics
Caballero-González and Muñoz-Repiso, 2021	Early childhood programming	Educational robotics
Critten et al., 2022	Early childhood programming	Educational robotics
Gerosa et al., 2022	Early childhood programming	Educational robotics
Kewalramani et al., 2020	Early childhood programming	Educational robotics
Kourti et al., 2023	Early childhood programming	Apps
Kory Westlund et al., 2017	Early childhood programming	Educational robotics
Lavigne et al., 2023	Early childhood programming	Educational robotics
Masarwa et al., 2023	Early childhood programming	Apps
Master et al., 2023	Early childhood programming	Educational robotics
Miguel, 2023	Early childhood programming	Connected and disconnected activities
Muñoz-Repiso and Caballero-González, 2019	Early childhood programming	Educational robotics
Nacher et al., 2016	Early childhood programming	Connected and disconnected activities
Odgaard, 2022	Early childhood programming	Educational robotics
Odgaard, 2023	Early childhood programming	Educational robotics
Pila et al., 2019	Early childhood programming	Apps
Pinto and Osório, 2019	Early childhood programming	Educational robotics
Presser et al., 2023	Early childhood programming	Apps
Pugnali et al., 2017	Early childhood programming	Connected and disconnected activities
Ramírez-Benavides et al., 2016	Early childhood programming	Apps
Sjödahl and Eckert, 2023	Early childhood programming	Apps
Silvis et al., 2022	Early childhood programming	Educational robotics
Sullivan and Bers, 2016	Early childhood programming	Educational robotics
Sung, 2022	Early childhood programming	Connected and disconnected activities
Sung et al., 2023	Early childhood programming	Educational robotics
Tadeu and Brigas, 2022	Early childhood programming	Educational robotics
Terroba et al., 2021	Early childhood programming	Educational robotics
da Silva Ticon et al., 2022	Early childhood programming	Connected and disconnected activities
Vogt and Hollenstein, 2021	Early childhood programming	Apps
Yang et al., 2022	Early childhood programming	Connected and disconnected activities

reason cited in the literature is that computational thinking serves not only as a means for imparting technological skills but also enhances essential cognitive functions, including problem-solving, logical reasoning, creativity, and algorithmic thinking (Acosta et al., 2023; Angeli and Georgiou, 2023; Liu et al., 2023). While computational thinking is intended to enable students to organize ideas, devise solutions, and employ analytical processes across various contexts—thereby enhancing certain aspects of child development—many existing practices predominantly emphasize coding or specific computational thinking skills, rather than incorporating it comprehensively into the curriculum. Moreover, numerous research indicate that instruction in computational thinking enhances the development of mathematical and scientific competencies by promoting abstraction, pattern recognition, and sequential task organization (Kanaki and Kalogiannakis, 2022; Gerosa et al., 2022; Master et al., 2023). The incorporation of computational concepts from a young age fosters analytical

TABLE 7 Articles on educational needs around the shortage of CT educational tools in the early childhood.

Article	Educational needs	Tools and strategies to promote computational thinking in early childhood
Álvarez-Herrero, 2021	Lack of CT educational tools	Educational Robotics
Barman and Kjällander, 2022	Lack of CT educational tools	Apps
Bezuidenhout, 2021	Lack of CT educational tools	Apps
Clarke-Midura et al., 2023	Lack of CT educational tools	Educational robotics
Clarke-Midura et al., 2021	Lack of CT educational tools	Educational robotics
Dufranc et al., 2020	Lack of CT educational tools	Educational robotics
García-Fuentes, 2022	Lack of CT educational tools	Educational robotics
Jack et al., 2019	Lack of CT educational tools	Educational robotics
Kim and Tscholl, 2021	Lack of CT educational tools	Educational robotics
Martin et al., 2020	Lack of CT educational tools	Educational robotics
Manches and Plowman, 2017	Lack of CT educational tools	Educational robotics
Mohanarajah and Sritharan, 2022	Lack of CT educational tools	Connected and disconnected activities
Papadakis, 2020	Lack of CT educational tools	Educational robotics
Papadakis, 2022	Lack of CT educational tools	Apps
Unahalekhaka and Bers, 2022	Lack of CT educational tools	Apps
Чернобровкин et al., 2020	Lack of CT educational tools	Educational robotics

TABLE 8 Articles on educational needs around the shortage of teacher training.

Article	Educational needs	Tools and strategies to promote computational thinking in early childhood
Akiba, 2022	Lack of teacher training	Connected and disconnected
Fridberg et al., 2023	Lack of teacher training	Educational robotics
Leung, 2023	Lack of teacher training	Teacher perception
Monteiro et al., 2021	Lack of teacher training	Teacher perception
Otterborn et al., 2020	Lack of teacher training	Connected and disconnected activities
Sullivan and Bers, 2012	Lack of teacher training	Educational robotics
Sullivan and Umashi Bers, 2018	Lack of teacher training	Educational robotics
Zeng et al., 2023	Lack of teacher training	Connected and disconnected activities

thinking and informed decision-making, crucial for problem-solving in various fields (Bers, 2018), while also enhancing self-regulation and socio-emotional skills (Kim and Tscholl, 2021; Clarke-Midura et al., 2021). It is essential for early childhood educators to first comprehend the concept of computational thinking before devising the pedagogical strategies they intend to implement with children.

However, despite the promise of computational thinking in early childhood education, the analysis of papers identified obstacles that limit its effective application. The absence of targeted training for educators has been recognized as a primary concern. A significant number of early childhood educators have not undergone training in computational thinking and lack the pedagogical tools necessary for its integration into their daily practices (Leung, 2023; Monteiro et al., 2021; Otterborn et al., 2020). Their reluctance to integrate computational thinking in the classroom stems from the belief that it is solely a domain of computer science, highlighting the necessity for professional development programs that illustrate its relevance across various educational disciplines (Yadav et al., 2014; Li, 2014).

One of the critical challenges highlighted by the reviewed studies is the lack of a consistent curricular framework to guide the integration of computational thinking in early childhood education. This issue may stem from a conceptual ambiguity surrounding the nature of computational thinking whether it should be treated solely as a technical skill, a cognitive competency, or a broader pedagogical paradigm. This lack of definitional clarity can hinder the development of coherent educational policies and teacher training programs, leading to fragmented or superficial implementations. Addressing this gap requires a unified conceptual framing that positions computational thinking as both a cognitive process and an educational approach, enabling its meaningful incorporation across diverse early learning environments.

A major obstacle identified across the reviewed literature is the absence of coherent curricular frameworks for integrating computational thinking into early childhood education. Although international bodies such as the OECD and ISTE advocate for the early incorporation of CT, most countries have yet to develop concrete policies or curricular guidelines to support this integration (Su and Zhong, 2022; Pérez-Suay et al., 2023). This lack of structured direction leaves educators without a clear roadmap, resulting in considerable variability in how CT is interpreted and implemented at the classroom level. Without institutional guidance, CT often remains an optional enrichment activity rather than a fundamental component of early learning, limiting its scalability and long-term developmental impact.

The root of this curricular inconsistency may lie in the ongoing conceptual ambiguity surrounding the nature of computational thinking. As the reviewed studies suggest, CT is variably understood as a technical programming skill, a domain-general cognitive competency, or a comprehensive pedagogical approach. This definitional fragmentation undermines the development of unified policies and training programs, leading to disjointed implementation efforts and a lack of continuity across educational levels (Clarke-Midura et al., 2021; Leung, 2023). Addressing this challenge requires establishing a clear and integrative conceptual framework that positions CT simultaneously as a cognitive and pedagogical construct, thereby enabling more systematic and context-sensitive curricular integration.

The analysis of studies indicates that the use of computational thinking enhances the acquisition of fundamental abilities in children aged 3–6, hence contributing to their learning and cognitive development in early childhood education. The

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study demonstrates that computational thinking enhances the development of mathematics and linguistic abilities, while also promoting collaboration and collective decision-making. The review indicates that the influence of computational thinking is contingent upon the pedagogical approach employed, underscoring the necessity of establishing suitable procedures for its instruction in early childhood education.

The studies reviewed indicate that educational robotics and tools such as Scratch Jr. are the most widely used resources for fostering CT in early childhood, along with assessment methods. However, the data suggest that CT instruction should not rely solely on technology. In this regard, strategies such as physical games, storytelling, and manipulatives that work without electronic devices have been shown to be equally effective in teaching foundational concepts (e.g., sequencing, patterns) in a tangible and inclusive way, especially in low-resource settings (Brackmann et al., 2017; Bell et al., 2009).

The unevenness in CT implementation is striking: while some countries have integrated it into early education policies, others face barriers such as limited technology or teacher training. This calls for flexible and accessible methodologies adapted to diverse contexts. To ensure impact, future research should explore all types of tools that are applicable in rural or public schools.

In addition to the general trends identified, the systematic analysis of the 84 studies revealed significant contextual variations in CT implementation approaches. Geographically, the research corpus demonstrates pronounced disparities in scholarly representation, with studies predominantly originating from high-income nations (e.g., United States, Spain, Germany, and Australia), whereas research output from low- and middle-income regions (particularly Latin America, Sub-Saharan Africa, and Southeast Asia) remains disproportionately limited. This geographical imbalance highlights critical gaps in the literature and the necessity for expanded empirical investigations in currently neglected educational contexts, where distinct infrastructural conditions, pedagogical traditions, and sociocultural factors may substantially influence CT adoption.

Furthermore, the review identified recurring implementation challenges, particularly regarding educator capacity development, institutional commitment, and technological resource availability—constraints that appear most acute in resource-constrained educational systems. Methodologically, the studies exhibited considerable heterogeneity in research designs, encompassing qualitative case studies, semi-structured interviews, and quantitative digital assessments, reflecting the absence of established evaluation protocols for early childhood CT interventions. The pedagogical tools documented ranged from analog, unplugged activities to programmable robotics platforms, with implementation strategies frequently adapted to local resource availability and prevailing educational philosophies.

Conclusion

This review offers an analysis of the fundamental principles, educational requirements, approaches, tactics, and instruments which are frequently employed in the incorporation of computational thinking in early childhood education. Based on these categories, the identified research gaps provide an opportunity for professionals who are interested in computational thinking and its early educational impact on children.

The findings suggested that the application of computational thinking in preschool education has a beneficial impact on the cognitive and motor capacities of children. Moreover, there is a recommendation to the academic community to include computational thinking throughout the curricula of early childhood education.

The analysis has several constraints, including the exclusive incorporation of applied research articles, disregarding review documents, conference papers, and other relevant sources, as well as the limited availability of literature on teacher training in computational thinking for early children.

Despite the value of this systematic review, it is important to acknowledge some limitations that may have influenced the findings obtained. Firstly, the literature search was conducted exclusively in Scopus and Web of Science, which, while ensuring a high standard of quality in the selected studies, may also have excluded relevant research published in other specialized databases or in gray literature. The inclusion of other sources, such as Google Scholar or regional databases, could have provided a broader perspective on the integration of computational thinking in early education.

Secondly, the review focused solely on open-access articles, which, while facilitating the replicability of the study and access to information, also limits the inclusion of studies with a more specialized focus that are often restricted. This could have left out relevant research on the implementation of computational thinking in specific contexts or with larger samples.

Furthermore, most of the analyzed studies come from Europe and North America, which leaves a gap in research on the integration of computational thinking in regions such as Latin America, Africa, and Asia. The lack of studies in these contexts limits the generalization of the results and highlights the need to promote research in diverse educational contexts.

For future research and educational applications, it is essential to expand search sources to include additional databases and gray literature to comprehensively analyze CT in early childhood education. Studies should be expanded to underrepresented regions such as Latin America and Asia, identifying context-specific barriers and opportunities for implementation. Curriculum frameworks tailored to developmental stages should be designed to progressively integrate CT. Teacher training programs should also be prioritized, equipping educators with practical and adaptable strategies to ensure equitable access. Finally, robust evaluation tools are needed to objectively measure the impact of CT and interdisciplinary transfer, allowing for rigorous assessment of its effectiveness.

Building on these recommendations, it is crucial to take concrete steps to advance the integration of computational thinking in early childhood education. Future research should develop and validate flexible curricular frameworks that position CT as both a cognitive and pedagogical tool, adaptable to diverse global contexts. Longitudinal studies are needed to examine its sustained developmental impacts, particularly on social-emotional and creative domains. At the policy level, national curricula must prioritize CT through scalable models that align with early education goals. Equally, teacher education must incorporate CT-specific training grounded in early childhood pedagogies and inclusive of unplugged approaches. Coordinated action across research, practice, and policy will be essential to realizing the full potential of CT as a transformative element in early learning worldwide.

Limitations

One of the limitations of this study is the time period of the database search, which was conducted between February and March 2023. Consequently, more recent publications that could offer novel perspectives on the integration of computational thinking in early childhood education may have been excluded. This time limitation may slightly affect the comprehensiveness and timeliness of the findings. To address this limitation, future research should consider ongoing or updated searches, allowing for the incorporation of emerging studies, to ensure the most recent and relevant literature is systematically integrated into the analysis.

This review is that inter-coder reliability was ensured through a consensus-building process among independent coders, rather than through the calculation of statistical coefficients such as Cohen's Kappa or Fleiss' Kappa. While consensus and arbitration are widely accepted practices in qualitative systematic reviews to ensure coding reliability, the absence of a statistical measure may be considered a limitation for readers expecting quantitative validation. Nonetheless, the systematic approach adopted double independent coding, structured discussions, and third-party arbitration strengthens the credibility and consistency of the coding framework applied throughout the study.

Author contributions

GP: Data curation, Formal analysis, Investigation, Writing – original draft. OB: Formal analysis, Investigation, Supervision, Writing – review & editing. AV: Formal analysis, Supervision, Validation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that Generative AI was used in the creation of this manuscript. Quillbot was exclusively used to adjust the style of some texts within the document, to give it a higher academic quality.

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