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Exploring Computational Thinking In Learning Mathematics: A Systematic Literature Review From 2017-2024

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Abstract: Objective: The benefits of computational thinking have become an increasingly acknowledged and popular subject of investigation among researchers. This research aims to gather detail and comprehensive information regarding the learning of computational thinking skills in mathematics at various educational levels through a systematic literature review approach. **Methods:** With a focus on education level, instructional media, mathematics content, and the components of computational thinking addressed by previous researchers, this paper applied the PRISMA Systematic Review Protocol to offer a comprehensive synthesis of sixteen empirical studies retrieved from the Scopus database on the implementation of computational thinking in mathematics education. **Findings:** Most research on fostering computational thinking in mathematics education is concentrated at the elementary and junior high school. To optimize the development of computational thinking in mathematics, teachers should be reminded of strategies to support students, particularly through activities involving simulations using various instructional media. Examples of such media include programming platforms, visualization tools, and interactive simulations and games. Number operations and geometry are the mathematical content most widely used for fostering computational thinking. Algorithmic thinking, a crucial component in fostering computational thinking among elementary school students, helps them develop a strong foundation for understanding higher mathematical concepts. **Conclusion:** A systematic review of computational thinking in learning mathematics at the various education level is conducted in this study. The chosen studies were systematically analyzed for the advancement of computational thinking in learning mathematics to provide new an insight information for educators and stakeholders.

Keywords: computational thinking, mathematics, systematic literature review.

▪ INTRODUCTION

As a 21st-century crucial skill, computational thinking has gained significant impact in recent years in the digitalization era. Ideally, 21st-century skills should provide the foundation for contemporary learning (Soebagyo & Amalia, 2022). Computational thinking was first introduced by Seymour Papert, a mathematician, computer scientist, and educator, in 1980 (Lodi & Martini, 2021). Papert (1980) stated that computational thinking is a product of his constructivist educational philosophy, which emphasizes that social and emotional learning is as important as technical knowledge. In his writings, Papert (1980) stated the goal of integrating computational thinking into everyday life. However, the initial response from academic community was not very enthusiastic (Tekdal, 2021). This concept gained widespread recognition in the academic community following Jeannette Marie Wing's influential research published in the Communications of the Association for Computing Machinery. Wing (2006) highlighted that computational thinking is not only essential for computer scientists but also for every child, extending beyond traditional skills such as reading, writing, and math. Through processes such as reduction, addition, transformation, or simulation, computational thinking restructures complex problems into more manageable solutions (Wing, 2006).

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The importance of computational thinking is also evident in professional life; individuals equipped with these skills are better prepared to be effective in their work and to face the challenges of the digital world (Shute et al., 2017). This demonstrates the critical importance of computational thinking in the technological era. Consequently, computational thinking is a skill that everyone needs to effectively navigate and overcome life's challenges.

Nowadays, computational thinking is a crucial concept in education. Researchers increasingly recognize its importance as they delve deeper into the topic (Irawan, et al. 2024a). The concept has received positive responses from various quarters. Countries like the United States, England, Spain, and China have taken concrete steps to integrate it into their school curricula to prepare the younger generation for the demands of the 21st century (Chen et al., 2018; Wilkerson et al., 2020). Interest in computational thinking research has surged exponentially since 2013 (Tekdal, 2021). Research in this area is largely dominated by literature reviews, followed by experimental designs and case studies (Ilic et al., 2018). The trend of publications on computational thinking has significantly increased and spread globally, with the United States being the most prolific in research contributions (Tang et al., 2020). Research topics within this domain are commonly categorized into three main themes: integrating computational thinking into STEM (Science, Technology, Engineering, and Mathematics) education, conducting empirical investigations on computational thinking skills, and deliberating on its definition (Tekdal, 2021). The OECD has also acknowledged this by including computational thinking in the draft PISA 2022 Mathematics Framework (OECD, 2022). Overall, this research reflects a global interest in understanding and developing computational thinking as an essential 21st-century skill.

As a relatively new and evolving focus of scientific study, computational thinking is experiencing ongoing developments in both its definition and its components. Wing (2017) defines computational thinking as a thought process that involves formulating problems and expressing solutions in a manner that can be executed effectively by computers, humans, or machines. In terms of its components, there are identified categories of computational thinking groupings. According to Looi et al. (2023), there are four interconnected components of computational thinking. Abstraction is an activity to reducing complexity to create a general representation of a process or group of objects so that it is not only suitable for the immediate goal or objective, but also used in different contexts. Pattern recognition is the activity of evaluating a data set to ensure that the data set facilitates the discovery of patterns and the relation. Decomposition is the activity of breaking down a problem into its constituent sub-problems. Finally, Algorithmic thinking is the activity of creating an ordered series of steps to solve a problem or achieve a goal. Grouping computational thinking components through this model is not only practical but also easy to adopt.

Computational thinking has long been integral to mathematics education. It encompasses a set of cognitive skills that prove highly valuable across various logical disciplines, particularly in mathematics (Holo, et al., 2022). Researchers argue that computational thinking significantly enhances problem-solving abilities inherent to mathematical thinking (Bers et al., 2022). Recognizing this synergy, computational thinking has been integrated into K–12 mathematics curricula (Looi et al., 2023). Mathematical and computational thinking share foundational concepts in problem solving, modeling, data analysis, statistics, and probability (Shute, et al., 2017). Numerous studies highlight the benefits of computational thinking in problem solving (Lin et al., 2021; Vourletsis & Politis, 2020; Yeung et al., 2024; Zaibon & Yunus, 2022), attributing improved reasoning and problem-solving skills across various subjects. Computational thinking correlates closely with mathematical modeling and critical thinking in mathematics education (Kannadass et al., 2023), consistent with findings by Lamb et al. (2021). Skills, such as collecting pertinent data, looking patterns, decomposing problems and coming up with sequential solution, are essential in mathematical modeling (Ang, 2012). Therefore, it is evident that computational thinking is not only applicable to mathematics learning but also profoundly interconnected with it.

Computational thinking and mathematics can be integrated together in the learning process. Weintrop et al. (2016) recommends that computational thinking be included in mathematics and science learning. There are at least three benefits obtained from the integration of computational thinking in mathematics learning, namely creating a reciprocal relationship between computational thinking and mathematics, ensuring the presence of teachers who are skilled in both fields, and aligning mathematics education with the demands of current professional practice (Weintrop, et al., 2016). The integration of computational thinking into learning mathematics becomes a subject of numerous literature review studies in recent years. Several studies are already done, as reported by Subramaniam, et al. (2022) which examine instructional strategies encouraging computational thinking in teaching mathematics. In comparison, Isharyadi & Junaidi (2023); Ye, et al. (2023); Irawan, et al. (2024b); and Fitriyah, et al. (2023) report on integration of computational thinking in K-12 mathematics. Different from the research previously mentioned, this research was conducted specifically on mathematics learning and limited to the Scopus database only.

Given all of the advantages of computational thinking, further research is necessary to determine how best to use it in mathematics learning. The primary objective of this research is to investigate how computational thinking can be fostered in mathematics education. This study examines various aspects in relation to educational level, instructional media, mathematical content, and the characteristics for fostering computational thinking in mathematics learning from previous studies. A thorough comprehension of this research environment is expected to provide deep insights into the future of computational thinking in mathematics education. To achieve the research objectives, four research questions (RQ) guide the implementation of this systematic review.

RQ1: What education levels are involved in using computational thinking to learn mathematics?
RQ2: How are instructional media utilized to foster computational thinking in mathematics learning?
RQ3: What mathematics content is used to foster computational thinking?
RQ4: What characteristics of fostering computational thinking in mathematics learning? Further technical methods related to this idea will be discussed in the following section.

▪ METHOD

Research Design

This study is a systematic literature review that analyzed various research findings related to computational thinking in mathematics learning. Systematic Literature Review (SLR) is a method for identifying, evaluating, and interpreting all available research relevant to the formulation of a problem or area of study (Calderon & Ruiz, 2015). Secondary data source from research reports found in online scientific publication articles analyzed using the Preferred Reporting Items for Systematic Review (PRISMA) (Page, et al., 2021).

Search Strategy

The data sources used in this study were obtained from the Scopus database, accessed using the Publish or Perish 8 application. Literature was searched using terms: "computational thinking" and "mathematics" within the "topic" field, which included titles, abstracts, and author keywords. A total of 107 articles pertaining to computational thinking and mathematics from 2017 to 2024 were gathered, ready for further screening. Figure 1 illustrates the three stages and procedures used in this process.

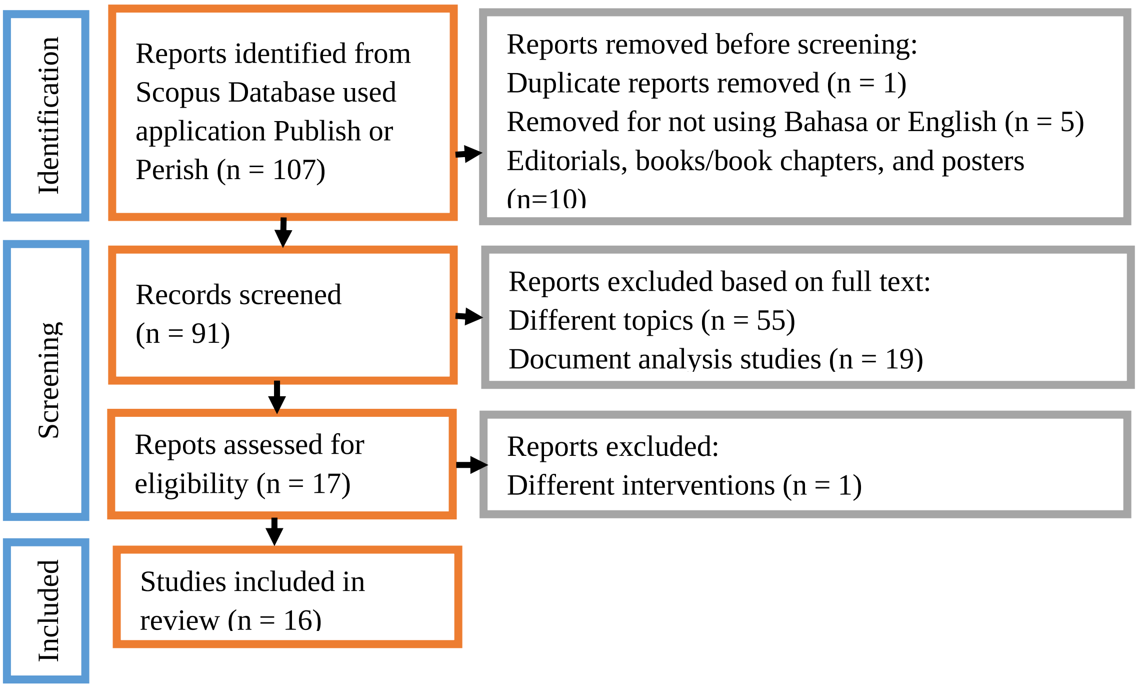


Figure 1. Literature Identification Process Using PRISMA Adapted from Page et al. (2021)

Inclusion and Exclusion Criteria

Articles identified through the search were selected based on the inclusion and exclusion criteria. These criteria encompass literature type, database indexing, language, type of research, focus of study, and publication year, as detailed in Table 1. The articles were obtained from academic journal or conference proceedings that focus on fostering students' computational thinking skill particularly in mathematics education.

Table 1. Inclusion and exclusion criteria

[A1][A2]**Criterion**	**Inclusion**	**Exclusion**
Literature type	Proceedings and Journal Articles	Editorial, Book Chapters, Reviews, and Book
Database indexing	Scopus	Other database
Language	Bahasa or English	Other language
Type of research	Research Studies	Systematic literature review, Bibliometric, and meta-analysis
Focus of study	Computational thinking in mathematics education	Computational thinking beside mathematics education
Year of publication	All years	No exclusion

Data Analysis

In conducting a systematic review, it was crucial to implement a well-structured and sustainable approach as outlined in the protocol. The process began with collecting and reviewing data based on established eligibility criteria. This involved extensive searching through databases, gathering documents, and reviewing reference lists from already eligible studies. Software such as Publish or Perish and Atlas.ti significantly eased this process by helping identify pertinent literature. The next step involved creating and identifying codes by connecting data through common ideas, highlighting keywords, and categorizing information. Concept maps were useful in this phase for better visualization. Subsequently, these codes were developed into themes. Finally, conclusions were derived, and findings were summarized. Themes were presented cohesively to address the research question, providing high-quality conclusions and insights. The results of this research and discussion will be explained more clearly in the following section.

▪ RESULT AND DISSCUSSION

After conducting the data analysis, the characteristics of the articles were presented in Table 2. This section first describes the educational context in which computational thinking-based mathematics learning activities are implemented, including the education level. Then, the pedagogical aspects of the articles are outlined, encompassing the tools and functions of instructional media and the mathematics topics used during computational thinking-based mathematics instruction. Finally, the characteristics of fostering computational thinking in mathematics learning based on the educational level, as evident in the reviewed literature, are described. The results are discussed along with further insights in each sub-section.

Table 2. Article characteristics

Author	Code	Year	Country	Participant	Research Design
Hsu, & Hu	A01	2017	Taiwan	20	Experiment
Costa, et al	A02	2017	Brazil	46	Quasi-experiment
Sung, et al	A03	2017	New York	66	Experiment
Martinez, et al	A04	2019	Spain	47	Quasi-experiment
Sunendar, et al	A05	2019	Indonesia	9	Qualitative
Lavigne, et al	A06	2020	Kentucky, Massachusett, New York	25	Exploratory

Author	Code	Year	Country	Participant	Research Design
Israel, & Lash	A07	2020	Midwestern	5 class	Qualitative
Sung, & Black	A08	2020	New York	115	Quasi-experiment
Fofang, et al	A09	2020	Mid-Atlantic	21	Qualitative
Aminah, et al	A10	2023	Indonesia	132	Mix method
Ng, et al	A11	2023	Hong Kong	95	Design-Based Research
Presser, et al	A12	2023	Rhode Island	85	Mix Method
Moller, & Kaup	A13	2023	Denmark	4	Cultural probe
Lee, et al	A14	2023	Taiwan	86	Quasi- experiment
Looi, et al	A15	2023	Singapore	168	Mix Method
Mumcu, et al	A16	2023	Turkey	80	Research and Development

RQ1: Level of Education Involved in Using Computational Thinking to Teach Mathematics

Research on computational thinking in mathematics has been conducted across various educational levels, predominantly in Asia. In this context, Indonesian terminology is used to define educational levels: "elementary school" refers to the first six years of basic education, "junior high school" to the subsequent three years, "senior high school" to the final three years, and "kindergarten" to pre-formal education activities. Most studies adopt this terminology, and for those that do not, the educational level was inferred for consistency. The data is summarized in Table 3.The majority of research (87.5%) targets basic education levels (elementary and junior high school). Recently, there has been a significant increase in interest regarding the implementation of computational thinking in mathematics at these levels. Among sixteen relevant articles, 73.3% were published between 2020 and 2023, indicating growing attention to this field.

Table 3. Participant educational level

Educational Level	Amount of Article	Percentage
Single Participant:		
Kindergarten	2	12.5%
Elementary School	5	31.2%
Junior High School	5	31.2%
Senior High School	0	0.0%
Undergraduate Students	2	12.5%
Mixed Participant:		
Kindergarten/ Elementary School	1	6.3%
Elementary School/ Junior High School	1	6.3%
Total	**16**	**100.0%**

Teacher can teach computational thinking in mathematics education at various levels of education from kindergarten until higher education. In kindergarten integrating hands-on activities and digital applications with existing mathematical knowledge has shown positive outcomes in early mathematics and flexible problem-solving skills (Lavigne et al., 2020; Presser et al., 2023). At the basic education level (elementary and junior high school), students' problem-solving abilities in mathematics learning can be enhanced through computational thinking (Martinez et al., 2019; Costa et al., 2017; Aminah et al., 2023). At the university level, computational thinking can guide practical tasks and enhance problem-solving skills and interdisciplinary knowledge (Lee et al., 2023). Empirical research suggests that fostering computational thinking in mathematics education yields positive outcomes for students at all educational levels.

Most studies focus on elementary and junior high schools, reflecting the cognitive development stages of these age groups. Elementary students solve problems using concrete objects, while junior high students develop logical reasoning and abstract understanding (Piaget, 1964). The emphasis on these levels is also influenced by Jeannette Marie Wing’s promotion of integrating computational thinking into basic education. Despite this focus, research potential remains significant at the senior high school level, which is relatively underexplored.

RQ2: Instructional Media Utilized to Foster Computational Thinking in Mathematics Learning

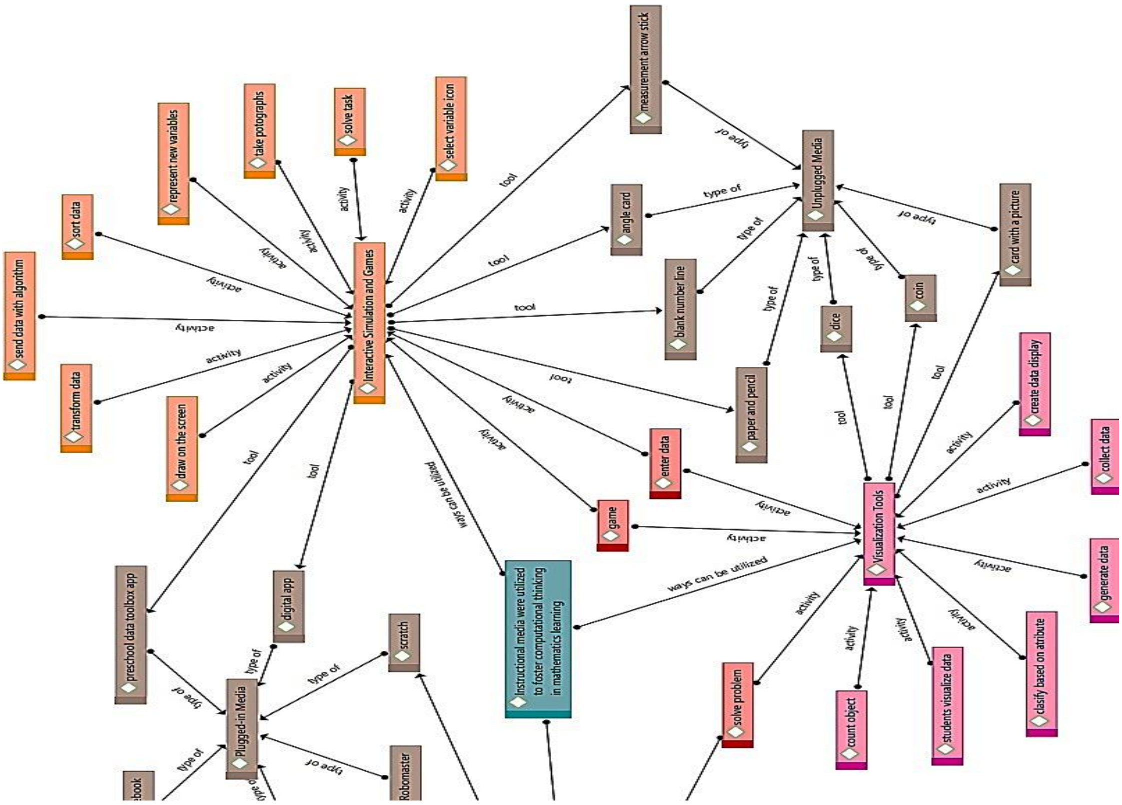
Based on data synthesis, fostering computational thinking in mathematics learning can utilize both instructional media or proceed without the media. There were two types of instructional media: first, plugged-in media, which consisted of software, an electronic device, or digital technology; and second, unplugged media, which excludes all forms of plugged-in media. The students' mathematics learning experiences described in certain studies mostly utilized plugged-in media throughout the process. More specifically, 6 of the 10 articles that utilized plugged-in media were developed in the Scratch environment. Details of instructional media used were presented in Table 4.

Table 4. Detail of instructional media used to foster computational thinking in mathematics

Code	Educational Level	Topics	Learning Media	Type
A01	Elementary School	Equality Axiom	Scratch	Plugged-in
A04	Elementary School	LCM and GCD	Scratch	Plugged-in
A07	Elementary School	Addition word problem, geometry, Fractions, multiplication, and number sense, area and volume, algebraic operation	Scratch	Plugged-in
A09	Elementary School	Prime Number	Sphero robot	Plugged-in
A10	Junior High School	Sequence and series	Scratch	Plugged-in
A11	Junior High School	Symmetry and arithmetic sequence	Scratch	Plugged-in
A13	Junior High School	Coordinate systems, Translation, Rotation, Geometric shapes (squares and rectangles), and Algebra	DJI RoboMaster	Plugged-in
A14	Undergraduate Student	Function, Geometry, Ratio, Calculus	Jupyter Notebook	Plugged-in

Code	Educational Level	Topics	Learning Media	Type
A02	Junior High School	Probability and statistic	Dice and coins	Unplugged
A16	Elementary School and Junior High School	Counting, Geometry, and Operation	Hands on	Unplugged
A06	Kindergarten	Sequence and shape	Card and a digital app prototype	Unplugged & Plugged-in
A12	Kindergarten	Data collection and analysis (counting, sorting, classifying, comparing, and ordering)	Card with a picture and Preschool data toolbox app	Unplugged & Plugged-in
A03	Kindergarten and Elementary School	Number line sense and arithmetic skills	Measurement arrow card, Measurement arrow stick, and Scratch	Unplugged & Plugged-in
A08	Elementary School	Number line sense and geometry	Angle Card and Hopscotch	Unplugged & Plugged-in

The instructional media were utilized in various ways, such as programing platform (A01, A04, A07, A09, A10, A11, A13, A14, and A08), visualization tools (A02 and A12), and interactive simulation and game (A06, A03, A08, A12, and A16). The results of data analysis on the use of instructional media conducted through the ATLAS.ti, were presented in Figure 2.



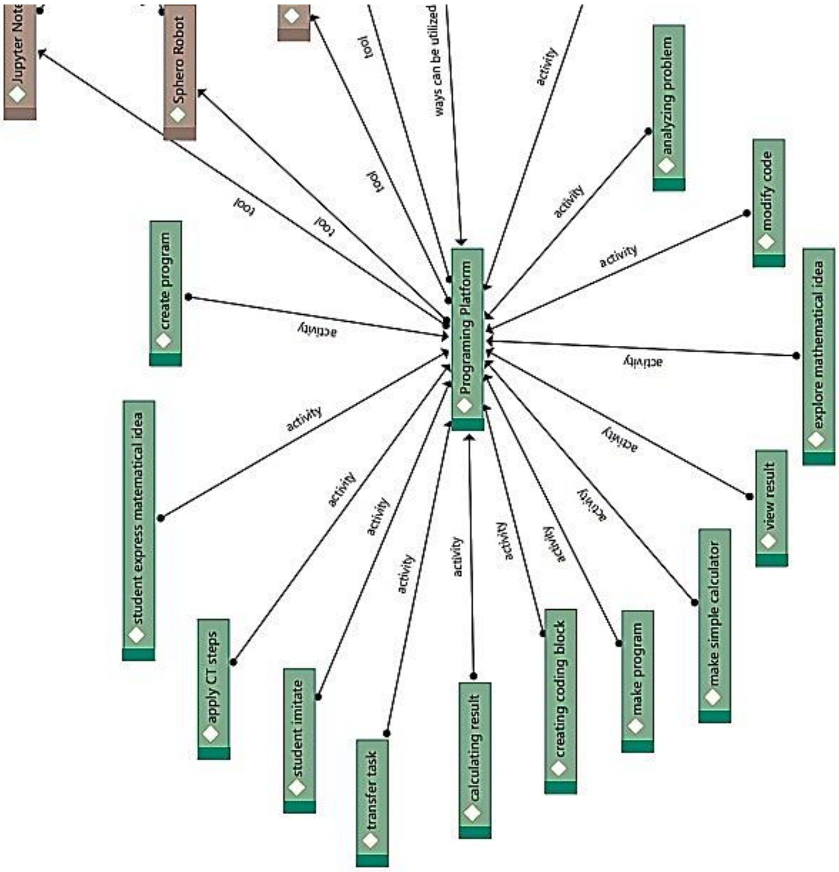


Figure 2. Use of instructional media to foster computational thinking

Instructional media could be utilized as one of the solutions in the learning process to make the content easier for student understanding. The methods for fostering computational thinking include the use of programming platforms, visualization tools, and interactive simulations and games. The use of programming platforms as instructional media has been proven effective to students fostering computational thinking skills in mathematics (Aminah et al., 2023; Ng et al., 2023; Moller & Kaup. 2023). Studies show that integrating programming tools such as Python, Scratch, and Blockly into the mathematics curriculum can help students understand abstract mathematical concepts through interactive visualizations and simulations (Findyani, et al., 2023; Grover & Pea, 2013). This approach also facilitates more collaborative and creative learning, as students can work together on programming projects that require complex and innovative problem-solving (Weintrop et al., 2016).

Visualization tools can be effectively utilized to fostering computational thinking in mathematics learning (Costa et al. 2017 & Presser, et al. 2023). Through visualization, students can more easily identify patterns, understand mathematical relationships, and develop deeper problem-solving abilities (Hegedus & Armella, 2010). Ainsworth (2006) emphasized that through visualization, students can directly observe mathematical patterns, relationships, and dynamics. Additionally, the use of interactive simulations and games holds great potential in developing students' computational thinking in mathematical content. Research has shown that interactive simulations and games can effectively foster computational thinking in mathematics learning (Presser et al., 2023; Mumcu et al., 2023; Lavigne et al., 2020; Sung & Black, 2020; Sung et al. 2017). Through an engagement with programing platforms, visualization tools, and interactive simulations and games, students are encouraged to think logically, analytically and systematically, which are essential aspects of computational thinking. Moreover, these tools bridge the gap between theory and practice in mathematics learning, providing students with practical experiences that enhance their understanding and application of mathematical concepts (Shute et al., 2016).

The use of instructional media, can maximize student understanding in the learning process. Plugged-in media, which utilizes technology or internet access, is typically more interactive because information is presented in various formats (Grover & Pea, 2013). In learning activities, students can use plugged-in or unplugged media with direct or indirect instructions, or even without any instructions. Instructional media enable students to actively construct knowledge through interaction with learning content and the learning environment (Piaget, 1972; Vygotsky, 1978). According to Dale (1969), simulating real experiences and engaging in real activities can achieve effective assimilation. This realization has led educators to understand the importance of providing learning facilities such as instructional media that offer stimulation and a comprehensive learning experience for students. Despite the many advantages of using instructional media, it is essential to employ them wisely.

RQ3: Mathematical Content Used to Foster Computational Thinking

The math-related abilities and content that were being developed in conjunction with computational thinking in the selected studies were then examined. In this case, 8 categories of mathematics contents were identified from the grouping of studies developing correlated concepts as presented in Table 5. Additionally, examples of developed themes were provided for each group. From the mapping of the mathematical content used in the article, there were five activities of using more than one mathematical content, such as: A06, A07, A08, A16, A13, and A14. At the kindergarten education level, an article used sequence and geometry together in learning and another article used geometry. On the other hand, at the mix audience for kindergarten and elementary school level education used number operations. Meanwhile, mathematics modeling and calculus were used in undergraduate students.

Table 5. Mathematical content used in fostering computational thinking

Mathematical Content	Amount of Article	Content's Examples
Number Operation	8	Number line sense, arithmetic skill, the least common multiple, the greatest common factor, fractional parts and fractions on the number line, prime number, counting, sorting, classifying, comparing, ordering, and using ratio to solve the Networks Embedded System and Application problem
Algebra	3	Algebraic thinking, equality axiom, and use function to solve the Networks Embedded System and Application problem

Mathematical Content	Amount of Article	Content's Examples
Geometry	8	Use individual shapes and combined shapes that form "modules", the properties of polygons, square, rectangles, coordinate systems, translation, rotation, and use geometry to solve the Networks Embedded System and Application problem
Measurement	1	Area and volume
Data Analysis and Probability	1	Probability and statistics
Sequence	3	Placing the cards in a logical order, symmetry and arithmetic sequence
Mathematics Modeling	1	Transforming daily life problems into mathematical models
Calculus	1	Use calculus to solve the Networks Embedded System and Application problem

In recent years, there has been a growing recognition of the role that mathematics content plays in fostering computational thinking (Weintrop, et al. 2016). Mathematics provides a structured and logical framework essential for developing problem-solving skills and algorithmic thinking (Lye & Koh, 2014). Teachers can leverage various types of mathematics content from the educational curriculum to teach computational thinking. Table 3 summarizes the number of publications corresponding to the educational level at which the research was carried out, showing that more studies have been conducted in elementary and junior high school contexts. This finding aligns with Table 5, which indicates that number operations are the most common learning content at these levels.

Number operations are crucial for fostering computational thinking in mathematics because computations are built up from basic operations such as subtraction, addition, division, and multiplication (McCarthy, 1959). The National Research Council (2001) states that solving mathematical problems often involves applying numerical operations in the correct order. Real-world situations can frequently be modeled as mathematical problems involving number operations (Steen, 2001). Moreover, understanding algorithms, many of which are based on number operations, is a key aspect of computational thinking (Wing, 2006). In software development, understanding number operations is paramount (Wing, 2006). Therefore, number operations are not only important for building a strong understanding of mathematics but also for developing essential computational thinking skills across various contexts.

However, this does not imply that the other content cannot encourage computational thinking. As shown in Table 4, geometry is the second most used content, studied in junior high and senior high school. Geometry content often facilitates computational thinking because it involves depicting objects and patterns in space (Clements & Battista, 1992). The use of dynamic geometry software such as Scratch and Jupyter Notebook allows students to experiment with geometry concepts interactively (Israel & Lash, 2020; Lee, et al., 2023). This helps visualize mathematical ideas and encourages exploration, an important aspect of computational thinking (Wing, 2006). Consequently, geometry provides a rich context for developing computational thinking skills in mathematics by incorporating visual representations.

In learning mathematics, content is used to fostering computational thinking through various strategies. Hsu et al. (2018) stated that Problem-Based Learning, Cooperative Learning, and Game-Based Learning are the main strategies for learning computational thinking. Therefore, the right combination of mathematics content and learning strategies can effectively foster computational thinking. Additionally, the limited use of certain content in fostering computational thinking in mathematics highlights opportunities to explore and integrate other content areas to enhance this skill further.

RQ4: Characteristics of Fostering Computational Thinking in Mathematics Learning

The subsequent identification process was carried out to determine the computational thinking components that were the focus in each article. The articles were read manually to perform this identification process. As a result, twenty-two computational thinking components were identified. For mixed participant, such as kindergarten and elementary school, the computational thinking components were grouped into both categories. The same grouping applied to mixed participants elementary school and junior high school students. The computational thinking components used based on the level of education was presented in Figure 3 below. In general, the computational thinking components that were frequently used included decomposition, abstraction, pattern recognition, and algorithmic thinking.

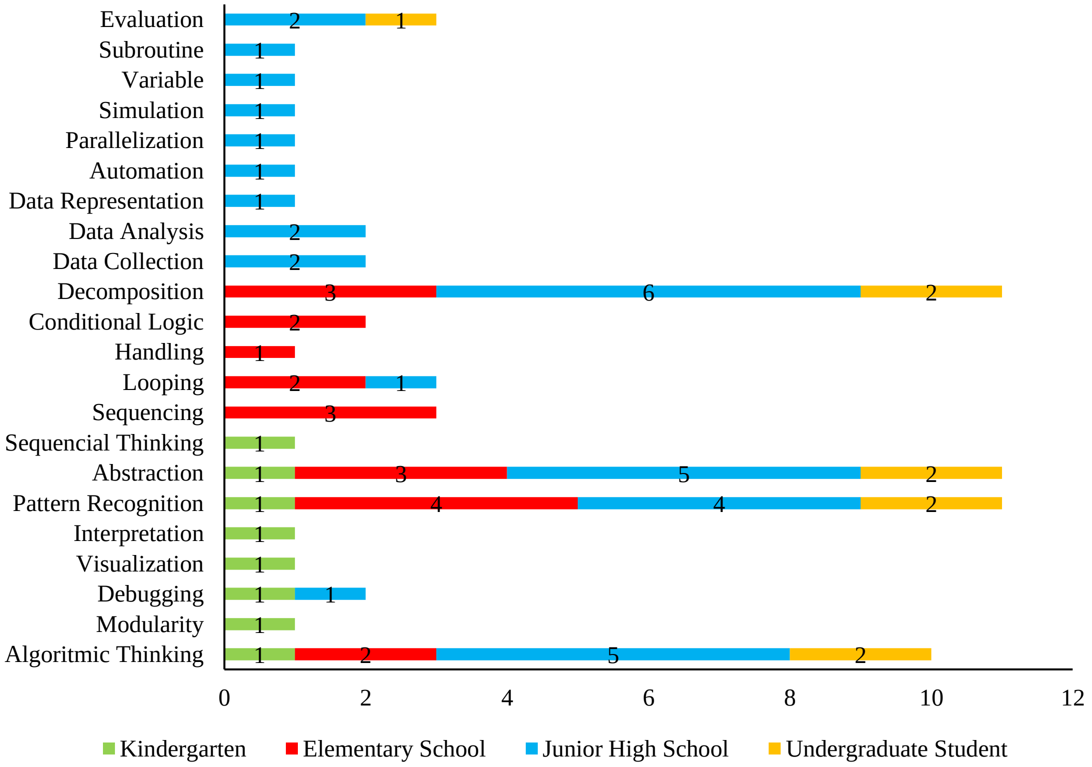


Figure 3. Computational thinking components

Figure 3 present that computational thinking can be taught to kindergarten children through various cognitive processes such as sequential thinking, abstraction, pattern recognition, interpretation, visualization, debugging, modularity and algorithmic thinking (Lavigne et al., 2020; Presser et al., 2023; Sung et al. 2017). Referring to the K12 Computer Science Framework, modularity synonymous with decomposition, and sequential thinking, which involves repeating patterns of instructions and using events to initiate instructions, align closely with algorithm thinking (Looi et al. 2023). Debugging serves as a mechanism for refining solutions, where children learn to identify errors through backward reasoning to enhance their problem-solving skill. Although in implementation, kindergarten children tend to use trial and error to correct problems rather than reasoning (Poole et al. 2004). Lavigne et al. (2020) further elaborate that modularity in early childhood involves breaking down larger shape into smaller one or vice versa, demonstrating the foundational understanding of this concept at a young age. The Table 3 present that in kindergarten, computational thinking can be fostered trough both plugged-in and unplugged media. While interactive simulation activities and games introduce children to plugged-in media, unplugged media remains essential during this developmental stage. Direct experiences and manipulatives play a crucial role in early childhood learning, allowing children to internalize abstract concepts through tangible interactions (Piaget, 1964; Clements & Sarama, 2009). Therefore, employing unplugged media to introduce mathematics to kindergarten children remains vital for nurturing their computational thinking skills, especially considering their stage of cognitive development where gross and fine motor skills are equally significant for exploration and learning.

In elementary school, fostering computational thinking in mathematics can be accomplished through various cognitive processes such as decomposition, abstraction, pattern recognition, algorithmic thinking, conditional logic, handling, looping, and sequencing. According to the K12 Computer Science Framework for grades K-2 and 3-5, students learn to understand and create step-by-step instructions (algorithms) to solve simple problems, as well as recognize the basics of programming using age-appropriate tools or programming languages. This encompasses event handlers, conditional statements (if/then), and loops (repetition). At this level, students learn basic concepts such as making decisions (e.g., "if it rains, take an umbrella") and performing repeated actions (e.g., "repeat this step five times"). For instance, in teaching mathematics, first-grade lesson plans focused primarily on basic programming concepts and did not introduce looping or conditional logic. In the second grade, lessons focused on sequencing highlighted the role of looping in optimizing program efficiency and functionality. Moreover, these lessons introduced conditional logic through unplugged activities, although students were not tasked with applying this understanding to their own computational endeavors. Moving into third grade, students were presented with opportunities to investigate the idea that not all code is executed when employing conditional logic or branching in more intricate programs. By fourth grade, lessons provided occasions for students to employ their understanding of sequencing and conditional logic in developing their own programs (Israel & Lash, 2020). It is important to ensure that students build a strong foundation in mathematical concepts through computational thinking.

Nearly all articles involving elementary school student participants utilize algorithmic thinking when learning mathematics, except for article A08. Specifically, two of these articles (A04 & A07) focus on exploring students' algorithmic thinking processes in mathematical lessons. This underscores the importance of algorithmic thinking as a crucial skill in cultivating computational thinking among elementary school students in mathematics. The widespread use of algorithmic thinking in research signifies researchers' recognition of it as a key component in the developing problem-solving abilities and critical thinking in children. This aligns with Smith & Johnson (2020), who assert that algorithmic thinking is a cornerstone of computational thinking. Their research highlights the significance of students' ability to systematically and logically solve problems through algorithm development, forming the foundation of computational thinking. By integrating algorithmic thinking into mathematics education, students not only deepen their understanding of mathematical concepts but also develop skills in logical reasoning, problem-solving, and abstraction (Brennan & Resnick, 2012). Through solving mathematical problems using algorithmic approaches, students can practice structuring steps, identifying patterns, and generalizing solutions to various problems (Grover & Pea, 2013). Focusing on algorithmic thinking helps elementary students prepare a strong foundation for understanding higher mathematical concepts.

In learning mathematics in elementary school, computational thinking can be fostered through both plugged-in and unplugged media. The majority opts for plugged-in media because, according to Bebell and O'Dwyer (2010), integrating technologies like computers and digital devices can expand concrete experiences in ways that support interactive learning. However, it is crucial to consider students' readiness when utilizing such tools. The influence of utilizing plugged-in media can be significantly heightened when students are initially equipped with suitable learning activities that reinforce computational viewpoints and practices before their introduction to plugged-in media. (Sung, 2017). Additionally, Martinez et al., (2019) emphasizes the necessity of explicit instruction to develop fundamental computing concepts at the elementary school level. This approach ensures that students not only use plugged-in media effectively but also understand the underlying computational principles, enhancing their overall learning experience and mathematics skill development in technology-integrated education.

In junior high school and undergraduate education, computational thinking is frequently imparted to students through various cognitive processes such as abstraction, decomposition, pattern recognition, and algorithmic thinking. These components are crucial elements of computational thinking (Dong et al., 2019). The articles reviewed indicate diverse approaches in utilizing these components, influenced significantly by the primary references chosen by each researcher. The use of instructional media in fostering computational thinking diminishes with educational level progression. Data analysis shows that all studies in kindergarten and elementary school incorporate instructional media, whereas 67% utilize it in junior high school, declining further to 50% in undergraduate education. Similarly, the use of unplugged media decreases progressively. This might happen because in junior high school emphasizes skill development in problem-solving and critical thinking (Sercenia et al., 2023). Moreover, undergraduate students frequently employ advanced tools such as programming software, computer simulations, and data analysis tools, which are more aligned with the needs of computational thinking compared to unplugged media (Rubinstein & Chor, 2014). This often necessitates a more practical and interactive approach than unplugged media. Overall, the reduced use of instructional media among junior high school and undergraduate students aligns with Piaget's theory (1952), which suggests that digital learning media usage decreases as students' transition to more abstract thinking in junior high school and the formal operational stages in undergraduate education. These stages require more challenging and in-depth learning approaches. Simple or concrete learning media may not sufficiently stimulate cognitive development corresponding to their developmental stages (Papert, 1980). Therefore, interactive, problem-based learning that fosters critical and independent thinking is prioritized during these educational phases.

▪ CONCLUSION

Computational thinking is a vital skill that children should develop as early as possible through mathematics learning, as it enables them to effectively solve problems in today's technological era. Researchers and educators have recognized the benefits of this skill, leading to a surge in investigations into computational thinking in mathematics education. Since 2017, educators have been actively fostering these skills across all educational levels, with a particular emphasis on elementary schools and junior high schools. The senior high school level presents substantial research opportunities that have received relatively scant exploration. To optimize fostering computational thinking in mathematics, teachers should be reminded of strategies to support students, particularly through activities involving simulations using various instructional media depending on the student's level of readiness. These instructional media for instance, programming platforms, visualization tools, and interactive simulations and games, both plugged-in and unplugged. Although the use of instructional media is still relevant, its effectiveness diminishes with educational level progression. Number operations and geometry are the mathematical content most widely used for fostering computational thinking. Number operations not only enhance mathematical understanding but also develop crucial computational thinking skills across diverse contexts. Geometry, with its visual representations, provides a fertile ground for cultivating computational thinking skills. The restricted utilization of specific content in promoting computational thinking in mathematics underscores the potential to investigate and incorporate alternative content domains to further enrich this competency. The components of computational thinking that are often used are Abstraction, Decomposition, Pattern Recognition, and Algorithmic thinking. Algorithmic thinking is a crucial component in cultivating computational thinking among elementary school students in mathematics, as it helps them develop a strong foundation for understanding higher mathematical concepts. However, each researcher can choose their approach to use computational thinking components based on their main reference and learning objectives.

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