Hipotenusa : Journal of Mathematical Society
Volume 6 Issue 2 Year 2024
ISSN: 2716-3156
Website: https://ejournal.uinsalatiga.ac.id/index.php/hipotenusa/index

The Pedagogical Role of ICT on Computational Thinking in Learning Mathematics: A Systematic Review of Scopus Database

Alberta Parinters Makur[1], Darhim[2]*, Bambang Avip Priatna Martadiputra[3]
[1]Doctoral Student, Department of Mathematics Education, Universitas Pendidikan Indonesia, Bandung, Indonesia
[2,3]Department of Mathematics Education, Universitas Pendidikan Indonesia, Bandung, Indonesia
*Corresponding Author. Email: darhim@upi.edu[2]
DOI: 10.18326/hipotenusa.v6i2.1964

Article submitted: June 8, 2024
Article reviewed: December 10, 2024
Article published: December 30, 2024

Abstract

The systematic review literature on the integration of computational thinking in learning mathematics at K-12 mathematics education showed that student-centered teaching approaches can bridge computational thinking and mathematics. However, studies on the role of ICT in improving the quality of learning and the integration of computational thinking in supporting the academic ability of K-12 students are still little reviewed in the current literature. In an effort to fill this gap, a systematic review of the pedagogical role of ICT in asssisting the improvement of students' computational thinking in K-12 mathematics learning needs to be conducted. This study analyzed 14 studies from the Scopus database that met the inclusion requirements. The PRISMA protocol was used to assess the 14 studies reviewed. The results of this research are that several ICT tools effectively enhance students' CT in mathematics education, including augmented reality, digital gamification technology, robots, tablets, ePCR devices, online platforms for algorithm-based tasks, and problem-based programming. These studies recommend integrating these ICT tools into standard mathematics curricula, with careful design of learning activities, appropriate to students' developmental levels, and supported by adequate teacher training.

Keywords: computational thinking; k-12; ict

INTRODUCTION

Mathematics education has become the centre of attention to advance the quality of global education (Santamaría-Cárdaba et al., 2021; Wang et al., 2024). In the digital era, incorporating Information and Communication Technologies (ICT) is gaining popularity in the instructional approach of the mathematics learning process, as it offers a real and interactive context for students and allows for personalized learning (Lecca et al., 2024; Nur et al., 2021; Osipovskaya et al., 2021). Given that students' environments nowadays are already saturated with ICT, incorporating these technologies into learning environments is essential to remain relevant and engaging (Dahal et al., 2022; Msafiri et al., 2023; Timotheou et al., 2023). This integration it expected to directly contribute to strengthening students' mathematical thinking. The mathematical thinking in context goes beyond basic computational procedures, but it encompasses both deductive and inductive reasoning (OECD, 2023). The critical role of reasoning requires more attention during the education process when assessing mathematical literacy. The OECD redefined the PISA framework for mathematical literacy, which initially focused on basic numeracy skills, in light of rapid technological advances (OECD, 2023). To adapt to the digital world, mathematical thinking skills must now include the ability to generalize and abstract concepts, recognize patterns, break problems into manageable parts, and design step-by-step solutions, which are considered cornerstones of Computational Thinking (CT).

PISA 2022 Framework raises CT as one of the important aspects for students to have because it is believed that in addition to problem-solving, this PISA framework states that the particular aspects of CT and mathematical reasoning are included in 21st-century mathematical literacy. Computational Thinking (CT) is defines as a thought process that contains defining and addressing problems that can be articulated in a way that information processing agents can process effectively (Cuny et al., 2010). Computational Thinking has become a fundamental skill, often juxtaposed with reading, writing, and math, crucial ability to help students solve complex problems in life. CT is a type of analytical thinking, which takes an approach to solving problems, system design, and analysis of behavior in humans that draws on basic computational concepts. PISA 2022 Study Framework emphasizes the important role of technology in students' lives, so now mathematical literacy is not only limited to aspects of mathematical thinking but must be able to pay attention to synergy and reciprocal relationships with CT (OECD, 2023).

In today's rapidly evolving world, where computers are becoming an integral part of our daily lives and problem-solving processes, PISA 2022 Framework has highlighted the crucial role of CT as a key component of mathematical literacy and in helping solve mathematical problems. Nurturing CT from an early age is crucial for arming students with the essential tools needed to succeed in the rapidly evolving landscape of the 21st century, empowering them to become creative problem-solvers, critical thinkers, and active participants in shaping their own futures and the world around them (Robledo-Castro et al., 2023; Rodríguez-Martínez et al., 2020; Sohr et al., 2023; Xu et al., 2022; Zhang & Wong, 2023). The combination of mathematical thinking and CT is not only able to support the development of students' conceptual understanding of mathematics but is able to equip students with an understanding of the practical applications of mathematics so that it is expected to prepare students to choose careers in fields that emphasize CT. CT is currently one of the focuses tested in the PISA mathematical literacy test.

ICT plays a variety of roles in this interaction. It acts as a stimulant to get students interested in learning difficult subjects through virtual platforms, interactive simulations, and programming environments. The development of ICT has not only made knowledge more widely accessible, but it has also given rise to creative methods for fostering CT and mathematical thinking. ICT integration in mathematics learning has a positive impact on students' CT (Lewis Presser et al., 2023; Rodríguez-Martínez et al., 2020; Sezer, 2022). Lewis Presser et al. (2023) stated that an intervention consisting of digital investigations and applications, aided preschool teachers and students in answering data-focused questions by participating in each stage of the DCA process to develop CT and math skills, and it was found that students in classes that finished the intervention significantly had higher scores at post-intervention compared to students in classes that did not complete the intervention. Then, Rodríguez-Martínez et al. (2020) reports the results of a quasi-experimental study that involved sixth-graders studying the impact of Scratch on learning mathematical concepts, and on developing computational thinking and the findings show that Scratch is utilized to advance students' mathematical concepts and computational thinking. In line with that, the research conducted by Sezer & Namukasa (2021) aims to investigate how CT tools and concepts are useful to comprehend the Covid-19 outbreak better, and how the disease context is utilized as a real-world context to promote primary and secondary education. Teaching mathematical modeling and computational thinking can be achieved by designing a learning process that provides detailed context and real-world, unstructured problems. The hope is that these problems will serve as a stepping stone for students, encouraging them to solve surrounding issues using the knowledge and skills they acquire in the future. This was discovered through the use of a qualitative method of study, in this case, content analysis. Additionally, opportunities to encourage students by highlighting the worth and significance of CT and mathematics were explored. It is essential for students to be proficient in using technology and computational thinking to succeed in various academic and professional fields.

To explore the role of ICT in optimizing instructional approaches for strengthening computational thinking skills in mathematics, this paper reviews previous related studies. The review examines how various types of ICT are used to bridge mathematics learning with computational thinking, the associated learning models, the education levels targeted, the findings reported, and the implications for future research and practice.

METHODS

The authors carried out a systematic literature review using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) systematic review method to review the role of ICT on Computational thinking skills in learning mathematics.

Identification Stage

A literature review on computational thinking in learning mathematics was conducted since September 2023 to obtain preliminary information and an overview of both from various data sources. For the systematic literature review in this paper, the Scopus database was used as a source for conducting literature searches. This database was chosen because of its comprehensive coverage of over 42,000 peer-reviewed journals across a wide range of disciplines, including social sciences, life sciences, humanities, medicine, engineering business, and management. Also, the selection process of papers that can be included in the Scopus database is reliable, ensuring high data accuracy and quality. Spesifically for this research, Scopus was chosen as the primary database due to its high-performance search engine capabilities, refined data accuracy, and extensive collection of journal, making it an ideal resource for academic research in educational field. Consistent with the previous systematic review, the author additionally restricted the search to the year 2006, when Jeannette Wing popularized the phrase "computational thinking" again, following Seymour Papert's introduction of the word in 1980.

On May 9, 2024, the author conducted an identification using “search within field Article title, Abstract, Keywords”. The keywords used were: 1) Primary Search Terms: “computational think* (to capture various forms of computational thinking); 2) Secondary Search Terms: “math* (to focus on mathematics education); 3) Additional Search Terms: ict OR "Information and communication technology" OR technolog* (to include relevant ICT-related concepts); 4) Geographical and Educational Level Terms: school* OR elementary OR middle OR primary OR secondary OR k-12 (to cover different educational levels). These search terms were employed in the field “search document” to investigate the role of ICT on Computational thinking in learning mathematics. The search strategy involved an iterative process to refine the search terms and ensure comprehensive coverage of relevant studies. This approach aligns with best practices in systematic reviews, enhancing the reproducibility and credibility of the findings. The total number of articles obtained in this initial search process was 358 documents.

The papers at the identification stage are exterminated before moving on to the screening stage guided by the following criteria: 1) duplicate records; 2) entries flagged as unsuitable by automated systems; and 3) entries excluded for additional reasons. After checking, it was found that 1 article entitled "Students' Engagement through Computational Thinking and Robotics" was recorded twice. Furthermore, there were 22 entries in the form of conference reviews that were included as data and thus classified as unsuitable by automated systems.

Screening Stage

This screening stage consists of 3 stages to get records screened, ocuments requested for access, and reports assessed for eligibility. This screening stage was conducted to obtain articles that were relevant to the research objectives.

At the screening stage, the 335 articles obtained at the identification stage were further analyzed by looking at the suitability of the titles and abstracts of these articles to the research topic. The inclusion criteria used in considering articles for further screening were: 1) the article discusses how the integration of ICT in enhancing computational thinking specifically in the field of mathematics education; 2) the article must be published in academic peer-reviewed journals; 3) the article must be written in English. Articles were omitted if they did not comply the above inclusion criteria.

In the first stage, 12 articles in Spanish Chinese, and Portuguese were excluded from consideration due to the authors' limited understanding of the articles in these languages. After that, to guarantee the quality of the articles to be studied further, researchers only selected document-type articles to enter the next stage considering the article selection process to be published in Scopus Indexed Journals. Then, a further review of the abstracts or full texts was conducted to ensure that the articles to be further analyzed were only studies conducted at the primary and secondary school levels and that the studies were indeed related to CT in mathematics learning (not in the context of other subjects). To achieve this, the subject area filter was first limited to social sciences and mathematics. The social sciences were chosen because educational research was included in this category. By using these 3 criteria, **115** articles were obtained that could be forwarded to the next stage.

In stage 2, the title and abstract of the 115 articles were carefully read and assessed for their eligibility based on the same exclusion and inclusion criteria used in the screening stage. Additionally, the authors checked for the accessibility of the full-text PDF versions of the articles. A total of 81 articles did not meet the criteria and had to be discarded because those articles did not specifically address the integration of ICT in developing computational thinking skills in learning mathematics and those articles did not meet the criteria which the participants were not related to elementary or secondary school.

In stage 3, the researcher read the full texts of the remaining 34 articles to determine their true relevance to the research objectives. This involved a detailed examination of content to ensure that the articles provided substantial evidence and insights into the role of ICT in enhancing computational thinking in learning mathematics. After this thorough review, 14 articles were found to be truly relevant and were selected for further analysis. These articles will be used to draw conclusions and provide recommendations based on the systematic review and bibliometric analysis.

Included Stage

In this stage, the 14 selected articles will undergo detailed analysis to extract relevant data and insights. This stage involves 2 steps. First, studying key information from each article will be systematically extracted, including study objectives, methodologies, sample sizes, findings, and conclusions. This process was done carefully to ensure that all relevant data were included in the in-depth and comprehensive analysis that followed. Second, a synthesis was conducted to examine and understand thoroughly what the current conditions are regarding the contribution of ICT utilization in supporting the improvement of computational thinking skills in learning mathematics . This synthesis is intended to provide direction and recommendations for further research.

The study employed a rigorous selection procedure to find pertinent literature, focusing on the intersection of ICT and computational thinking in learning mathematics. The inclusion criteria targeted studies that explicitly discussed computational thinking in the setting of mathematics education, while exclusion criteria filtered out studies that did not focus on K-12 education or lacked clear definitions of computational thinking. Articles were assessed for relevance based on their alignment with the research question, leading to the final selection of 14 studies that provided substantial insights into the role of ICT in enhancing computational thinking skills related to K-12 students.

No	Author	Title	Year	Journal	Country
1	Soboleva, Elena V. Sabirova, Elvira G. Babieva, Nigina S.	Formation of Computational Thinking Skills Using Computer Games in Teaching Mathematics	2021	Eurasia Journal of Mathematics, Science and Technology Education	Russia
2	Angraini, Lilis Marina Yolanda, Fitriana Muhammad, Ilham	Augmented Reality: The Improvement of Computational Thinking Based on Students' Initial Mathematical Ability	2023	International Journal of Instruction	Indonesia
3	Martin, David A. Curtis, Peter Redmond, Petrea	Primary school students' perceptions and developed artefacts and language from learning coding and computational thinking using the 3C model	2024	Journal of Computer Assisted Learning	USA
4	Kaup, Camilla Finsterbach Pedersen, Pernille Ladegaard Tvedebrink, Torben	Integrating computational thinking to enhance students' mathematical understanding	2023	Journal of Pedagogical Research	Germany
5	Jin, Yi Wheeler, Rebecca Bosarge, Erin	A Mixed-method Cluster Analysis of Physical Computing and Robotics Integration in Middle-Grade Math Lesson Plans	2022	Computers and Education	China
6	Araya, Roberto	Enriching elementary school mathematical learning with the steepest descent algorithm	2021	Mathematics	Chile
7	Muhammad, Ilham Rusyid, Husnul Khatimah Maharani, Swasti Angraini, Lilis Marina	Computational Thinking Research in Mathematics Learning in the Last Decade: A Bibliometric Review	2023	Journal of Education in Mathematics, Science and Technology	Pakistan
8	Park, Woongbin Kwon, Hyuksoo	Research Trends And Issues Including Computational Thinking In Science Education And Mathematics Education In The Republic Of Korea	2022	Journal of Baltic Science Education	South Korea
9	Sırakaya, Didem Alsancak	Investigating computational thinking skills based on different variables and determining the predictor variables	2020	Participatory Educational Research	Turkey
10	Sung, Woonhee Black, John B.	Factors to consider when designing effective learning: Infusing computational thinking in mathematics to support thinking-doing	2020	Journal of Research on Technology in Education	USA
11	Rafiepour, Abolfazl Farsani, Danyal	Cultural historical analysis of iranian school mathematics curriculum: The role of computational thinking	2021	Journal on Mathematics Education	Iran
12	Valovičová, L'Ubomíra Ondruška, Ján Zelenický, L'Ubomír	Enhancing computational thinking through interdisciplinary steam activities using tablets	2020	Mathematics	Slovakia
13	Cui, Zhihao Ng, Oi lam Jong, Morris Siu Yung	Integration of Computational Thinking with Mathematical Problem-based Learning: Insights on Affordances for Learning	2023	Educational Technology and Society	China
14	Bouck, Emily C. Yadav, Aman	Providing Access and Opportunity for Computational Thinking and Computer Science to Support Mathematics for Students With Disabilities	2022	Journal of Special Education Technology	USA

Figure 1. Reviewed Studies

To provide a clear overview of our systematic review process, a PRISMA flow diagram has been included, which details the stages of study selection and exclusion.

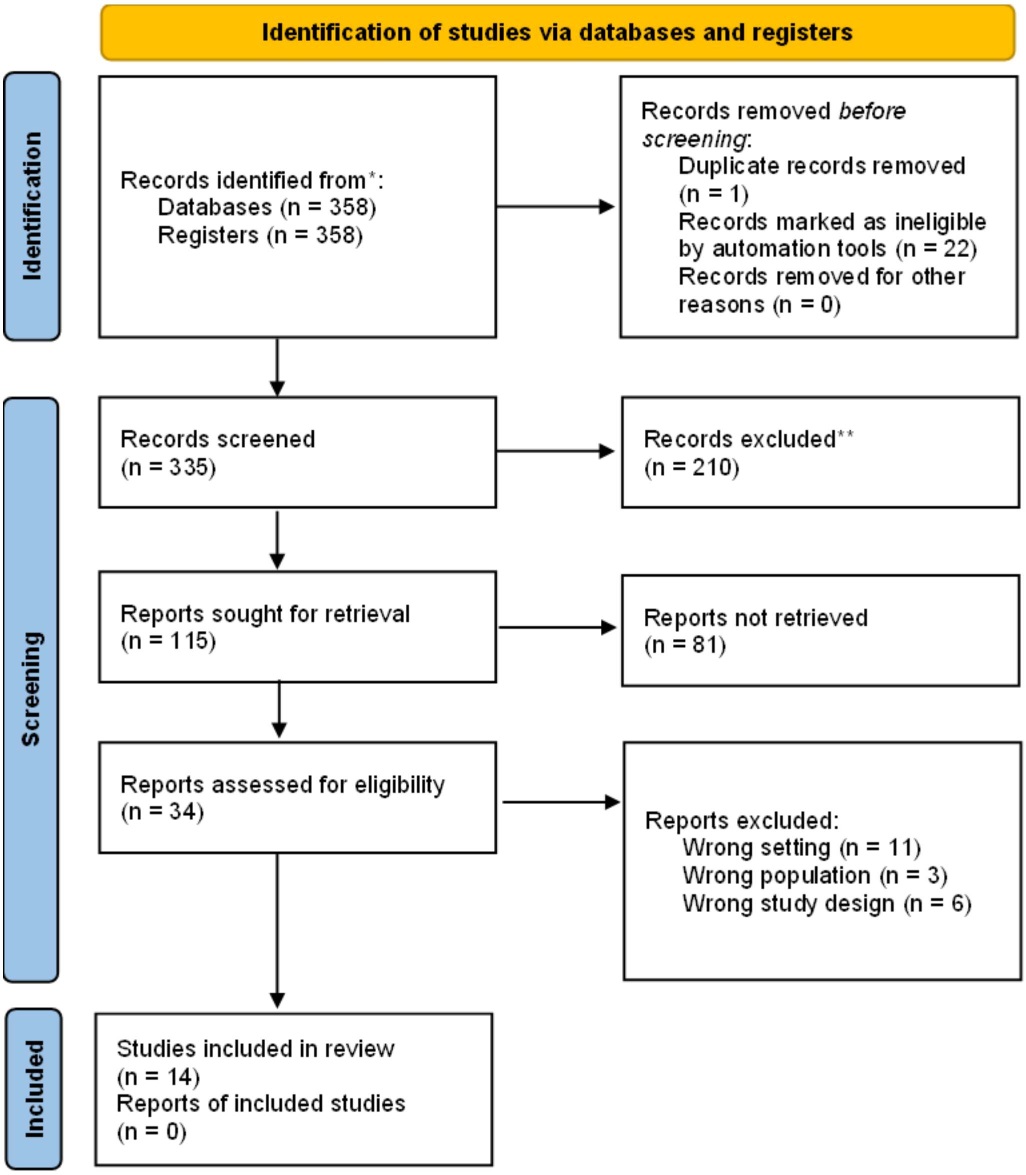

Figure 2. PRISMA Flowchart Diagram (Page et al., 2021)

RESULTS AND DISCUSSION

Results

The selected studies span a range of years and journals, providing a comprehensive view of the role of ICT in developing Computational thinking in learning mathematics .

Soboleva et al. (2021) examined the frameworks for applying gamification concepts in math instruction to foster the development of abilities and skills, intending to define the essence of computational thinking. The authors explain in detail the concept of "computational thinking", which includes a set of procedures to activate patterns, the relationship between games and human memory, constructing effective algorithms, stating problems and models, and using software products with mathematical content. This research focuses on defining the concept of computational thinking and its application in the field of education and cognitive activities using digital gamification resources so that students can develop CT through the activity of designing and developing games with mathematical content.

Angraini et al. (2023) are motivated by poor proficiency in computational thinking of students during the hasty development of ICT in the digital age. The researcher developed Augmented Reality (AR)-based educational content supported by Unity 3D that proved to be more effective in improving students' mathematical CT, especially with low initial mathematical ability, compared to traditional learning methods.

Martin et al. (2024) drafted an article based on the fact that there is no pedagogical sequence for teaching coding that is intended to improve computational thinking. The present research seeks to address the existing gap by establishing the 3C Model (Context, Capability, Computation) as a fitting pedagogical approach for imparting coding and computational thinking concepts to elementary school students at the concrete operational in alignment with their developmental stage. It was proven that the 3C Model not only heightened students' engagement levels but also yielded in improved curriculum learning results.

Kaup et al. (2023) discusses how CT relates to 3 areas of mathematics: geometry, algebra, and arithmetic. The author states that how CT and arithmetic can support or share mutual ground is undistinguishable. Also concerning algebra, CT contains acquiring language's symbolic representations and a more comprehensive approach to problem-solving, and Emphasizing that the relationship between CT and geometry is probably related to spatial thinking and reasoning, spatial reasoning and thinking was considered as a component of helping students increase their comprehension of geometry. The researcher conducted an experiment where students worked with digital CT activities. The pre-and post-test results discovered that the experimental group's result was significantly better than the control group's result for the areas involving CT activities.

Jin et al. (2022) conducted a research by analyzing different types of ePCR (Physical Computing and Robotics) integration in middle-grade math lessons, then categorizing integration, suggesting a revisiting of the TPACK framework, emphasizing the importance of teacher competency development, calling for more research on lesson impact, and stressing the importance of designing discussion activities and ePCR technology in future studies. The results showed three types of lesson plans based on the integration of ePCR technology and different levels of computational thinking and coding skills, categorized lesson plans into five main clusters, and showed differences from previous integration categories identified in a review.

Araya (2021) explores the feasibility of teaching the steepest descent algorithm to elementary school students to enhance STEM integration and Computational Thinking, emphasizing the importance of mathematical modeling and connecting abstract concepts with real-life experiences. Teachers and fourth-grade students successfully understood and applied the steepest descent algorithm to complex models after a brief introduction. The activities based on the algorithm were engaging and integrated real-life scenarios, enhancing STEM integration and Computational Thinking skills.

Muhammad et al. (2023) recommends that Incorporating computational thinking into the mathematics curriculum can prepare students to face the digital era, where the use of technology should be directed towards optimizing the understanding of mathematics. For this, teachers need to be equipped with adequate training to be able to design learning models and also conduct assessments that are beneficial in enhancing computational thinking by selecting appropriate teaching techniques according to the context of mathematics learning.

Park & Kwon (2022) emphasizes that CT in science and mathematics education about software that has been included in the Korean National curriculum has a diverse theoretical approach from CT in computer education, and specifically in mathematics education where it mostly uses an approach related to 'abstraction'. The key to enlightening CT in math lessons is to apply practical understanding in science and math education.

Sirakaya (2020) conducted a research to look at several variables affecting students' computational thinking abilities in secondary school as well as attitudes toward science and math. The results showed that computational thinking skills are not influenced by gender, but the influencing factors are possession of a mobile device, technological proficiency, frequency of everyday technology use, attitudes toward science, and attitudes toward math.

Sung & Black (2020) are preparing students for technology-driven changes, realizing the importance of computer programming in STEM education, and integrating Computational Thinking (CT) in STEM disciplines, using embodied activities combined with computational perspectives to improve knowledge in mathematics, programming concepts, and computational thinking among young learners, and providing evidence-based instructional strategies for integrating computational thinking in math-related activities in the classroom. Embodied activities combined with computational perspectives enhanced the understanding of mathematics, programming ideas, and computational thinking in young students. Interdisciplinary effectiveness was demonstrated by coherent classroom activities that integrated computational viewpoints into pre-existing mathematics curricula. A roadmap for departing from standard programming education is provided by the effects of embodied activities and computational viewpoints. that heavily relies on technological tools.

Rafiepour & Farsani (2021) provide a comprehensive analysis of the historical changes in the Iranian mathematics curriculum, culminating in the recent integration of Computational Thinking as a response to globalization, emphasizing problem-solving skills and real-world applications in mathematics education. The main findings of the paper emphasize the significance of integrating Computational Thinking (CT) into the official curriculum, particularly for developing countries, and the importance of designing better programs for migrant students who have studied in developing countries.

Valovičová et al. (2020) emphasizes the importance of computational thinking in mathematics and the use of interdisciplinary STEAM activities, particularly involving technology, to enhance students' learning and develop their computational thinking skills. The study aimed to enhance computational thinking through interdisciplinary problem-solving activities using tablets, with a focus on the influence of background knowledge and the potential for technology to enhance computational thinking.

Cui et al. (2023) discusses the integration of problem-based learning and computational thinking in learning mathematics, highlighting the benefits of dynamic representations, non-obvious solution processes, and customization for student learning. The tasks integrated CT with mathematical problem-based learning effectively - Co-development of mathematics and CT concepts and practices was observed among students Emphasized the importance of not making solution processes immediately obvious in mathematical learning

Bouck & Yadav (2022) emphasizes the importance of providing access and opportunities for students with disabilities to engage in computational thinking and computer science within mathematics education, highlighting the benefits, rights, challenges, and implementation steps. The main findings emphasize the importance of integrating CT and CS into mathematics education for students with disabilities, highlighting the benefits and the need to provide access and opportunities for these students.

Discussion

Based on the 14 studies analyzed, it is evident that Information and Communication Technology (ICT) plays a crucial role in developing Computational thinking in learning mathematics . The use of gamification and Augmented Reality (AR) technology has proven to be more effective than traditional teaching methods in enhancing students' mathematical and CT abilities, as shown by Soboleva et al. (2021) and Angraini et al. (2023). Furthermore, well-structured teaching models, such as the 3C Model introduced by Martin et al. (2024) and digital CT activities studied by Kaup et al. (2023), demonstrate significant improvements in student engagement and curriculum outcomes. Physical and computing technologies, such as physical computing and robotics, also play a pivotal role in enhancing CT understanding, as outlined in the research by Jin et al. (2022) and Araya (2021).

Bibliometric analysis and national curriculum considerations by Muhammad et al. (2023) and Park & Kwon (2022) underscore the importance of efficient training programs for educators and the use of effective CT learning tools. Multidisciplinary approaches and interdisciplinary STEAM activities involving technology, as explored by Valovičová et al. (2020) and Sung & Black (2020), also show improved CT capabilities in students. Moreover, providing access and opportunities for students with disabilities to engage in CT and computer science within mathematics education, as emphasized by Bouck & Yadav (2022), is crucial to ensure inclusivity and equal opportunities for all students. Historical and cultural approaches to understanding the role of CT in the mathematics curriculum, as researched by Rafiepour & Farsani (2021) and Sirakaya (2020), are also vital in designing better and more inclusive learning programs. Overall, ICT significantly contributes to developing CT in mathematics education through the use of appropriate technology, innovative teaching models, and inclusive and interdisciplinary approaches.

The research methods employed in these articles encompass a diverse range, including literature reviews, experimental and quasi-experimental designs, case studies, qualitative approaches, and more specific methodologies such as systemic activity approaches and cultural-historical approaches. The choice of research method is tailored to the objectives and context of each study to explore the integration of computational thinking in learning mathematics.

Several studies have adopted literature review approaches. For instance, Muhammad et al. (2023) conducted a literature review using data from the Scopus database and analyzed 113 publications through bibliometric analysis. Similarly, Park & Kwon (2022) surveyed domestic academic journals and theses from 2013 to 2021 in science and mathematics education. Other methodological approaches include case studies, such as the one carried out by Cui et al. (2023), which utilized case studies as an analytical methodology and collected data through various sources, including programming artifacts, classroom observations, video recordings, field notes, and student interviews. Some studies have also employed qualitative approaches. Martin et al. (2024) involved a qualitative design, data triangulation using interviews and observations, thematic analysis, and reflection on the researchers' actions. Rafiepour & Farsani (2021) used a cultural-historical approach by collecting and analyzing various materials related to changes in the Iranian mathematics curriculum through thematic analysis.

Several studies have employed experimental or quasi-experimental designs to investigate the integration of computational thinking in learning mathematics . For instance, Kaup et al. (2023) used a quasi-experimental design with an experimental group engaging in digital CT activities and a control group without such intervention. Sung & Black (2020) utilized a factorial design with two factors (level of embodiment and presence of computational perspective-taking) to evaluate the impact on young learners' mathematics and programming skills. Angraini et al. (2023) conducted a meta-analysis to investigate the impact of augmented reality on mathematical computational thinking abilities. Moreover, some studies have adopted more specific approaches. Soboleva et al. (2021) employed a systemic activity approach as the main research method, while Araya (2021) involved the use of the USAB framework for mathematical modeling and designed the steepest descent activities with real-life models. Valovičová et al. (2020) designed and tested interdisciplinary STEAM collaborative problem-solving activities as part of a longitudinal study spanning over 5 years.

This in-depth study on the integration of CT in mathematics education, based on 14 articles, suggests that embedding CT into mathematics curricula and instruction can provide significant benefits for students in terms of developing problem-solving skills, logical reasoning, and algorithmic thinking. Effective approaches involve the use of embodied activities, computational perspective-taking practices, problem-based programming tasks, and the integration of CT principles into standard mathematics curricula. These studies cover various age levels, from elementary to secondary school students, and employ diverse research methodologies, such as experimental designs, quasi-experimental designs, case studies, and literature reviews.

While most studies report positive outcomes, some identified challenges include the need for effective teacher training, the lack of widely accepted pedagogical approaches for teaching CT, and difficulties in designing age-appropriate learning activities. Addressing these challenges will be crucial for the successful integration of CT in mathematics education and ensuring that students can reap the benefits of this innovative approach to learning.

From the review of 14 selected studies, to improve CT, several tools used in mathematics learning were identified, namely: (1) Augmented reality, where its utilization in the learning process is proven effective in improving students' mathematical computational thinking skills when compared to conventional learning; (2) Digital gamification technology, particularly using HTML 5 tools, can foster the development of computational thinking abilities.through a gaming education space; (3) Student performance on tests pertaining to numbers, algebra, and geometry has significantly improved as a result of the development of calculators and the deployment of robots like BeeBot; (3) Use of smartmeasure tablets and apps for interdisciplinary STEAM collaborative problem-solving activities designed to improve computational thinking; (4) Use of ePCR (educational programmable circuit-related) devices in a middle grade math lesson, with lesson plans integrating ePCR technology, pedagogy and content; (5) An online platform for steepest descent algorithm-based tasks, involving and integrating real-life scenarios, enhancing STEM integration and Computational Thinking skills; (6) Use of problem-based programming in math tasks designed in partnership with experts, focusing on various problem-based math learning tasks.

It should be realized that the effectiveness of the above tools is highly dependent on the careful design of learning activities, making appropriate teaching materials, and proper integration with the mathematics curriculum, for example, choosing which materials allow for the integration of tools to improve CT, and the need for preparation for teachers who will use these tools so that learning objectives are achieved. The selection of the right learning model, teaching modules integrated with ICT tools, and teacher readiness is believed to be able to effectively improve CT and at the same time of course able to improve understanding of mathematical concepts of problem-solving skills which are an integral part of CT.

The use of ICT in developing students' CT also contributes to improving mathematical concept understanding, problem-solving skills, critical thinking, and learning motivation. For example, CT-based interventions using robots and embodied activities have been shown to improve knowledge of numbers, algebraic geometry, and programming skills(Kaup et al., 2023; Sung et al., 2017).

It is necessary to design learning activities that actively involve students, according to their developmental level, initial mathematical ability so that the potential of ICT tools such as gamification, augmented reality, robotics, and programming can be optimized. Teachers need to be prepared to understand the core concepts of CT, pedagogical strategies to teach CT using technology, and skills in designing effective learning activities. In Indonesia, where the authors resides, studies that describe the importance of lesson design by teachers have also discussed how ICT is applied in mathematics education (Badawi et al., 2023; Putrie & Syah, 2023). Research on the implementation of CT in mathematics education has also been conducted and has yielded promising results (Mukhibin & Juandi, 2023; Putri et al., 2022).

This study has several drawbacks that should be noted when interpreting the findings. Firstly, the selection of articles was restricted to those published in English and sourced exclusively from the Scopus database. This may have led to the exclusion of relevant studies published in other languages or indexed in other databases, potentially limiting the diversity of perspectives included in the review. Secondly, there is a possibility of selection bias in the choice of articles. The criteria used for selecting studies may have inadvertently excluded important research that could provide additional insights. Efforts were made to minimize bias, but it is acknowledged that not all relevant studies may have been captured. Additionally, the methodologies of the reviewed studies varied, which presents a limitation in synthesizing the results. Differences in research design, sample sizes, and data collection methods could affect the comparability and overall conclusions drawn from the studies. The generalizability of the findings is also limited. The results may be more applicable to certain educational contexts and may not be directly transferable to others. Lastly, there are practical limitations in implementing the study's recommendations. By acknowledging these limitations, this study aims to provide a transparent and nuanced understanding of the findings and their implications for future research and practice.

Further research is needed to explore the applicability of these findings in diverse educational settings. Studies conducted in various contexts can provide valuable insights into how different environments affect the implementation and effectiveness of ICT tools in enhancing CT. The integration of Information and Communication Technology (ICT) tools, such as augmented reality, digital gamification, and robotics, holds significant potential for transforming mathematics education. These technologies can inform curriculum designers on effective ways to incorporate innovative tools that align with educational goals and standards, thereby enhancing students' computational thinking (CT) and mathematical skills. To achieve this, it is crucial to ensure that these tools are seamlessly integrated into the curriculum and that they complement traditional teaching methods. Moreover, the successful implementation of ICT tools in education requires well-prepared teachers. Professional development opportunities should be provided to educators, focusing on CT, pedagogical strategies, and the effective use of technology in teaching. This preparation will enable teachers to confidently integrate ICT tools into their classrooms and maximize their potential to improve learning outcomes. Also, exploring innovative pedagogical models that effectively integrate ICT tools with traditional teaching methods is encouraged like the 3C Learning Model to enhance students' CT in mathematics education eventhough real-world application may face challenges such as resource availability, teacher training, and curriculum alignment.

CONCLUSION

A study of 14 studies related to the integration of computational thinking in learning mathematics recommended several effective ICT tools for improving CT, namely augmented reality (AR), digital gamification technology using HTML 5 tools to design and develop educational gaming spaces with mathematical content, the use of robots such as BeeBot and the creation of calculators with micro: bits that improve student performance on tests related to number, algebra and geometry, interdisciplinary STEAM collaborative problem-solving activities using tablets and smart measure apps, use of ePCR devices in math lessons that integrate technology, pedagogy and content related to ePCR, online platforms for algorithm-based tasks, and use of problem-based programming in math tasks designed with experts with a focus on various problem-based math learning tasks.

These studies recommend the integration of these ICT tools into mathematics learning with careful design of learning activities, appropriate to students' developmental levels, and supported by adequate teacher training. Nonetheless, further research is still needed to address existing gaps, such as the exploration of factors that encourage students' use of CT, applications of CT beyond programming, development of developmentally appropriate pedagogical approaches, and investigation of innovative technology applications in mathematics learning.

REFERENCES

Angraini, L. M., Yolanda, F., & Muhammad, I. (2023). Augmented Reality: The Improvement of Computational Thinking Based on Students' Initial Mathematical Ability. *International Journal of Instruction*, *16*(3), 1033–1054. https://doi.org/10.29333/iji.2023.16355a

Araya, R. (2021). Enriching elementary school mathematical learning with the steepest descent algorithm. *Mathematics*, *9*(11). https://doi.org/10.3390/math9111197

Badawi, A., Herman, T., & Juandi, D. (2023). Pedagogical Content Knowledge Analysis of Mathematics Teachers in Developing Lesson Plans on Ratio Topic. *Hipotenusa : Journal of Mathematical Society*, *5*(1), 29–43. https://doi.org/10.18326/hipotenusa.v5i1.8934

Bouck, E. C., & Yadav, A. (2022). Providing Access and Opportunity for Computational Thinking and Computer Science to Support Mathematics for Students With Disabilities. *Journal of Special Education Technology*, *37*(1), 151–160. https://doi.org/10.1177/0162643420978564

Cui, Z., Ng, O. lam, & Jong, M. S. Y. (2023). Integration of Computational Thinking with Mathematical Problem-based Learning: Insights on Affordances for Learning. *Educational Technology and Society*, *26*(2), 131–146. https://doi.org/10.30191/ETS.202304_26(2).0010

Cuny, J., Snyder, L., & Wing, J. M. (2010). *Computational Thinking: What and Why?*

Dahal, N., Manandhar, N. K., Luitel, L., Luitel, B. C., Pant, B. P., & Shrestha, I. M. (2022). ICT tools for remote teaching and learning mathematics: A proposal for autonomy and engagements. *Advances in Mobile Learning Educational Research*, *2*(1), 289–296. https://doi.org/10.25082/AMLER.2022.01.013

Jin, Y., Wheeler, R., & Bosarge, E. (2022). A Mixed-method Cluster Analysis of Physical Computing and Robotics Integration in Middle-Grade Math Lesson Plans. *Computers and Education*, *190*(3), 104623.

Kaup, C. F., Pedersen, P. L., & Tvedebrink, T. (2023). Integrating computational thinking to enhance students' mathematical understanding. *Journal of Pedagogical Research*, *7*(2), 127–142. https://doi.org/10.33902/JPR.202318531

Lecca, S. M. V., Chávez, J. A. M., Torres, R. J. B., Malca, W. A. H., Quispe, W. W. C., & Egusquiza, R. C. (2024). Math Gamification and ICT for University Learning:

Systematic Review Article. *International Journal of Religion*, *5*(1), 218–236. https://doi.org/10.61707/j5c9ts33

Lewis Presser, A. E., Young, J. M., Rosenfeld, D., Clements, L. J., Kook, J. F., Sherwood, H., & Cerrone, M. (2023). Data collection and analysis for preschoolers: An engaging context for integrating mathematics and computational thinking with digital tools. *Early Childhood Research Quarterly*, *65*, 42–56. https://doi.org/10.1016/J.ECRESQ.2023.05.012

Martin, D. A., Curtis, P., & Redmond, P. (2024). Primary school students' perceptions and developed artefacts and language from learning coding and computational thinking using the 3C model. *Journal of Computer Assisted Learning*. https://doi.org/10.1111/jcal.12972

Msafiri, M. M., Kangwa, D., & Cai, L. (2023). A systematic literature review of ICT integration in secondary education: what works, what does not, and what next? *Discover Education*, *2*(1). https://doi.org/10.1007/s44217-023-00070-x

Muhammad, I., Rusyid, H. K., Maharani, S., & Angraini, L. M. (2023). Computational Thinking Research in Mathematics Learning in the Last Decade: A Bibliometric Review. *International Journal of Education in Mathematics, Science and Technology*, *12*(1), 178–202. https://doi.org/10.46328/ijemst.3086

Mukhibin, A., & Juandi, D. (2023). The Implementation of Computational Thinking on Mathematics Learning Research: A Systematic Literature Review. *Hipotenusa : Journal of Mathematical Society*, *5*(1), 82–94. https://doi.org/10.18326/hipotenusa.v5i1.9007

Nur, A. S., Marlissa, I., Kamariah, K., Palobo, M., & Ramadhani, W. P. (2021). Mathematics education research in Indonesia: A scoping review. *Beta: Jurnal Tadris Matematika*, *14*(2), 154–174. https://doi.org/10.20414/betajtm.v14i2.464

OECD. (2023). *PISA 2022 Assessment and Analytical Framework*. OECD. https://doi.org/10.1787/dfe0bf9c-en

Osipovskaya, E. A., Pshenichny, N. G., & Kharakhordina, M. V. (2021). Using technologies to design personalized learning pathways as a part of scientific practice of students. *RUDN Journal of Informatization in Education*, *18*(3), 203–211. https://doi.org/10.22363/2312-8631-2021-18-3-203-211

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. In *The BMJ* (Vol. 372). BMJ Publishing Group. https://doi.org/10.1136/bmj.n71

Park, W., & Kwon, H. (2022). RESEARCH TRENDS AND ISSUES INCLUDING COMPUTATIONAL THINKING IN SCIENCE EDUCATION AND MATHEMATICS EDUCATION IN THE REPUBLIC OF KOREA. *Journal of Baltic Science Education*, *21*(5), 875–887. https://doi.org/10.33225/jbse/22.21.875

Putri, Y. F., Kadir, K., & Dimyati, A. (2022). Analysis of Content Validity on Mathematical Computational Thinking Skill Test for Junior High School Student

Using Aiken Method. *Hipotenusa : Journal of Mathematical Society*, *4*(2), 108–119. https://doi.org/10.18326/hipotenusa.v4i2.7465

Putrie, S. N., & Syah, M. N. S. (2023). Development of 3D Math AR Applications as Mathematics Learning Media Augmented Reality Based. *Hipotenusa : Journal of Mathematical Society*, *5*(1), 72–81. https://doi.org/10.18326/hipotenusa.v5i1.6401

Rafiepour, A., & Farsani, D. (2021). Cultural historical analysis of iranian school mathematics curriculum: The role of computational thinking. *Journal on Mathematics Education*, *12*(3), 411–426. https://doi.org/10.22342/JME.12.3.14296.411-426

Robledo-Castro, C., Castillo-Ossa, L. F., & Hederich-Martínez, C. (2023). Effects of a computational thinking intervention program on executive functions in children aged 10 to 11. *International Journal of Child-Computer Interaction*, *35*, 100563. https://doi.org/10.1016/J.IJCCI.2022.100563

Rodríguez-Martínez, J. A., González-Calero, J. A., & Sáez-López, J. M. (2020). Computational thinking and mathematics using Scratch: an experiment with sixth-grade students. *Interactive Learning Environments*, *28*(3), 316–327. https://doi.org/10.1080/10494820.2019.1612448

Santamaría-Cárdaba, N., Martins, C., & Sousa, J. (2021). Mathematics Teachers Facing the Challenges of Global Society: A Study in Primary and Secondary Education in Spain. *Eurasia Journal of Mathematics, Science and Technology Education*, *17*(4), 1–9. https://doi.org/10.29333/ejmste/10806

Sezer, H. B. (2022). *The Integration of Computational Thinking in Mathematics The Integration of Computational Thinking in Mathematics Education: The Current State of Practices in School, Outreach, and Education: The Current State of Practices in School, Outreach, and Public Educational Settings Public Educational Settings*. https://ir.lib.uwo.ca/etdhttps://ir.lib.uwo.ca/etd/8498

Sezer, H. B., & Namukasa, I. K. (2021). Real-world problems through computational thinking tools and concepts: the case of coronavirus disease (COVID-19). *Journal of Research in Innovative Teaching and Learning*, *14*(1), 46–64. https://doi.org/10.1108/JRIT-12-2020-0085

Sırakaya, D. A. (2020). Investigating computational thinking skills based on different variables and determining the predictor variables. *Participatory Educational Research*, *7*(2), 102–114. https://doi.org/10.17275/per.20.22.7.2

Soboleva, E. V., Sabirova, E. G., Babieva, N. S., Sergeeva, M. G., & Torkunova, J. V. (2021). Formation of Computational Thinking Skills Using Computer Games in Teaching Mathematics. *Eurasia Journal of Mathematics, Science and Technology Education*, *17*(10), 1–16. https://doi.org/10.29333/ejmste/11177

Sohr, E. R., Gupta, A., Elby, A., & Radoff, J. (2023). How a child entangles empathy and computational thinking in reasoning about fairness. *Early Childhood Research Quarterly*, *65*, 92–101. https://doi.org/10.1016/J.ECRESQ.2023.05.010

Sung, W., Ahn, J., & Black, J. B. (2017). Introducing Computational Thinking to Young Learners: Practicing Computational Perspectives Through Embodiment in

Mathematics Education. *Technology, Knowledge and Learning*, *22*(3), 443–463. https://doi.org/10.1007/s10758-017-9328-x

Sung, W., & Black, J. B. (2020). Factors to consider when designing effective learning: Infusing computational thinking in mathematics to support thinking-doing. *Journal of Research on Technology in Education*, *53*(4), 404–426. https://doi.org/10.1080/15391523.2020.1784066

Timotheou, S., Miliou, O., Dimitriadis, Y., Sobrino, S. V., Giannoutsou, N., Cachia, R., Monés, A. M., & Ioannou, A. (2023). Impacts of digital technologies on education and factors influencing schools' digital capacity and transformation: A literature review. *Education and Information Technologies*, *28*(6), 6695–6726. https://doi.org/10.1007/s10639-022-11431-8

Valovičová, L., Ondruška, J., Zelenický, L., Chytrý, V., & Medová, J. (2020). Enhancing computational thinking through interdisciplinary steam activities using tablets. *Mathematics*, *8*(12), 1–15. https://doi.org/10.3390/math8122128

Wang, C., Chen, X., Yu, T., Liu, Y., & Jing, Y. (2024). Education reform and change driven by digital technology: a bibliometric study from a global perspective. In *Humanities and Social Sciences Communications* (Vol. 11, Issue 1). Springer Nature. https://doi.org/10.1057/s41599-024-02717-y

Xu, W., Geng, F., & Wang, L. (2022). Relations of computational thinking to reasoning ability and creative thinking in young children: Mediating role of arithmetic fluency. *Thinking Skills and Creativity*, *44*, 101041. https://doi.org/10.1016/J.TSC.2022.101041

Zhang, S., & Wong, G. K. W. (2023). Exploring the underlying cognitive process of computational thinking in primary education. *Thinking Skills and Creativity*, *48*, 101314. https://doi.org/10.1016/J.TSC.2023.101314