COMPUTATIONAL THINKING IN MATHEMATICS EDUCATION: A SYSTEMATIC REVIEW OF TRENDS AND INNOVATION IN THE DIGITAL ERA

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Abstract. *This systematic literature review aims to explore the trends and innovations in the integration of computational thinking within mathematics education in the digital era. A total of 23 relevant articles were analyzed using a systematic review methodology. The review followed three main phases: identification, selection, and data analysis. All articles were sourced from the Scopus database, and the review process adhered to the PRISMA 2020 guidelines. Data were analyzed using both descriptive statistics and thematic analysis. The findings reveal a growing research trend, with the number of publications increasing steadily from 2016 to 2024. Quantitative methods dominate the field, accounting for 65% of the studies reviewed. This growth reflects a rising interest in and the perceived importance of integrating computational thinking into mathematics education through innovative approaches. Notably, the STEAM learning model and the use of Scratch as a digital tool emerged as the most frequently adopted pedagogical strategies. Most studies reported significant improvements in students' computational thinking abilities. However, some studies noted limited outcomes due to constraints such as time, task complexity, and the need for more flexible and adaptive teaching methods.*

Keywords: *Computational Thinking; Innovation; Mathematics Education; Systematic Review*

1. INTRODUCTION

The digital era is marked by the pervasive influence of digital technology in daily life, including the growing integration of information and communication technology (ICT). The advancement of ICT has led to significant transformations in the field of education, particularly in mathematics instruction. In this context, mathematics learning is no longer solely centered on conceptual understanding but must also adapt to the competencies required for engaging with ICT-based environments (Irawan et al., 2024c). Among these essential competencies is computational thinking. According to Wing (2006) computational thinking is a fundamental skill for everyone, not only for computer scientists. It is widely recognized as a critical approach to problem-solving, including within the domain of mathematics education (Irawan et al., 2024b).

In the context of mathematics education, (Weintrop et al., 2016) highlight the role of computational thinking in fostering logical, systematic, and effective problem-solving skills. A systematic review by Scherer et al. (2023) further demonstrates that approaches grounded in computational thinking enhance student engagement and improve learning outcomes in mathematics. Notably,The OECD (2022) has incorporated computational thinking into the 2022 PISA mathematics framework, emphasizing that mathematical literacy entails not only problem-solving abilities but also mathematical reasoning and elements of computational thinking. These developments underscore the growing recognition of computational thinking as a core global competency that students at all educational levels are expected to develop.

The growing importance of computational thinking has been reflected in various global education policies. Countries such as the United States, Spain, China, and the United Kingdom have taken concrete measures by integrating computational thinking into their national school curricula, aiming to equip younger generations with the skills needed to meet the demands of rapid technological advancement (Irawan, 2024). In Indonesia, computational thinking is recognized as a key feature of the national curriculum and is embedded across all levels of education (Natali, 2022). However, despite its inclusion in policy frameworks, the practical implementation of computational thinking remains inconsistent and faces numerous contextual challenges within individual educational institutions. Without adequate support, its integration into the curriculum may hinder rather than enhance learning. Many educators encounter difficulties in applying computational thinking in both curriculum design and classroom instruction. A key obstacle lies in the lack of sufficient skills, time, and access to professional development opportunities (Irawan et al., 2024c). These challenges suggest that the successful integration of computational thinking depends not only on curriculum design but also on teachers' capacity, infrastructure readiness, and the availability of relevant and context-sensitive pedagogical models.

In response to these challenges, a variety of approaches and innovations have been developed to support the integration of computational thinking into mathematics education. (Subramaniam et al., 2022) highlight a range of pedagogical innovations and tools designed to facilitate this integration. These include teaching strategies, coding programs, robotics activities, game-based learning, and the use of visual programming languages and computational logic. Such approaches aim not only to cultivate computational thinking skills but also to promote student engagement, creativity, and higher-order thinking through meaningful and enjoyable learning experiences. Aligned with these developments, numerous studies have investigated how computational thinking can be integrated into mathematics education. For instance, Syauqiyyah (2023), Yuntawati et al. (2021), and Zahara (2023) examine the role of computational thinking in mathematical problem solving, while Amalia (2022) and Nur Marifah et al. (2022) explore its implementation in elementary school curricula. Previous systematic reviews have also provided valuable insights into this domain. Subramaniam et al. (2022), mapped various computational thinking tools; Mangiri & Prabawanto (2024), analyzed its application in mathematics learning across educational levels, media, content, and instructional characteristics. Moreover, (Irawan et al., 2024c, 2024b, 2024a) explored broader research trends, programming developments, and the evolving research landscape concerning computational thinking in mathematics education.

However, to date, there has been limited systematic research that examines the relationship between pedagogical innovation trends and the tools used to integrate computational thinking within the context of mathematics education. To address this gap, the present study adopts a systematic literature review approach to explore prevailing trends and innovations in the integration of computational thinking in mathematics education in the digital era. In line with this objective, the study is guided by the following three research questions:

RQ1: How have research trends in computational thinking within mathematics education evolved in relation to pedagogical innovations or tools?

This question aims to provide insight into the development trajectory and methodological approaches used in recent studies.

RQ2: What pedagogical innovations or tools are used to integrate computational thinking in mathematics education?

The answer to this question will help educators and curriculum developers identify, adopt, or adapt proven innovations that effectively support the integration of computational thinking.

RQ3: How effective are the reported findings in studies that integrate computational thinking into mathematics education?

This question seeks to assess the educational impact of pedagogical innovations and tools on students' computational thinking development.

2. LITERATURE REVIEW

2.1 Computational Thinking

Computational thinking was first introduced by Papert (1980) and later developed by Wing (2006). Jeannette M. Wing defines computational thinking as a process of thinking in problem solving and presenting solutions that can be carried out effectively by humans, computers, or machines (Wing, 2017). The components of computational thinking have varied over time, one of which was developed by Dong et al. (2019),which include pattern recognition, which is observing and identifying patterns, trends, and regularities in data, processes, or problems; abstraction, which is identifying important and relevant principles and general properties of a problem; decomposition, which is breaking down data, processes, or problems into smaller, more manageable parts; and algorithm, which is developing step-by-step instructions for solving problems.

2.2 Computational Thinking in Mathematics

In the field of mathematics, computational thinking plays a role in developing logical, systematic, and effective mathematical problem-solving skills (Weintrop et al., 2016). The integration of computational thinking in mathematics education is essential to teach students that mathematics is not only about finding the correct answer but also about understanding the problem and exploring multiple solutions to solve it (Helsa et al., 2023). Mathematics and computational thinking influence each other; computational thinking enriches mathematics learning, and computational thinking applies mathematical contexts to enrich computational thinking (Weintrop et al., 2016).This relationship is reinforced by the findings of Alyahya & Alotaibi (2019), whose hypothesis testing showed that computational thinking influences mathematical achievement on the TIMSS test. Additionally, these findings are supported by the research of Pajow et al. (2024), which explains that a positive and significant relationship between computational thinking ability and mathematical concept understanding of number pattern material was found. Thus, it can be concluded that the better students' computational thinking ability, the better their understanding of mathematics.

3. RESEARCH METHODS

This study is a systematic literature review that analyzes various research findings related to computational thinking in mathematics education. The systematic literature review in this study uses three processes: search, selection, and data analysis (Snyder, 2019). Secondary data sources from research reports found in online scientific publications were analyzed using the Preferred Reporting Items for Systematic Review (PRISMA) (Page et al., 2021).

3.1 Search Process

The data sources used in this study were obtained from the Scopus database. The search in the Scopus database was conducted using the keywords (TITLE-ABS-KEY ("computational thinking") AND TITLE-ABS-KEY ("math*" OR "mathematics education" OR "mathematics learning") AND TITLE-ABS-KEY ("school*" OR "educat*") AND TITLE-ABS-KEY ("primary" OR "elementary" OR "secondary" OR "middle" OR "high")). These keywords indicate the search for articles containing the terms computational thinking and mathematics education that appear in the title, abstract, or keywords. The articles obtained were from the Scopus database accessed on July 7, 2025, totaling 144 articles. The articles identified through the search process were selected based on inclusion and exclusion criteria. These criteria include literature type, database, language, research type, research focus, and year of publication, as detailed in Table 1.

Table 1. Inclusion and Exclusion Criteria

Criteria	Inclusion	Exclusion
Literature type	Proceedings and Journal Articles	Other than Conference Proceedings and Journal Articles
Database	Scopus	Other than Scopus
Language	English	Other than English
Type of research	Research study	Systematic literature review, bibliometric analysis, and meta-analysis
Educational level	Kindergarten, Elementary School, Middle School, High School	In addition to kindergarten, elementary school, junior high school, and high school
Focus of study	Computational thinking in mathematics education	Computational thinking in other fields.
Publication year	2016–2025	Before 2016

3.2 Search Process

The literature to be analyzed was selected using the inclusion and exclusion criteria presented in Table 1. The screening process began with a search in the Scopus database with time limits from 2016 to 2025, document type using articles and conference papers, source type from journals and conference proceedings, language used in English, and all open access files. Further screening was conducted based on the type of research, study focus, and educational level based on the title and abstract. As a result, six articles covered systematic literature reviews, bibliometric studies, and meta-analyses. Additionally, fifty-nine articles were found to be unrelated to computational thinking in mathematics education, A further forty-six articles were removed for addressing educational levels other than kindergarten, elementary school, junior high school, and senior high school. During the full-text review phase, five articles were unavailable for retrieval, and another five were excluded due to the absence of pedagogical innovations or tools. Consequently, after completing all screening stages, a total of twenty-three articles were selected for in-depth analysis, as illustrated in Figure 1.

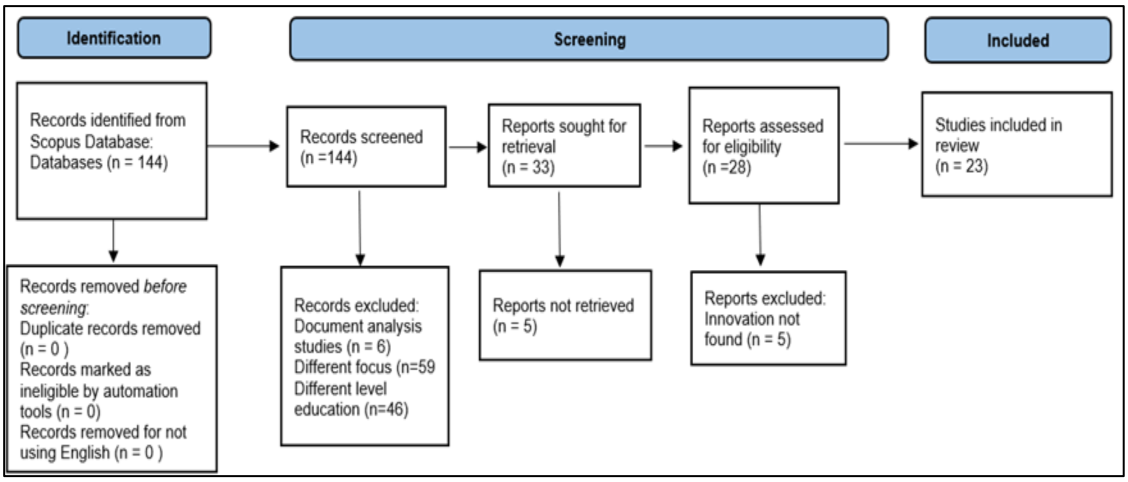

Figure 1. Literature Identification Process Using the PRISMA Procedure

3.3 Analysis Data

This study used quantitative data analysis with a descriptive statistical approach to identify trends and themes to explore patterns of findings. Each study was mapped and coded based on a thorough reading. The findings were identified based on the year of publication, type of innovation raised per year, education level, research method, classification of innovation, and article findings. The articles were identified based on a thorough reading. Microsoft Excel was used in the coding and data analysis process in this study.

4. RESULTS AND DISCUSSION

4.1 RQ1: How Have Research Trends in Computational Thinking Within Mathematics Education Evolved in Relation to Pedagogical Innovations or Tools?

The development of computational thinking research in mathematics education, particularly studies that apply pedagogical innovations or tools, can be observed through publication trends over time. The results obtained from the systematic search, following the inclusion and exclusion criteria, yielded data on the number of relevant articles published each year. These annual publication trends are presented in Figure 2.

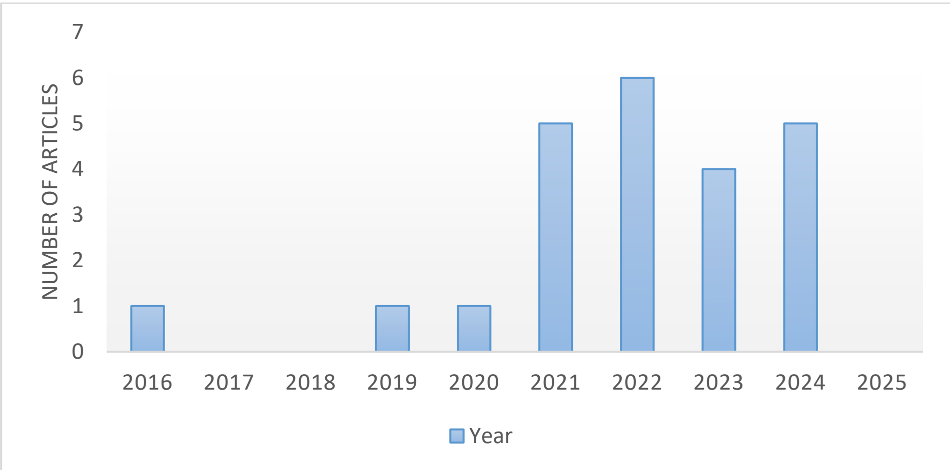

Figure 2. Trends In Computational Thinking In Mathematics Education That Apply Innovations

Figure 2 presents a graphical representation of the number of articles published per year related to computational thinking in mathematics education that incorporate pedagogical innovations or tools. Although the initial search covered a ten-year period, from 2016 to 2025, only articles published between 2016 and 2024 met the inclusion criteria. Notably, no eligible articles were found for the years 2017, 2018, or 2025. he data reveal an overall upward trend in publications focusing on the integration of computational thinking in mathematics education through innovative pedagogical approaches and tools. This trend supports the findings of Araya et al. (2021), who noted that research in this area is expanding in response to the growing demand to equip students with 21st-century skills. In particular, the number of relevant publications peaked in 2022, indicating heightened interest during that period. According to Fanchamps et al. (2019), surges in publication activity in specific years are often driven by advancements in educational technologies and policy initiatives that encourage innovation. For instance, the development of technologies such as augmented reality and digital learning platforms has stimulated research in fields like artificial intelligence and supported its practical application in educational contexts (Angraini et al., 2023, 2024). Furthermore, educational policies promoting computational thinking as a key competency in the digital era have also contributed to the increased volume of research in mathematics education.

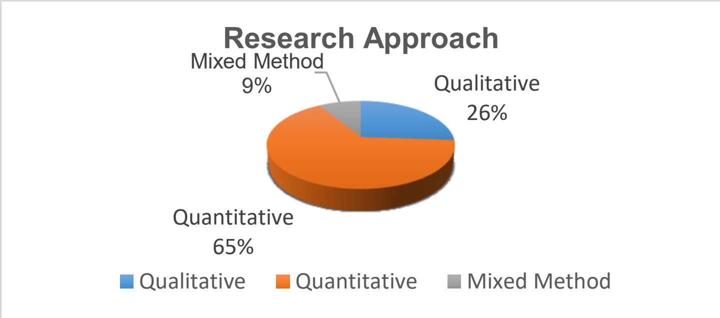

Figure 3. Research approaches on computational thinking in mathematics education that apply innovation

Figure 3 illustrates the distribution of research approaches employed in the selected studies, which are categorized into three types: quantitative, qualitative, and mixed methods. The quantitative approach accounts for the highest proportion, representing 65% of the studies. This approach typically emphasizes the measurement of learning outcomes, student performance, and the effectiveness of pedagogical innovations or tools. For example, Seo & Kim (2016), demonstrated that the implementation of pair programming using the Entry platform significantly improved elementary students' computational thinking skills in geometry learning.

The qualitative approach, comprising 26% of the studies, focuses on exploring students' or teachers' experiences, reflections, and interactive learning dynamics. As noted by Welch et al. (2022) qualitative methods offer valuable insights into the lived experiences of students and educators in the application of computational thinking within the classroom context. The mixed methods approach accounts for the remaining 9%, integrating both quantitative and qualitative elements to provide a more comprehensive understanding of research problems. Johnson & Onwuegbuzie (2007) emphasize that mixed methods research enables a richer, more holistic, and contextual analysis of educational phenomena.

Taken together with the publication trends shown in Figure 2, the data indicate that research on computational thinking in mathematics education through pedagogical innovations and tools has experienced steady growth, despite a slight decline in 2023. The increase in the number of studies and the diversity of research approaches reflect the growing importance of exploring how computational thinking can be effectively integrated into mathematics education through innovative and adaptive strategies.

4.2 RQ2: What Pedagogical Innovations or Tools Are Used to Integrate Computational Thinking in Mathematics Education?

Table 2. Forms of Pedagogical Innovations or Tools

No	Author and year	Form of Innovation		Key Findings
		Pedagogy	Tools	
1	Seo & Kim (2016)	Pair Programming Method	Entry	The implementation of pair programming using Entry has been shown to enhance students' computational thinking skills.
2	Fanchamps et al. (2019)	Scaffolding, Direct Instruction	Lego Robotics-based SRA Programming	Scaffolding through SRA programming with LEGO Robotics has been found to improve students' algorithmic skills, although the improvement was not statistically significant.
3	Valovicova et al.	Problem-based Interdisciplinary	SmartMeasure, Spreadsheet	Problem-based interdisciplinary STEAM learning has been

No	Author and year	Form of Innovation		Key Findings
		Pedagogy	Tools	
	(2020)	STEAM Learning		shown to enhance students' computational thinking skills.
4	Soboleva et al. (2021)	Gamified learning	HTML5	The use of HTML5-based educational games has been shown to enhance students' computational thinking skills.
5	Araya et al. (2021)	Exemplar learning model	Spreadsheet	The integration of computational thinking into mathematics education during the COVID-19 pandemic has contributed to the development of students' computational thinking skills.
6	Goldenberg & Carter (2021)	Exploratory approach "programming as a language"	Microworlds, Snap!	The use of visual programming as a 'third language' has been shown to support students' understanding of computational thinking concepts.
7	Chan et al. (2021)	Computational thinking learning	Spreadsheet	The use of visual programming as a 'third language' has been shown to support students' understanding of computational thinking concepts.
8	Salac et al. (2021)	TIPPSEE learning strategy	Scratch	The TIPP&SEE strategy has been shown to support students' understanding of programming concepts, although it did not lead to a significant improvement in mathematics scores.
9	Welch et al. (2022)	-	Cubetto	Students began to develop an understanding of the concept of length through interaction with coding toys, although some misconceptions persisted. Both physical and social interactions played a significant role in supporting the development of early mathematical understanding in a more structured and meaningful way.
10	Laurent et al. (2022)	Algorithmic-to-Algebraic Register	Scratch	The use of Scratch in mathematics learning has been found to lower student learning outcomes, as students often struggle to manage two registers of representation.
11	Funk et al. (2022)	PeCOT (Computational Thinking with Tangible Objects)	Azbot-1C	The use of Azbot-1C has been shown to promote the development of computational thinking skills, while robotic learning activities more broadly have been found to enhance students' motivation and curiosity.
12	Bubno & Takacs (2022)	"Analogy-based algorithmization" learning method	Google Blockly	The analogy-based algorithmizing method, supported by the use of

No	Author and year	Form of Innovation		Key Findings
		Pedagogy	**Tools**	
				Blockly, has been shown to improve students' computational thinking skills both before and after the pandemic.
13	Duo-Terron et al. (2022)	STEAM-CT-based Future Classroom	Google Blockly	The Future Classroom approach, based on STEAM and computational thinking (CT), was found to effectively enhance students' communication and transdisciplinary thinking skills prior to the pandemic.
14	Ozcakir (2022)	Coding-based instructional approach	Code.org	The integration of Code.org into mathematics instruction has been shown to enhance students' computational thinking skills.
15	Kaup et al. (2023)	-	Beebot, Scratch, Micro:bit, and Ozobot.	Integrating computational thinking through digital tools such as Beebot and Micro: bit has been shown to significantly enhance students' abilities to apply computational thinking in mathematical problem solving.
16	Perez (2023)	Didactic Sequence	Bee-Bot	The gradual use of Bee-Bot effectively improves computational thinking skills.
17	Fojtík et al. (2023)	Exploratory activity-based learning strategies	Micro:bit	The integration of BBC micro: bit into statistics-based projects has been shown to support the development of students' computational thinking skills.
18	Angraini et al. (2023)	AR-adaptive learning strategies	Augmented Reality (AR) based on Unity 3D	The implementation of Augmented Reality applications developed with Unity 3D has been shown to significantly enhance students' computational thinking skills.
19	Molina-Ayuso et al. (2024)	-	Scratch	The use of Scratch has been shown to significantly enhance students' computational thinking skills by engaging them in active and creative digital project-based learning.
20	Mohamed et al. (2024)	Game-Based Learning (GBL)	-	The game-based learning approach has been shown to significantly enhance students' computational thinking skills.
21	Suweken (2024)	Integration of Agent-Based Modeling (ABM) in Teaching	Geogebra, Starlogo TNG, and Turbowarp	The use of Agent-Based Modeling (ABM) has been shown to enhance students' computational thinking skills.
22	Angraini et al. (2024)	Visual and interactive learning strategies	Augmented Reality (AR) maker	The use of Augmented Reality (AR) in educational settings has been shown to significantly enhance students'

No	Author and year	Form of Innovation		Key Findings
		Pedagogy	Tools	
				computational thinking skills.
23	Berk & Gulcu, (2024)	Real-world project-based STEM learning approach	Wolfram Mathematica	The use of computer-based STEM applications has been shown to significantly enhance students' mathematics achievement and computational thinking skills.

Table 2 presents a synthesis of findings from 23 selected articles that applied pedagogical innovations or tools in the integration of computational thinking within mathematics education. Pedagogical innovations include various learning approaches, models, or strategies such as pair programming, gamification-based learning, the TIPP&SEE instructional strategy, didactic sequences, and project-based STEAM learning. Meanwhile, tool-based innovations encompass a range of applications, devices, and programming platforms designed to facilitate interactive and visual learning of computational thinking. The synthesis reveals that the majority of studies combined both pedagogical and technological innovations. Only four articles implemented a single type of innovation. Three of these focused solely on tools, for example, Scratch was used by Molina-Ayuso et al. (2024), Beebot, Scratch, Micro:bit, and Ozobot by Kaup et al. (2023), and Cubetto by Welch et al. (2022). In contrast, Mohamed et al. (2024) applied a pedagogical innovation exclusively, implementing a Game-Based Learning (GBL) approach.

The diversity of tools found in these studies can be categorized into four main groups: (1) visual programming tools such as Scratch, Google Blockly, Entry, Code.org, Turbowarp, and Snap!; (2) educational robotics such as Beebot, LEGO Robotics, Micro:bit, Azbot, Ozobot, and Cubetto; (3) AR and 3D visualization tools such as AR Maker and UNITY 3D; and numerical or simulation applications such as Spreadsheet, Wolfram Mathematica, HTML5, and Microworlds.

These findings suggest that the integration of computational thinking in mathematics education is closely tied to the use of pedagogical or tools innovations. Learning environments that combine both elements tend to yield more significant improvements in students' computational thinking skills. Moreover, such integrated approaches better prepare students to engage in authentic mathematical problem-solving within the context of the digital age.

4.3 RQ3: How Effective Are the Reported Findings in Studies That Integrate Computational Thinking into Mathematics Education?

Evaluating student learning outcomes is a critical component in assessing the effectiveness of integrating computational thinking into mathematics education. Table 2 summarizes the findings from 23 reviewed articles that examined the implementation of pedagogical innovations or tools to support computational thinking in mathematics learning. This analysis provides a comprehensive overview of the impact of such innovations on students' computational thinking skills, understanding of mathematical concepts, creativity, and learning motivation across different educational levels.

Most studies reported that computational thinking contributes positively to students' creativity, problem-solving, and algorithmic reasoning skills. In particular, the use of visual programming environments such as Scratch, Blockly, Entry, and Code.org has been shown to promote deeper conceptual understanding in mathematics. For example, Seo & Kim (2016) demonstrated that applying pair programming as a collaborative instructional strategy using Entry significantly improved elementary students' computational thinking and creativity. Additionally, the integration of Scratch and other visual programming tools into mathematics instruction, especially in domains such as geometry and arithmetic operations, has been found to enhance conceptual comprehension and increase student motivation to learn (Kaup et al., 2023; Ozcakir, 2022).

Furthermore, the use of tools such as spreadsheets, educational applications, and robotics such as Lego Mindstorms and Azbot-1C when combined with physical manipulatives and real-world activities, can significantly enhance students' understanding of mathematical concepts and computational thinking (Fanchamps et al., 2019; Funk et al., 2022; Valovicova et al., 2020). In parallel, the application of gamification strategies and computer-based games has been shown to improve students' algorithmic skills while fostering engagement in interactive mathematics learning environments (Soboleva et al., 2021). Both scaffolding approaches and direct instruction have been found effective in supporting the development of algorithmic thinking. However, scaffolding tends to yield more sustainable understanding over time, enabling students to internalize key concepts more deeply (Fanchamps et al., 2019).

Studies that combine pedagogical strategies with technological tools offer a more holistic and engaging learning experience. For instance, the integration of spreadsheet simulations with an exemplars-based approach encourages students to engage in systematic thinking and understand mathematical modeling, thereby illustrating the potential for meaningful integration of computational thinking into mathematics instruction (Araya et al., 2021). Ultimately, the success of integrating computational thinking in mathematics education is influenced by several contextual factors, including teacher training, access to appropriate learning resources, and curriculum design that promotes active and student-centered learning (Molina-Ayuso et al., 2024).

However, not all interventions involving the integration of computational thinking (CT) yield positive or significant outcomes. Several studies report that the incorporation of CT does not always lead to immediate improvements in students' mathematical performance. For instance, Laurent et al. (2022) found that using Scratch to teach mathematical expressions led to a decrease in students' test scores on topics such as division, decomposition, and fractions. This outcome may be attributed to the high cognitive load students experience when attempting to transfer knowledge between visual programming interfaces and symbolic mathematical representations. Other studies, such as those by Chan et al. (2021) and Kaup et al. (2023), similarly reported only partial gains or statistically insignificant improvements. These findings underscore that the success of CT integration is strongly influenced by the quality of instructional design, the presence of effective scaffolding, and the degree of student readiness.

Key supporting factors for successful CT integration include adequate teacher training, the availability of interactive and accessible digital tools, and the presence of a flexible curriculum that supports project-based and interdisciplinary approaches. On the other hand, frequently reported barriers include limited instructional time, technical challenges in using tools, low levels of student digital literacy, and teachers' difficulties in meaningfully linking digital tools to mathematical concepts (Berk & Gülcü, 2024; Fanchamps et al., 2019)

Taken together, these findings suggest that the integration of computational thinking in mathematics education through programming, robotics, gamification, and interdisciplinary approaches significantly contributes to strengthening 21st-century skills. Approaches that effectively combine pedagogical innovations with digital tools have demonstrated greater success in creating meaningful, engaging, and contextualized learning experiences. However, the implementation of these approaches still requires support from policy-makers, teacher training, and adaptive instructional design, especially in addressing challenges such as pandemics or resource constraints in educational institutions.

CONCLUSION

Based on the analysis and discussion of the integration of computational thinking in mathematics education through the application of pedagogical innovations and tools, several key conclusions can be drawn: First, the trend in research shows a steady increase in publications between 2016 and 2024, with quantitative research being the most commonly employed approach (65%). This upward trend, along with the diversification of research methodologies, highlights the growing interest and the continued need to explore effective strategies for integrating computational thinking into mathematics education. Second, the STEAM learning approach and the use of Scratch are identified as the most frequently adopted pedagogical innovation and digital tool, respectively, across the reviewed studies. These tools not only support computational thinking development but also foster creativity and interdisciplinary learning. Third the majority of studies report a significant improvement in students' computational thinking skills following the implementation of these innovations. However, some studies reveal partial or inconclusive results, often due to factors such as limited instructional time, the complexity of programming tasks, and the lack of flexible and adaptive teaching approaches.

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