Computational Thinking Skills in 21st Century Mathematics Learning

Netti Kariani Mendrofa
Universitas Nias, Indonesia
E-mail: netti.mend14@gmail.com

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Abstract
Computational thinking skills are a crucial mental skill in the 21st century, enabling individuals to solve problems, understand data, and make decisions with a structured and computational-based approach. Integrating computational thinking skills in mathematics learning has an important role in preparing students to become skilled in thinking computationally in the 21st century. The method used in this research is library research in which relevant data are collected from sources such as books, dictionaries, journals, magazines, and others without the need to conduct direct investigations in the field. Applying computational thinking in mathematics learning will foster skills such as decomposition (breaking down a problem into manageable parts), pattern recognition, abstraction, and algorithm design as well as developing analytical and abstract thinking skills.

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Abstrak
Keterampilan berpikir komputasi merupakan keterampilan mental yang penting di abad ke-21, yang memungkinkan individu memecahkan masalah, memahami data, dan mengambil keputusan dengan pendekatan terstruktur dan berbasis komputasi. Mengintegrasikan keterampilan berpikir komputasional dalam pembelajaran matematika mempunyai peranan penting dalam mempersiapkan siswa menjadi terampil berpikir komputasional di abad ke-21. Metode yang digunakan dalam penelitian ini adalah penelitian kepustakaan, yaitu pengumpulan data yang relevan dari sumber-sumber seperti buku, kamus, jurnal, majalah, dan lain-lain tanpa perlu melakukan penyelidikan langsung di lapangan. Penerapan berpikir komputasi dalam pembelajaran matematika akan menumbuhkan keterampilan seperti dekomposisi (memecah suatu masalah menjadi bagian-bagian yang dapat dikelola), pengenalan pola, abstraksi, dan desain algoritma serta mengembangkan keterampilan berpikir analitis dan abstrak.

I. INTRODUCTION

The Industrial Revolution 4.0 that first emerged in the 21st century is characterized by extraordinary advances in technology and information. This indicates that education needs to design and develop curriculum and learning that shapes students to have skills and be able to compete internationally. Combining knowledge and technology is a solution to problems that will become a trend (Voskoglou & Buckley, 2012). Computational thinking is one of the important skills that support the development of Information and Communication Technologies (ICT) in the 21st century (Cahdriyana, 2020; Syarifuddin et al., 2016).

Mastery of ICT is very necessary to equip students to have the ability to create new values through creative, innovative, collaborative, communicative and open-minded thinking (OECD, 2018). This was emphasized by Wing (2006), who stated that computational thinking will become a fundamental ability utilized by everyone in the world in the mid-21st century. Furthermore, Ansori 2020 and Binkley et al. (2012), adding that computational thinking is in line with 21st century competencies including creativity, critical thinking, and problem solving. Computational thinking is a process that requires a problem-solving mindset, abstract reasoning, and the development of creative problem solving (Ioannidou et al., 2011). Computational thinking forms students' cognitive stages with regular patterns in solving problems (Citta et al., 2019; Supiarmo et al. 2022). Many developed countries have introduced computational thinking and included it in the school curriculum at elementary and middle school levels (Brackmann et al., 2017; Città et al., 2019). The United States, England, the Netherlands, Australia, and Mexico are countries that have included CT in the educational curriculum (Yadav et al., 2018).

Computational thinking skills have received significant attention in the context of mathematics education due to their potential to improve problem-solving abilities and cognitive processes (Kallia et al., 2021). The integration of computational thinking in mathematics learning has been emphasized as an important component in STEM education, aiming to improve students' analytical abilities (Grover & Pea, 2013). Computational thinking in mathematics education has been defined to focus on thinking skills, such as abstraction, rather than just the use of computers (Park & Kwon, 2022). This approach is particularly important as it highlights the cognitive aspects of computational thinking and its relevance to mathematics learning.

Additionally, the relevance of computational thinking in mathematics education includes its potential to improve students' mathematical modeling abilities (Sanford & Naidu, 2017). Mathematical modeling, which is considered the core of computational thinking, plays an important role in developing students' computational perspectives and problem-solving skills in the context of mathematics education (Sanford & Naidu, 2017). This highlights the interdisciplinary nature of computational thinking, which intersects with various aspects of mathematics education, including problem solving, critical thinking, and mathematical modeling.

The research gap related to Computational Thinking Skills in Mathematics Learning lies in the need for further exploration of the effectiveness of specific teaching strategies and interventions aimed at improving computational thinking skills in the context of mathematics education. Although existing research has highlighted the importance of computational thinking in mathematics learning, there is a lack of comprehensive research that specifically evaluates the impact of various learning approaches, such as problem-based learning, metaphorical thinking, and flipped classroom models, on the development of mathematics learning. computational thinking skills in mathematics (Putri et al., 2022; Yerizon et al., 2022; Widyatiningtyas et al., 2015). Apart from that, the influence of students' intrapersonal intelligence, learning motivation, and self-regulated learning on mathematical computa-tional thinking abilities is still an area that requires further investigation (Aswin et al., 2022; Maratusyo seen et al., 2021; Mulyono et al., 2020).

Additionally, existing literature primarily focuses on the impact of computational thinking on critical thinking skills in mathematics (Fajari et al., 2020), but there is a need for research that investigates the relationship between computational thinking and other important cognitive abilities. such as creative thinking abilities and mathematical modeling (Maratusyo seen et al., 2021). Additionally, although several studies have examined the use of computational thinking taxonomy frameworks and gamification in teaching computational thinking skills (Gilchrist et al., 2021; Tan et al., 2019), there is a gap in research evaluating long-term effective-ness. and the sustainability of innovative approaches in mathematics education.

In addition, existing research has largely concentrated on the impact of computational thinking on students' mathematical abilities, with limited exploration of the role of teachers in improving computational thinking skills in mathematics classes (Ardiyani et al., 2018; Denning & Tedre, 2019). Investigating the effectiveness of professional development programs and instructional resources for educators to integrate computational thinking into mathematics teaching will contribute to addressing this gap. In summary, existing research on computational thinking skills in mathematics learning has laid the foundation for understanding their significance. However, there is a need for further empirical studies that specifically examine the effectiveness of learning strategies, the influence of individual factors, and the role of educators in fostering computational thinking skills in the context of mathematics education.

The importance of computational thinking in mathematics learning lies in its potential to enhance problem solving, critical thinking, and cognitive processes, thus contributing to the holistic development of students' mathematical abilities. By integrating computational thinking into mathematics education, educators can effectively develop students' analytical skills and prepare them for the demands of STEM-related fields. When applied to mathematics learning, computational thinking can improve problem-solving skills, improve logical reasoning, and help students face mathematical challenges more systematically. By integrating computational thinking into mathematics education, students can understand abstract concepts more effectively, understand the underlying structure of mathematical problems, and develop critical thinking skills that can be applied beyond mathematics itself.

Researchers often explore how to integrate computational thinking strategies into mathematics curricula, design educational tools and activities that encourage computational thinking skills, and assess the impact of these approaches on students' mathematical under-standing and problem-solving abilities. The ultimate goal is to empower students not only with mathematical knowledge but also analytical, logical, and creative thinking abilities, which are essential skills for success in an increasingly technology-driven world.

II. METHOD

This research is library research. The method used involves analysis of a collection of texts, articles, books, journals, or other documents related to computational thinking in mathematics learning. The stages taken are: *First*, collect research materials. Material is collected from empirical data sourced from books, journals, research reports, such as *Google Scholar, Science Direct, Eric* and*ProQuest*. *Second*, reading library materials. It is important to read research materials to carry out careful exploration, which may produce new ideas related to the research title. Overall, the information that has been obtained is then processed or analyzed to obtain a conclusion which is then presented in the form of a research report on computational thinking in mathematics learning.

III. RESULT AND DISCUSSION

1. 21st Century Math Skills

The 21st century is marked by the availability of information anywhere and at any time (information), the implementation of the use of machines (computing), being able to reach all routine work (automation) and communication that can be done from anywhere and everywhere (R&D Ministry of Education and Culture, 2013). The theoretical framework of 21st-century math skills encom-passes a range of competencies essential for success in the modern world. These skills include critical thinking, creativity, communi-cation, collaboration, problem solving, and technological literacy (Luo, 2022). The TPACK framework, which integrates technology, pedagogy, and content knowledge, has been adapted to measure pre-service teachers' readiness for these skills (Valtonen et al., 2017). Additionally, the 4C1V framework, based on the P21 framework, emphasizes communication, collaboration, critical thinking, creative thinking, and values and ethics as important components of 21st century skills (Shafie et al., 2019). Furthermore, the OECD framework, the Partnership of 21st Century Skills in teaching and learning, and the key competencies for lifelong learning framework proposed by the European Commission are also integral to the development of 21st-century skills (Alahmad et al., 2021).

The development of these skills is crucial for students to adapt to the challenges of the modern workforce (Kusno & Setyaningsih, 2021). Mathematics education plays a significant role in fostering these skills, as it enables students to cultivate creative thinking and effective learning, which are essential for addressing real-world problems (Lan, 2020). Moreover, the ability to transfer mathematical learning to other disciplines is particularly important for the development of 21st-century skills (Nakakoji & Wilson, 2020). Problem-solving in mathematics education has been identified as an efficient way to develop 21st-century skills and provide learners with cross-curricular experiences with real-world significance (Szabo et al., 2020).

The implementation of 21st-century learning frameworks, such as the Partnership for 21st Century Skills (P21), is essential for designing curricula that support the achievement of 21st-century skills for students (Dra.Rosdiana et al., 2020). These frameworks provide a comprehensive approach to developing skills such as critical thinking, collaboration, leadership, agility, adaptability, effective communication, information analysis, and imagination (Kusno & Setyaningsih, 2021). Additionally, the influence of technical skills and 21st-century skills on the job readiness of vocational students highlights the importance of these competencies in preparing students for the workforce (Widayana, 2023). In conclusion, the theoretical framework of 21st-century math skills encompasses a multidimensional approach that integrates technological, pedagogical, and content knowledge, along with the development of critical thinking, creativity, communication, collaboration, problem-solving, and technological literacy. These skills are essential for students to thrive in the modern world and are supported by various international frameworks and educational initiatives.

2. Computational Thinking

The phrase "*Computational Thinking*" first appeared in a book by Seymour Papert entitled "Mindstorms: Children, Computers, and Powerful Ideas" published in 1980 (Papert, 1980). Papert used this term to refer to a systematic way of thinking that is closely related to computing and the use of computers in the thinking and learning process. In the book, Paper highlights the importance of computing in education and how computational thinking can be embedded in children's learning processes

Previously, the phrase “computational thinking” was known as “algorithmic thinking”, especially in the 1950s and 1960s (Denning & Freeman, 2009). The term "algorithmic thinking" is used to refer to a way of thinking that focuses on the use of algorithms in solving problems, which later developed into what we now know as "computational thinking". The concept of “algorithmic thinking” highlights the importance of developing algorithms, detailed steps to solve a specific problem, in the context of computing. As technology developed and broader approaches to understanding computing developed, the term evolved into "computational thinking," which more encompasses various aspects of thinking related to computing such as problem modeling, data analysis, and systematic problem solving using computational concepts. .

Initially, computational thinking was solely created as a way to teach students programming. However, as technology and artificial intelligence advance, this idea expands to include systematic, logical, and creative ways of thinking to solve problems using technology. Computational Thinking or Computational Thinking is a concept that is currently developing in the field of computer science. Computational thinking is an approach to problem-solving that draws on the power and limits of computing (Jacob & Warschauer, 2018). It involves a series of thinking activities that use relevant concepts of computer science to solve problems ("CiteSpace Map Analysis of Computational Thinking Research in China", 2022). This approach emphasizes problem representation, abstraction, decomposition, recursion, simulation, and verification, drawing on fundamental computing concepts (Jacob & Warschauer, 2018). The importance of computational thinking is further emphasized by its connection to 21st century skills, academic success, and problem-solving abilities. This is in line with Voogt et al (2015) who stated that computational thinking has been recognized as an important skill in the 21st century, the implementation of which extends to compulsory education, including elementary school.

The development of computational thinking skills is not limited to computer science education but can be integrated into all scientific disciplines (Peel et al., 2022). Additionally, computational thinking processes align with problem solving and information processing, thereby providing a framework for analyzing and understanding computational thinking (Labusch et al., 2019). The relationship between computational thinking and literacy is explored through a three-dimensional framework, highlighting the ways in which computational thinking skills facilitate literacy development (Jacob & Warschauer, 2018). Additionally, a teaching framework for developing computational thinking based on embodied cognitive theory is proposed, emphasizing the early development of computational thinking (Deng et al., 2022). The importance of computational thinking in the development of 21st century skills has been emphasized, with patterns of its integration determined from a disciplinary perspective (Lee & Malyn-Smith, 2019). The ability to solve practical problems is considered a key aspect of computational thinking, emphasizing its relevance in real-world contexts (Kang et al., 2022).

The computational thinking component involves several key aspects that help in solving complex problems in a way that can be understood and executed by computers. The components that are widely used are Four*Key Techniques* in *Computational Thinking* which refers to*Decomposition, Pattern Recognition, Abstraction, Serta Algorithm Design* (Liem, 2018). Following are the main components:

a) Problem Solving (Decomposition): Breaking down complex problems or systems into smaller, more manageable parts or sub-problems. This involves breaking down a large problem into smaller, easier to understand parts, so that each part can be solved individually.

b) Pattern Recognition (Pattern Recognition): Identify similarities or patterns in problems, data, or systems. This involves recognizing commonalities or trends that can help in understanding the problem better and finding solutions efficiently.
c) Abstraction (Abstraction): Focus on important details while ignoring irrelevant information. It involves simplifying and generalizing a complex system or problem into its core components, allowing it to be understood more easily and facilitating problem solving.
d) Algorithm Design (Algorithm Design): Develop step-by-step instructions or procedures to solve problems or complete tasks. An algorithm is a precise rule or instruction that, when followed correctly, leads to the solution of a problem.

These components are interrelated and often work together to address problems in a structured and logical manner, allowing individuals to think like computer scientists when facing various challenges. Moreover, the impact of STEM attitudes and computational thinking on 21st-century skills has been a subject of study, indicating the growing recognition of computational thinking as a key competence for today's digital learners (Richardo et al., 2023). The development of instruments to measure cognitive skills related to computational thinking has been proposed, particularly in the context of mathematics learning (Ihsan et al., 2019). Moreover, the impact of STEM attitudes and computational thinking on 21st-century skills has been a subject of study, indicating the growing recognition of computational thinking as a key competence for today's digital learners (Richardo et al., 2023).

The theoretical framework of computational thinking extends to the early development of cognitive skills, proposing teaching practices based on embodied cognitive theory (Deng et al., 2022). Furthermore, computational thinking has been linked to mathematical modeling, emphasizing its significance in logical reasoning and problem-solving (Sanford & Naidu, 2017). The integration of computational and creative thinking has been explored to improve learning and performance, highlighting the potential for interdisciplinary approaches to computational thinking (Miller et al., 2014).

In conclusion, computational thinking is a multifaceted approach to problem solving that integrates concepts from computer science and emphasizes basic computing concepts. It is not limited to computer science education and can be integrated into various scientific disciplines. Computational thinking encompasses a wide range of cognitive processes and skills that are important for individuals in the digital age. It goes beyond traditional computer science and mathematics education, impacting multiple disciplines and enhancing critical thinking, problem solving, and creativity.

3. The Importance of Computational Thinking in Mathematics Learning

The integration of computational thinking in mathematics learning has gained attention due to its potential to enhance problem-solving skills and cognitive development. Computational thinking has been recognized as a new dimension of computer literacy, emphasizing its inclusion in curricula standards Tsai et al. (2020). Furthermore, the integration patterns of computational thinking from a disciplinary perspective provide insights into how computational thinking elements can be integrated into mathematics education, reflecting the work of computational thinking-enabled STEM professionals (Lee & Malyn-Smith, 2019). Additionally, an unplugged instructional approach has been proposed to integrate science and computational thinking, which can be extended to mathematics education, emphasizing the practical application of computational thinking in STEM subjects (Peel et al., 2022).

Moreover, computational thinking has been regarded as the ability to solve practical problems, and its integration into Grade 10 mathematics learning has been perceived as a vital tool to develop problem-solving skills in mathematics classrooms (Kang et al., 2022; Ramaila & Shilenge, 2023). The reciprocal relationship between computational thinking and mathematics learning has been highlighted, emphasizing the use of computation to enrich mathematics learning and applying mathematics contexts to enrich computational learning (English, 2018). Furthermore, the development and assessment of computational thinking in secondary education using a guided Scratch visual execution environment have shown significant improvement in students' computational thinking development (Connolly et al., 2021). Additionally, a case study of integrating computational thinking into primary mathematics through Scratch programming activities has emphasized the promotion of mathematical ideas and thinking through computational thinking (Fang et al., 2023).

Some theories and ideas related to the importance of computational thinking in mathematics include:

a) Constructivism Theory: This theory emphasizes the importance of building knowledge through direct experience and interaction with materials. Computational thinking in mathematics allows students to construct their own knowledge by applying mathematical concepts in a computational context.
b) Problem-Based Learning Theory: Through computational thinking, students are exposed to solving real mathematical problems, allowing them to apply mathematical concepts in relevant and meaningful situations.
c) Mathematical Knowledge Construction Theory: Computational thinking allows students to build a deeper understanding of mathematical concepts by experiencing and practicing the application of those concepts in a computing environment.
d) Social Constructivist Approach to Mathematics Learning: Through cooperation and communication in computational problem solving, students can expand their understanding of mathematics by considering other people's points of view.
e) Technology-Based Learning Theory: Incorporating computer technology in mathematics learning encourages the use of software or computing tools that can improve understanding of mathematical concepts.

Computational thinking is very important in mathematics learning because it provides students with opportunities to develop problem solving, logical thinking and mathematical modeling skills. This involves the use of algorithms, understanding how computers work, as well as applying mathematical concepts in a computing context.

The importance of computational thinking in mathematics learning can be seen from several dimensions that highlight its benefits:

a) Solution to problem:
   Focuses on using algorithmic and logical thinking to solve complex mathematical problems. Computational thinking allows students to develop structured problem-solving strategies.
b) Mathematical Modeling:
   Computational thinking enables the application of mathematical concepts into real contexts through the use of programming tools or languages. It helps students understand how mathematics can be applied to model real-world phenomena.
c) Abstraction Capabilities:
   Through programming or the use of algorithms, students must understand mathematical concepts in a more abstract way. This helps in developing abstraction and generalization skills.
d) Critical Thinking Skills:
   Focuses on critical thinking in analyzing, evaluating, and improving mathematical solutions using computational approaches. It teaches students to consider various solutions and choose the best one.
e) Creativity and Innovation:
   Computational thinking also stimulates creativity by enabling the exploration of alternative solutions and the development of new ideas in a mathematical context.
f) Preparation for the World of Work:
   Provide students with an understanding of the close relationship between mathematics, computing, and technology in the professional world. This prepares them with relevant skills in a world of work that is increasingly dominated by technology.
g) Communication and Collaboration:
   Through computing projects, students can learn to collaborate, share ideas, and communicate in designing mathematical solutions, improving their social skills.
h) Introduction to Computer Science Principles:
   Computational thinking helps students understand the basic principles of computer science, such as algorithms, data structures, and programming logic, which can be applied in a variety of contexts.

The importance of computational thinking in mathematics is not only to help students understand mathematical concepts, but also to help them develop skills that are relevant in this century which is increasingly driven by technology. By thinking computationally, students can:

a) Develop Problem Solving: They learn to solve math problems with a systematic and logical approach, similar to the way computers solve problems.
b) Understanding Mathematical Concepts in Deeper: Through the use of mathematical software or programming languages, students can apply mathematical concepts practically, which helps in deeper understanding.
c) Sharpens Critical Thinking Skills: Computational thinking requires careful analysis, evaluation, and problem solving which are important skills in mathematics and everyday life.
d) Realizing the Relevance of Mathematics in the Real World: Through computing applications, students can see how mathematics is used in various fields such as science, technology, and engineering.
e) Preparing for the World of Work: Computational thinking skills are highly sought after in the modern workforce, where understanding mathematics and the ability to operate technology are highly valued skills.

It can be concluded that integrating computational thinking in mathematics learning can help students develop the skills needed for success in the future, both academically and professionally. Encouraging students to approach math problems using computational thinking will foster skills such as decomposition (breaking a problem into manageable parts), pattern recognition, abstraction, and algorithm design. All of this shows that computational thinking is not only relevant for mathematics learning, but also supports the development of skills that are important in various aspects of students' lives both inside and outside the classroom.

IV. CONCLUSION AND SUGGESTION

A. Conclusion

Computational Thinking Ability has a crucial role in mathematics learning in the 21st century. Several factors influence the development of Computational Thinking Skills in the context of mathematics learning, namely developing problem solving, namely helping in developing decomposition skills, pattern recognition, abstraction, and algorithm design; understand mathematical concepts more deeply by integrating computational thinking strategies in learning; connecting mathematical concepts to real-world problems helps students see the relevance and practical application of computational thinking skills; and encourage innovation and creativity in approaches to mathematics. By considering and integrating these factors into mathematics education, educators can effectively develop computational thinking skills in students, enabling them to face mathematical challenges with a computing-related mindset.

B. Suggestion

The discussion regarding this research is still very limited and requires a lot of input. The suggestion for future authors is to study it more deeply and comprehensively about Computational Thinking Skills in 21st Century Mathematics Learning.

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