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Integrating Computational Thinking Into Mathematics Education

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Abstract

Computational Thinking (CT) has emerged as an essential twenty-first-century competency that has received increasing attention in mathematics education because of its potential to support logical, systematic, and critical thinking, as well as problem-solving skills. Integrating CT into mathematics instruction is considered a relevant strategy for strengthening numeracy while addressing the demands of digital transformation and the implementation of the Merdeka Curriculum in Indonesia. This study aims to analyze research trends, implementation models, impacts, challenges, and research gaps concerning the integration of Computational Thinking into mathematics education. A descriptive qualitative literature review was employed. Data were obtained from national and international scholarly articles published between 2021 and 2025, complemented by several key references relevant to the topic. The literature search was conducted through Google Scholar using keywords related to Computational Thinking and mathematics education. The data were analyzed using content analysis through the stages of identification, selection, thematic categorization, and synthesis of research findings. The results indicate that research on the integration of CT into mathematics education has increased over the past five years, with studies predominantly conducted at the primary and lower-secondary school levels. CT has been integrated through various instructional approaches, including Problem-Based Learning, Project-Based Learning, STEM, Inquiry-Based Learning, and Game-Based Learning. The reviewed studies demonstrate that CT integration contributes positively to students' mathematical problem-solving, mathematical reasoning, critical thinking, numeracy, and algorithmic thinking skills. Nevertheless, the implementation of CT continues to face several challenges, including limited teacher competence, a lack of instructional resources that systematically integrate CT, the misconception that CT is synonymous with coding, and inadequate curricular and assessment support. Furthermore, the synthesis reveals that most existing studies focus on examining the effectiveness of instructional models, whereas research on developing a comprehensive conceptual framework for integrating

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CT into mathematics education remains relatively limited. Therefore, this study offers a conceptual synthesis of Computational Thinking as a pedagogical approach to mathematics education, which can serve as a foundation for developing instructional designs, teaching materials, and future research aimed at improving the quality of mathematics education in response to twenty-first-century demands.

Keyword: Computational Thinking, mathematics education, problem-solving skills.

INTRODUCTION

The rapid development of digital technologies, artificial intelligence (AI), and the transition toward data-driven societies have transformed educational paradigms worldwide. Educational systems are no longer expected merely to produce learners who possess conceptual knowledge but also individuals who are able to think critically and creatively, collaborate effectively, and solve complex problems. In this context, *Computational Thinking* (CT) has emerged as an essential twenty-first-century competency recognized internationally. Initially introduced as a concept within computer science, CT is now increasingly viewed as a universal thinking framework that can be applied across disciplines, including mathematics. UNESCO, the OECD, and various international educational organizations have emphasized CT as an important competency to be incorporated into curricula to prepare learners for the challenges of the digital era, automation, and the rapid development of artificial intelligence. Notably, the OECD explicitly incorporated computational thinking into the PISA 2022 mathematics assessment framework, indicating that computational thinking has become an increasingly integral component of mathematical literacy in the twenty-first century.

The growing recognition of the importance of CT has significant implications for mathematics education. Mathematics shares strong conceptual connections with computational thinking because both emphasize the ability to identify patterns, perform abstraction, formulate algorithms, and solve problems logically and systematically. Accordingly, integrating CT into mathematics education should not be limited to improving students' mastery of mathematical concepts but should also foster higher-order thinking skills required to address real-world problems. Countries such as the United Kingdom, Singapore, Finland, Australia, and South Korea have incorporated CT into mathematics education as part of broader national curriculum reforms. This trend reflects a paradigm shift in mathematics education from predominantly procedural approaches toward learning that emphasizes reasoning, problem solving, and the development of computational thinking competencies.

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In Indonesia, the development of CT is aligned with the implementation of the *Merdeka Curriculum*, which emphasizes literacy, numeracy, Higher-Order Thinking Skills (HOTS), and problem-based learning. Nevertheless, various indicators suggest that the mathematical competencies of Indonesian students still require substantial improvement. According to the results of the Programme for International Student Assessment (PISA) 2022, Indonesia obtained a mathematics score of 366, substantially below the OECD average of 472. Moreover, only approximately 18% of Indonesian students attained the minimum proficiency level (Level 2) in mathematics, compared with 69% of students across OECD countries (OECD, 2022). These findings indicate that a large proportion of Indonesian students continue to experience difficulties in solving problems that require mathematical reasoning, modeling, and analytical thinking. This situation suggests that mathematics instruction in Indonesia remains considerably influenced by procedural approaches and has not yet fully developed the computational thinking competencies required in twenty-first-century education.

Despite the growing urgency to develop CT, its implementation in mathematics education continues to face various challenges. Previous studies indicate that many teachers still associate CT primarily with programming or coding activities and the use of digital technologies, resulting in its application being more prevalent in computer science education than in mathematics education. However, CT represents a cognitive approach that can be developed through mathematical activities such as problem decomposition, pattern recognition, abstraction, and algorithm design without necessarily involving programming languages. In addition, limited teacher understanding of the dimensions of CT, a lack of instructional resources that explicitly integrate CT, and insufficient professional development opportunities constitute major barriers to implementing CT in mathematics classrooms. A systematic review conducted by Ye et al., (2023) indicates that challenges in implementing CT are not limited to technological readiness but also involve teachers' pedagogical competence in designing learning activities that meaningfully foster computational thinking. Similar findings were reported by Fauzi et al., (2024), who concluded that the successful integration of CT into mathematics education is strongly influenced by the quality of instructional design, teachers' understanding of CT, and the appropriateness of the instructional strategies employed.

A growing body of empirical research over the past five years has consistently demonstrated that CT integration can contribute positively to the quality of mathematics learning. The systematic review conducted by Ye et al., (2023) indicates that integrating CT can enhance students' mathematical problem-solving skills, reasoning, critical thinking, conceptual understanding, and engagement in the learning process. In addition, studies synthesized by

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Rosadi et al., (2024) demonstrate that CT has been successfully integrated through various instructional approaches, including *Problem-Based Learning*, *Project-Based Learning*, *Inquiry-Based Learning*, STEM, and interactive digital media. Meanwhile, a recent literature review by Hikmah et al., (2025) reveals that the implementation of CT in mathematics education has increasingly incorporated Scratch, educational games, scaffolding, and the Bebras program, which have been shown to facilitate the development of students' computational thinking skills. These findings demonstrate the considerable potential of CT as a pedagogical approach for improving mathematics education when systematically integrated into instructional processes.

Nevertheless, the literature reveals several research gaps that warrant further investigation. First, most previous studies have focused on measuring the effectiveness of instructional models in improving students' CT skills or learning outcomes, whereas research addressing a systematic framework for integrating CT across the various stages of mathematics instruction remains relatively limited. Second, existing studies have frequently positioned CT within the context of technology use or programming activities, while relatively few studies have conceptualized CT as a pedagogical approach for developing mathematical reasoning without dependence on digital devices. Third, research examining the integration of CT within the context of the *Merdeka Curriculum* and the strengthening of numeracy in Indonesia remains limited. Several recent systematic literature reviews have further highlighted that empirical research on CT integration in mathematics education remains relatively scarce compared with other STEM fields and has yet to produce a comprehensive implementation framework that can be readily adapted by teachers across different mathematical topics. Therefore, this study offers a novel contribution by developing an integrative framework for CT in mathematics education that positions CT as a pedagogical strategy for simultaneously developing mathematical thinking, numeracy, and problem-solving skills in accordance with the characteristics of the *Merdeka Curriculum*. This framework is expected to broaden the conceptualization of CT integration from a predominantly technology-oriented perspective toward a more contextualized, systematic, and applicable approach to mathematics instruction.

Based on the foregoing discussion, research on the integration of CT into mathematics education is of considerable importance. The rapid development of digital technologies, the increasing demands for twenty-first-century competencies, Indonesia's relatively low mathematics literacy achievement, and the need to effectively implement the *Merdeka Curriculum* indicate that CT-based instructional innovation can no longer be overlooked. This study is expected to contribute not only to the theoretical development of mathematics education but also to provide a conceptual framework and practical recommendations that can

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guide teachers, curriculum developers, and policymakers in designing mathematics instruction that is more adaptive, contextualized, and relevant to the needs of an increasingly digital society.

METHOD

This study employed a literature review method using a descriptive qualitative approach. The method was designed to identify, examine, compare, and synthesize relevant research findings concerning the integration of *Computational Thinking* (CT) into mathematics education. The literature review involved an examination of various scholarly sources without direct data collection from the field. This approach was selected because it provides a comprehensive overview of the development of concepts, implementation practices, challenges, and opportunities associated with integrating CT into mathematics education based on findings from previous studies. A literature review relies on the systematic collection of scholarly sources, followed by reading, note-taking, evaluation, and analysis to develop a conceptual understanding of the research topic.

The literature search was conducted through the Google Scholar academic database using the keywords *Computational Thinking*, *mathematics education*, *computational thinking in mathematics*, *mathematics learning*, and *computational thinking integration*. The selected literature was primarily published between 2021 and 2025 to reflect recent developments in the field, supplemented by several seminal references that provide the theoretical foundation for the study.

The literature selection process was conducted in several stages based on the following inclusion criteria: (1) relevance to the integration of CT into mathematics education; (2) publication in scholarly journals or conference proceedings with recognized academic quality; (3) substantive discussion of CT concepts, implementation, instructional strategies, or outcomes; and (4) availability of full-text versions to enable comprehensive analysis. Studies that were unrelated to the research focus, duplicated, or available only in abstract form without access to the full text were excluded from the review.

The collected data were analyzed using content analysis. The analysis consisted of four stages: (1) comprehensively reading each selected article; (2) identifying the research objectives, methodological approaches, major findings, and recommendations; (3) categorizing the findings into major themes, including the conceptualization of CT, strategies for integrating CT into mathematics education, benefits, implementation challenges, and future research directions; and (4) synthesizing the findings to identify research trends, similarities, differences, and research gaps that could inform the development of recommendations and the contribution of

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the study. The resulting synthesis was presented descriptively and narratively to provide a comprehensive account of the development of research on the integration of CT into mathematics education.

RESULTS AND DISCUSSION

RESULT

Based on the synthesis of various articles published between 2021 and 2025, research on the integration of *Computational Thinking* (CT) into mathematics education has increased substantially. This growth has been driven by increasing attention to the development of twenty-first-century competencies, the integration of *Artificial Intelligence* (AI), digital transformation in education, and the strengthening of numeracy within educational policies across countries. The review indicates that a considerable proportion of studies were published after 2022, coinciding with growing attention to Computational Thinking within the PISA 2022 framework and various national curriculum reforms.

In terms of educational level, research has predominantly focused on primary and lower-secondary education, whereas studies at the upper-secondary and higher-education levels remain relatively limited. This pattern suggests that the development of CT has largely been emphasized from an early age as a foundation for more complex learning in subsequent educational stages. In addition, the mathematical topics most frequently used as contexts for CT integration include algebra, geometry, number patterns, functions, statistics, and contextual problem solving. These topics are considered suitable for CT integration because they enable students to decompose problems, recognize patterns, perform abstraction, and formulate solution algorithms systematically.

The synthesis indicates that *Computational Thinking* is generally not implemented as a standalone instructional model but is integrated into established instructional approaches. The most frequently used approach is *Problem-Based Learning* (PBL), as it provides opportunities for students to analyze real-world problems through processes of decomposition, abstraction, and the development of solution strategies. Various studies have reported that CT-based PBL can improve students' mathematical problem-solving skills, critical thinking, and reasoning abilities.

In addition to PBL, *Project-Based Learning* (PjBL) has also been widely employed because it enables students to develop products or solutions through computational thinking processes. This approach encourages students to design, evaluate, and revise solutions progressively, thereby fostering algorithmic thinking in a natural manner. Furthermore, the *Science, Technology, Engineering, and Mathematics* (STEM) approach has become one of the most

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frequently adopted strategies in international research because it integrates mathematical concepts with technology and interdisciplinary problem solving. Meanwhile, *Inquiry-Based Learning* facilitates students' discovery of mathematical concepts through investigation, whereas *Game-Based Learning* and tools such as Scratch and Bebras are increasingly being utilized to enhance learning motivation while developing computational thinking skills through interactive activities.

Overall, the studies reviewed indicate that the integration of *Computational Thinking* has positive effects on various aspects of mathematics education. The most consistently reported outcome is an improvement in students' mathematical problem-solving skills. Students become better able to identify relevant information, break complex problems into simpler components, select appropriate solution strategies, and evaluate the solutions obtained. These findings suggest that CT helps students develop more systematic thinking processes than instructional approaches that primarily emphasize procedural problem solving.

In addition to problem-solving skills, most studies also report improvements in mathematical reasoning, critical thinking, and numeracy. CT integration encourages students not merely to obtain correct answers but also to explain their reasoning, construct mathematical arguments, and connect learned concepts with real-world situations. Several studies have also reported improvements in algorithmic thinking, defined as the ability to formulate solution steps logically, systematically, and efficiently. Thus, CT contributes to the development of higher-order competencies that constitute central objectives of twenty-first-century mathematics education.

Despite its various benefits, the implementation of *Computational Thinking* in mathematics education continues to face several challenges. The most frequently identified challenge concerns teachers' competence in understanding CT and integrating it into instructional practices. Some teachers continue to perceive CT primarily as a programming or *coding* skill, resulting in its implementation being largely limited to the use of digital devices or computer applications. Such perceptions indicate that the essence of CT as a way of thinking has not yet been fully understood.

Another challenge concerns the limited availability of instructional resources, including modules, student worksheets, learning media, and assessment instruments that explicitly integrate CT indicators with mathematical competencies. In addition, several studies indicate that CT implementation is constrained by limited professional development opportunities for teachers, inadequate infrastructure in some schools, and insufficient integration of CT into curriculum documents and assessment systems. These conditions demonstrate that successful CT implementation depends not only on teacher competence but also requires support from

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educational policies, curriculum development, and the provision of adequate learning resources.

DISCUSSION

The The synthesis indicates a significant increase in research on the integration of *Computational Thinking* (CT) into mathematics education between 2021 and 2025. This increase is closely associated with the expansion of digital transformation in education, the integration of *Artificial Intelligence* (AI), and growing attention to twenty-first-century competencies. Ye et al., (2023) reported that research on CT in mathematics education has developed rapidly since 2018, with a particularly notable increase in publications after 2021, when various countries began incorporating CT into curriculum reforms and mathematics instruction. Similarly, Irawan et al., (2024) reported a consistent upward trend in CT research in Indonesian mathematics education, particularly during the two most recent years, with studies focusing on the development of instructional models, learning resources, and assessment instruments for CT skills.

In terms of educational level, most studies have focused on primary and lower-secondary education. Hikmah et al., (2025) found that the dominance of research at these levels is associated with the importance of developing computational thinking from an early age as a foundation for increasingly complex mathematics learning at subsequent educational levels. Meanwhile, Zubainur et al., (2025) noted that research at the upper-secondary and higher-education levels remains relatively limited, despite the greater complexity of mathematical content at these levels, which provides substantial potential for developing more advanced abstraction and algorithmic thinking skills.

Regarding mathematical content, the synthesis indicates that CT has most frequently been integrated into algebra, number patterns, geometry, functions, statistics, and contextual problem solving. According to Ye et al., (2023), these topics are highly compatible with the core components of CT because they involve activities such as pattern recognition, abstraction, algorithm development, and systematic evaluation of solutions. This finding suggests that CT integration is not necessarily dependent on particular mathematical topics but rather on how teachers design learning activities that encourage students to engage in computational thinking processes while solving mathematical problems.

The findings further indicate that *Computational Thinking* is generally not implemented as an independent instructional model but is integrated into various established approaches in mathematics education. *Problem-Based Learning* (PBL) is the most frequently employed approach because it provides students with opportunities to solve authentic problems through

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processes involving problem identification, decomposition, abstraction, and the formulation of solution algorithms. Fauzi et al., (2024) explained that CT-based PBL consistently enhances critical thinking, problem-solving, and mathematical reasoning because students actively develop solution strategies based on analysis of the problems they encounter.

In addition to PBL, *Project-Based Learning* (PjBL) is widely employed because it enables students to produce tangible products or solutions through systematic investigation. Within this approach, CT develops through activities involving solution design, testing alternative solutions, and evaluating project outcomes. Ye et al., (2023) emphasized that PjBL provides greater opportunities for students to apply algorithmic and reflective thinking processes than conventional instructional approaches.

The STEM approach has also emerged as a prominent strategy in international research. Integrating CT through STEM enables students to connect mathematical concepts with science, technology, and engineering contexts, thereby making learning more contextualized. Zubainur et al., (2025) stated that the STEM approach strengthens the relationship between mathematical modeling and computational thinking because students are required to develop solutions to real-world problems using multiple mathematical representations. In addition, several studies have begun to explore CT integration through *Inquiry-Based Learning*, *Game-Based Learning*, Scratch, Bebras, and *scaffolding*-based activities, which have been shown to enhance students' engagement in the learning process.

The literature synthesis indicates that the most prominent impact of CT integration is improved mathematical problem-solving ability. Students become better able to identify relevant information, break complex problems into simpler components, select appropriate solution strategies, and systematically evaluate solutions. According to Ye et al., (2022), these abilities develop because CT provides a thinking framework that helps students understand relationships among mathematical concepts before determining the procedures required to solve a problem.

In addition to improving problem-solving skills, various studies have demonstrated that CT integration contributes to improvements in mathematical reasoning and critical thinking. Fauzi et al., (2024) explained that students who learn through CT-based approaches tend to be better able to provide logical justifications for each step of a solution, evaluate alternative solutions, and develop new strategies when confronted with different problems. These findings demonstrate that CT not only improves procedural competence but also strengthens the quality of mathematical reasoning.

Another important impact is the improvement of numeracy. CT integration helps

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students connect mathematical concepts with real-life situations through processes of modeling, data interpretation, and decision-making. Hikmah et al., (2025) reported that the use of Scratch, Bebras, and game-based learning media can improve numeracy while simultaneously fostering computational thinking skills in more contextualized ways. Several studies have also identified improvements in algorithmic thinking, namely the ability to organize solution steps logically, systematically, and efficiently. Thus, CT integration contributes to the development of multiple competencies that constitute key objectives of twenty-first-century mathematics education.

Despite the positive outcomes reported across the literature, the implementation of CT in mathematics education continues to encounter several obstacles. The most prominent challenge concerns teacher competence. Fauzi et al., (2024) revealed that many teachers still conceptualize CT primarily as a programming skill, resulting in its implementation being directed more toward technology use than toward the development of students' thinking processes. This condition indicates that teachers' conceptual understanding of CT needs to be strengthened through sustained professional development.

In addition, the limited availability of instructional resources represents another frequently identified barrier. Zubainur et al., (2025) explained that relatively few instructional materials explicitly integrate CT indicators with mathematics learning outcomes, making it difficult for teachers to implement CT systematically. Ye et al., (2023) further noted that research on instructional designs integrating the four major components of CT *decomposition, pattern recognition, abstraction,* and *algorithmic thinking* across the various stages of mathematics instruction remains relatively limited.

Another factor influencing CT implementation is curriculum and assessment support. Irawan et al., (2024) stated that although CT has begun to receive increasing attention in Indonesian educational policies, its implementation has not yet been explicitly integrated into mathematics curriculum resources and assessment systems. Consequently, teachers tend to prioritize the achievement of conceptual competencies over the development of computational thinking skills.

The synthesis of previous research further indicates that most existing studies have focused on examining the effectiveness of instructional models in improving CT skills or mathematics learning outcomes. Although the findings consistently demonstrate that CT integration can enhance problem solving, mathematical reasoning, critical thinking, and numeracy, research examining how CT can be conceptually integrated throughout the entire mathematics learning process remains relatively limited.

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Furthermore, many studies continue to associate CT primarily with digital devices, programming languages, or specific applications. However, the essence of CT lies in systematic thinking processes that can be applied to a wide range of mathematical activities without dependence on technology. Fauzi et al., (2024) and Zubainur et al., (2025) emphasize that future research should develop pedagogical models that position CT as an approach to mathematics education rather than merely as a technological skill.

CONCLUSION

Based on the literature review of studies examining the integration of *Computational Thinking* (CT) into mathematics education, it can be concluded that CT has emerged as an essential twenty-first-century competency with a strategic role in improving the quality of mathematics education. The synthesis indicates that CT integration has positive effects on various aspects of students' competencies, particularly mathematical problem solving, mathematical reasoning, critical thinking, numeracy, and algorithmic thinking. Various instructional approaches, including *Problem-Based Learning*, *Project-Based Learning*, STEM, *Inquiry-Based Learning*, and *Game-Based Learning*, have demonstrated their potential to facilitate the development of computational thinking when systematically designed and oriented toward problem solving. Nevertheless, the implementation of *Computational Thinking* in mathematics education continues to face several challenges, including limited teacher understanding of CT, the tendency to conceptualize CT merely as *coding* activities, the limited availability of instructional resources that explicitly integrate CT, and insufficient curriculum and assessment support. The review also indicates that most previous studies have focused on examining the effectiveness of instructional models in improving learning outcomes, whereas research on the development of a conceptual framework for integrating CT systematically across different mathematical topics remains relatively limited.

Future research should move beyond examining the effectiveness of CT-based instructional models and focus on developing and validating CT implementation frameworks that can be applied across different educational levels and mathematical topics. Empirical studies should also investigate the relationships between *Computational Thinking* and numeracy, creative thinking, metacognition, and the use of *Artificial Intelligence* in mathematics education. Furthermore, cross-level and cross-cultural studies are needed to obtain a more comprehensive understanding of the factors that influence the successful integration of CT across diverse educational contexts.

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