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A Systematics Literature Review of Computational Thinking in Mathematics Education: Benefits and Challenges

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Abstract: Computational thinking (CT) is a leading skill that must be possessed by students and is believed to be one of the keys to future success in a digital society. These skills are often associated with computer science but are now starting to be integrated with other fields of science, including learning mathematics. This literature review aims to study the benefits and challenges of computational thinking (CT) in learning mathematics. This literature review analyzes six references from the Scopus database based on predetermined keywords. Furthermore, content analysis was conducted to see the advantages and challenges of implementing CT in mathematics classes. Based on a literature review, there are several benefits of computational thinking in mathematics class, one of which is that CT improves student performance in learning mathematics; through CT skills, namely generalization and algorithmic thinking, it can help students solve computational problems well, learning that involves CT has the potential to have a positive influence on higher-level thinking skills (logic, algorithmic, and problem-solving views), as well as helping students solve real problems that he found. However, several challenges need to be faced, including the need to pay attention to the duration of learning to improve CT skills, the need for resource readiness which includes teacher competence, teaching materials, and assessment instruments, and teachers need to prepare and design didactic sequences. This literature review is expected to provide educators with an understanding of the extent to which CT can shape mathematics learning to be more creative and meaningful.

Keywords: computational thinking, CT, mathematics education, benefit, challenges, systematic literature review

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INTRODUCTION

The rapid development of technology in the past decade has extensively impacted many sectors, so the education sector must also be prepared to face it. Taking advantage of today's technology is also one of the basic skills that every citizen must have because, with this ability, all needs and problems will be easier to overcome. Therefore, there is no doubt that technical knowledge and skills will become fundamental elements in the future promotion and career development of current students (Rodríguez-Martínez et al., 2020).

As the digital society changes rapidly and improves, computational thinking (CT) skills have emerged as a necessary skill not only for computer scientists and engineers but also for all citizens (Wing, 2006; Wang et al., 2021; Bråting & Kilhamn, 2021). According to Pala & Mıhcı Türker (2021), computational thinking (CT) skills are the primary skills that individuals must possess in the future. In addition, CT is an important skill defined by many academic and professional fields (Wing, 2006),(Wing, 2011). CT also encourages analytical problem-solving and creative expression, the driving force behind new initiatives focused on introducing programming to children (Bers et al., 2022). According to Papert (1996), CT becomes the foundational knowledge necessary to prepare students for the 21st century, regardless of their main field of study or occupation. This explanation about CT convinces us that CT is very much needed in the future and needs to be prepared for our students.

CT includes a series of complex reasoning processes that are held to state and solve problems through computational tools. The ability to systematize and solve problems is considered a skill that all students must develop, along with language, math, and science skills (Barcelos et al., 2018). CT is also associated with improving the ability to reason and solve everyday problems related to almost all areas of learning, including mathematics (Rodríguez-Martínez et al., 2020), because the mathematical ability is often viewed as a core factor in predicting students' ability to learn computer programming and, as such, is required for that field of study.

Jeanette Wing introduced the term computational thinking in 2006 (Wing, 2006). According to her, computational thinking is a fundamental skill for everyone, not only for computer scientists. To read, write, and do arithmetic, we must add computational thinking to each child's analytical abilities. Computational thinking involves solving problems, designing systems, and understanding human behavior by drawing on fundamental computer science concepts. A search related to the term CT was found in an article written by Papert (1996), which states that Computer Science develops students' computational skills and critical thinking and shows them how to create new technologies, not just use them. This foundational knowledge is necessary to prepare students for the 21st century, regardless of their main field of study or work. It shows that CT has a vital role in other disciplines.

In 2011, Wing re-explained the definition of CT, a thought process involved in formulating problems and solutions so that solutions are represented in a form that can be carried out effectively by information processing agents (Wing, 2011). Furthermore, this understanding is simplified by Aho by defining CT as a thought process involved in formulating problems so that the solutions obtained can be represented as computational steps and algorithms (Grover & Pea, 2013). It is in line with the opinion of Khenner (Soboleva et al., 2021), who defines CT as a thought process when formulating problems and solving them and presenting them in a form that can be implemented effectively using information processing tools.

According to Bers et al. (2022), CT includes a broad range of analytical and problem-solving skills, dispositions, habits, and approaches most frequently used in computer science. However, CT can also be utilized in several other contexts. When applied in the classroom, computational thinking enables all students to conceptualize, analyze, and solve complex problems by selecting and implementing appropriate strategies and tools virtually and in the real world (Weintrop et al., 2016). In the computer field, programmers need this skill (Niemel et al., 2017). Based on the understanding, CT is limited to the computer field and can be utilized in many other fields. CT involves creative thinking, which includes how a person sees problems, recognizes patterns, and conceptualizes and plans solutions to problems that can later be executed through computer programs.

Mathematical thinking is very closely related to computational thinking (Barcelos et al., 2018) because solving mathematical problems is a construction process that requires an analytical problem-solving perspective, which is unique and fundamental for programmers or computer scientists (Sung et al., 2017). There is a natural relationship in student development between mathematical thinking and CT, relating the ability to generalize patterns and abstractions (Kong & Kwok, 2021), logical structure, or the ability to model mathematical relationships (Gadanidis, 2017). In addition, according to Kallia et al., (2021), CT and mathematics have many thoughts in common. They both use the concepts of cognition, metacognition, and disposition essential for problem-solving.

Bringing computational tools and practices into the mathematics classroom can give students a more realistic view of the field, better prepare students to pursue careers in the discipline, and help equip students to become smarter STEM citizens of the future (Weintrop et al., 2016). According to Park & Kwon (2022), most studies in mathematics education assume that the essence of CT is problem-solving and abstraction thinking.

CT is a fundamental skill that all individuals in mathematics education must learn. However, CT also requires other cognitive abilities in mathematics, which include decoding and abstraction, algorithms, pattern recognition, iterative thinking, transformation, problem reduction, error prevention and preservation, and intuitive reasoning. This skill is essential in developing problem-solving skills (Subramaniam, 2022). Several literature studies have also been conducted regarding the use of CT, as reported by Saidin et al. (2021), which describe the advantages and challenges of implementing CT in education. In comparison, a literature study Subramaniam (2022) reports on implementing the popular tool used in fostering CT skills in mathematics education. Unlike Saidin et al. (2021), this study was conducted specifically on mathematics education. In addition, the databases used are also different because this research is limited only to the Scopus database. This study also differs from the study by Subramaniam (2022) because, specifically, this study was conducted to see empirically how CT provides benefits and what challenges are faced when implementing CT so that preparation efforts can be made. This study will answer three research question, these are:

1. What are the research trends related to the application of CT in mathematics education?
2. What are the benefits of applying computational thinking in mathematics education?
3. What are the challenges of applying computational thinking in mathematics education?

METHODS

In order to obtain and present a comprehensive picture of the benefits and challenges of learning mathematics using CT, a systematic literature review was carried out with the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines. Systematic Review is a method of collecting data suitable for specific topics that meet predetermined eligibility criteria (Mengist et al., 2020). PRISMA is based on four steps: identification, screening, eligibility, and inclusion. This research stage starts with the formulation of a research problem, followed by the search for relevant research reports to formulate the problems, the evaluation of the studies to determine which studies should inform the review, the analysis and interpretation of research reports, and the presentation of the review (Ahmad., 2021). The stages of the PRISMA procedure carried out in detail can be seen in Figure 1.

Systematic Review Process

This literature review is limited to the Scopus database because it has a good reputation, so it is expected to provide the best picture regarding CT in mathematics classes.

The search was carried out at the identification stage using the keywords Computational Thinking AND Mathematics Education.

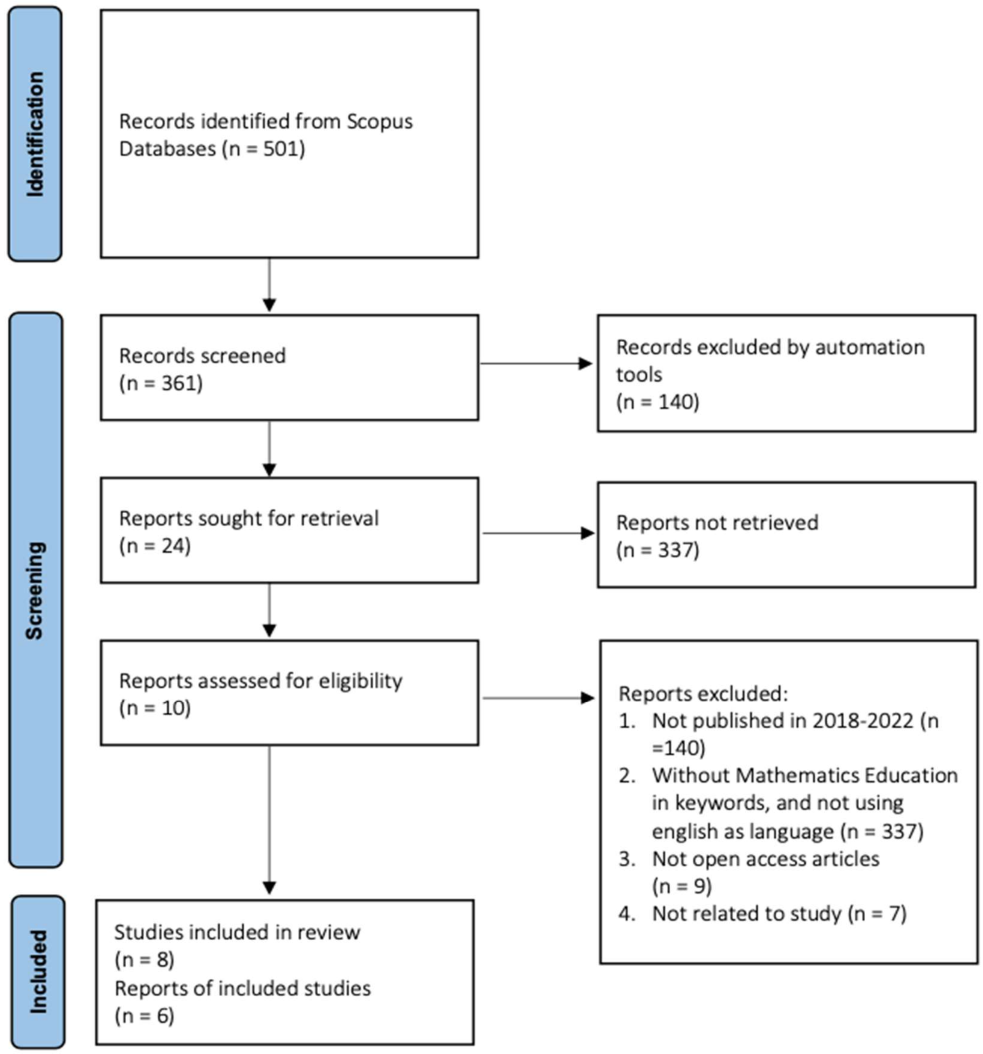

Figure 1. PRISMA diagram flow

The number of articles obtained is 501 articles. By determining the articles to be reviewed only in the last five years, 361 eligible articles were obtained. By limiting the articles that are the result of empirical research, six articles were obtained that met the criteria for review in the final stage. The purpose of the SLR is to analyze the contents of the six articles selected to answer the research questions. Specifically, articles that met the following inclusion criteria were selected:

1. Published in a Scopus-indexed academic journal, Computational Thinking and Mathematical Education.
2. It is an article based on research results, not a literature review.
3. Discuss the use of CT in learning mathematics.
4. Published within the last five years, namely 2018-2022.
5. Articles are open access

RESULTS & DISCUSSION

Results

RQ 1. What are the research trends related to the application of CT in mathematics education?

Visualizing research trends on the use of CT in mathematics classes was carried out using the Vos Viewer. This visualization is done to see the relationship between the keywords used. Of the 24 articles as a population, the following in Figure 2 is a visualization using the Vos Viewer.

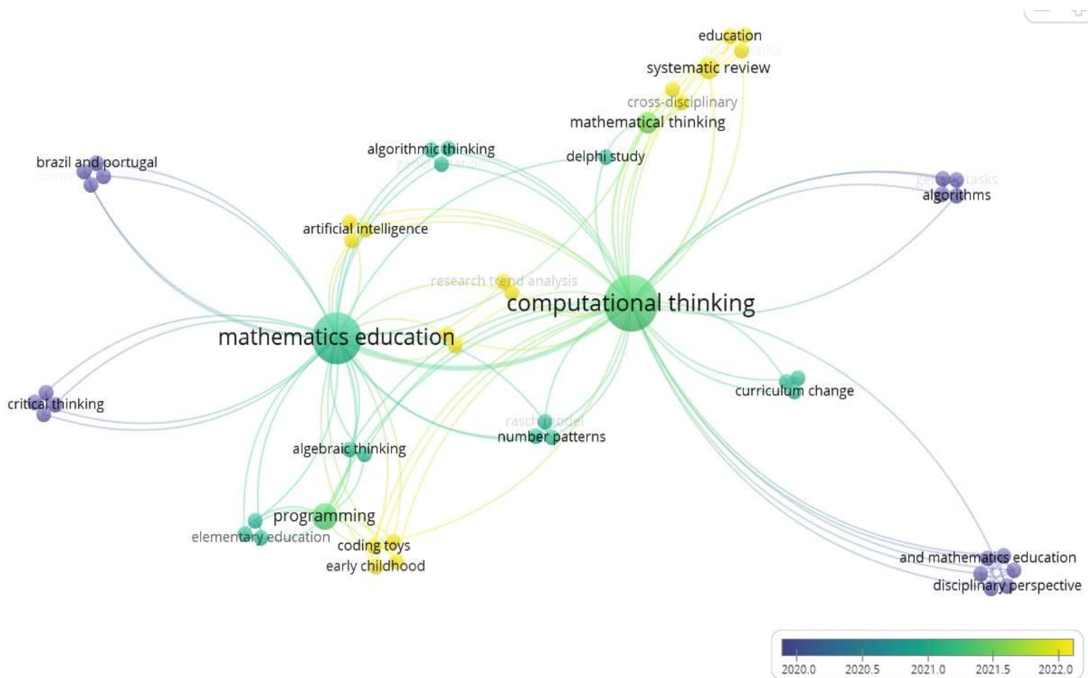

Figure 2. The Keyword Network Visualization of the 24 Processed Articles

Figure 2 depicts search trends over the past five years based on bibliographic data processed by VOSviewer. The colors shown represent the same groups, while the circle's size represents the keywords' popularity. The bigger the circle shown, the more the topic appears in the 24 selected articles. Mathematics education and CT are the most popular keywords because literature studies are aimed at these topics. While related topics between the two can be seen in keywords such as number patterns, algorithm thinking, algebraic thinking, coding toys, curriculum, and programming.

When viewed from the year the article was published, the latest discussion in 2022 includes coding toys for early childhood and artificial intelligence. Meanwhile, older articles in 2020 discuss keywords such as critical thinking and algorithms. This study reviewed six from 24 articles that met the criteria for looking at the benefits and challenges of CT in mathematics classes. The following six articles were reviewed.

Table 1. List of articles that become literature

No	Articles Titles	Country
1.	Chan, S.-W., Looi, C.-K., Ho, W. K., Huang, W., Seow, P., & Wu, L. (2021). *Learning number patterns through computational thinking activities: A Rasch model analysis*. https://doi.org/10.1016/j.heliyon.2021.e07922	Singapore
2.	Van Borkulo, S., Chytas, C., Drijvers, P., Barendsen, E., & Tolboom, J. (2021). Computational Thinking in the Mathematics Classroom: Fostering Algorithmic Thinking and Generalization Skills Using Dynamic Mathematics Software. *ACM International Conference Proceeding Series*. https://doi.org/10.1145/3481312.3481319	Netherland
3.	Pörn, R., Hemmi, K., & Kallio-Kujala, P. (2021). *Inspiring or confusing – A study of Finnish 1–6 teachers' relation to teaching programming*. https://doi.org/10.31129/LUMAT.9.1.1355	Finland
4.	Seckel, M. J., Breda, A., Farsani, D., & Parra, J. (2022). *Reflections of future kindergarten teachers on the design of a mathematical instruction process didactic sequences with the use of robots*. https://doi.org/10.29333/ejmste/12442	Chile
5.	Nordby, S. K., Bjerke, A. H., & Mifsud, L. (2022). Primary Mathematics Teachers' Understanding of Computational Thinking. KI - Kunstliche Intelligenz, 36(1), 35–46. https://doi.org/10.1007/s13218-021-00750-6	Norway
6.	Sunendar, A., Santika, S., Supratman, & Nurkamilah, M. (2020). The Analysis of Mathematics Students' Computational Thinking Ability at Universitas Siliwangi. *Journal of Physics: Conference Series*, *1477*(4). https://doi.org/10.1088/1742-6596/1477/4/042022	Indonesia

RQ 2. What are the benefits of applying computational thinking in mathematics education?

Previous studies reported that CT has many advantages for students to prepare for the future. Four advantages were found based on the advantages viewed from its use in learning mathematics: CT can improve student performance in learning mathematics, assist students in solving computational problems, positively influence higher-order thinking skills, and helps students in solving real problems they encounter. The following explains the advantages of using CT in mathematics classes.

1. CT improves student performance in learning mathematics

The first advantage relates to student performance in learning mathematics. These results are reported based on a study (Chan et al., 2021) in Singapore. The research was conducted using an experimental design with intervention in experimental class learning using CT-infused activities both on- and off-computer. However, in general, the findings do not support existing theories or the hypothesis that integrating CT into learning can result in better mathematics learning. One positive thing that was obtained was that a drastic increase was observed in each of the students from the experimental group. In contrast, there was no natural or extreme increase for students from the control group. This study provides new empirical evidence and practical contributions to embedding CT practice in mathematics classrooms.

2. **CT skills, namely generalization, and algorithmic thinking, can help students solve computational problems well.**

   The next advantage of applying CT is using two important aspects of CT: generalization and algorithmic thinking. These results were reported by (Van Borkulo et al., 2021), who conducted research in the Netherlands. The research he did was using GeoGebra in calculus class. Based on his findings, students with generalization skills and algorithmic thinking can solve them well when faced with computational problems. This study also reported that learning using CT was initially tricky, but after being carried out several times, learning finally became fun. It is confirmed by teachers who experience that students gradually complete assignments more efficiently and enthusiastically.

3. **Learning that involves CT has the potential to positively influence higher-order thinking skills (logic, algorithmic, and problem-solving views)**

   Another advantage of applying CT is related to the potential influence that CT has on other higher-order thinking skills, such as logic, algorithmic, and problem-solving abilities. Pörn et al., (2021) reported this study, which looked at teachers' responses to CT in Finland. Some of the teachers in this study have a broader and deeper view of programming in schools, reflecting knowledge and enthusiasm. Most teachers have a positive attitude toward teaching programming.

4. **CT helps students solve real problems they encounter.**

   Research results related to solving real problems encountered by students were reported by Sunendar et al (2020). This study analyzes the computational thinking abilities of students in Indonesia. One example of a problem solved by students is related to internet quota settings. Students take the initiative to solve problems so they can predict spending on internet quota for one month and make mathematical calculations. After students get the suitable model, they test it to see if it is applied to other situations. It trains computational thinking skills at the abstraction and algorithm development stages.

RQ 3. What are the challenges of applying computational thinking in mathematics education?

Although CT has reported advantages in its application in the classroom, previous studies have also reported that CT requires attention and has challenges because it is not easy to implement. Three challenges were found based on the challenges encountered when learning mathematics, namely the need to pay attention to the duration of learning when implementing CT in class, resource readiness which includes teacher competency, teaching materials, and assessment instruments. The following explains the challenges of using CT in mathematics classes.

1. **It is necessary to pay attention to the duration of learning to improve CT skills.**

   One of the challenges in improving computational thinking skills is the limited duration of learning in class. Computational thinking is a beneficial skill for students, but it takes time and practice to understand and apply it effectively. Many schools need more time to teach these skills, making it difficult for students to get sufficient practice and develop these skills effectively. The time for implementing learning to increase CT needs to be considered because research results (Chan et al., 2021) show that a short time is likely the cause of the discrepancy between previous theories regarding the impact of CT on mathematics learning. The short intervention time indicates no positive impact of CT on students' mathematics learning outcomes. Meanwhile, the research results of Van Borkulo et al (2021) found that sufficient time was needed for students to be able to get to know the software and find specific syntax rules, the use of algorithmic structures in formulas, or commands of an application.

2. **Resource readiness needs, including teacher competence, teaching materials, and assessment instruments.**

Adequate resources are needed if we want to apply CT in math classes. Teacher competence is an essential factor in the successful implementation of CT in the classroom. Teachers must have sufficient knowledge and competence about CT and be able to use it in everyday learning. Teachers must also understand how to present material in an exciting and motivating way for students and be able to provide appropriate support and guidance for students who are studying CT. The proper teaching materials are also necessary. Available teaching materials must be appropriate to students' competence level and provide suitable challenges for them. In addition, teaching materials must provide tangible examples of the application of CT in everyday life so that students can understand the benefits and relevance of this skill.

Appropriate assessment instruments are also necessary for measuring students' progress in learning CT. These can be written tests, presentations, or projects that require students to apply the computational skills they have learned. It is essential to choose an assessment instrument that measures students' abilities holistically, including their ability to apply computational skills in different situations.

Challenges related to teacher readiness and education in implementing CT were reported by the research of Chan et al (2021), Van Borkulo et al (2021), Pörn et al (2021), and Nordby et al (2022). Teacher readiness is also associated with positive attitudes and a broad view of programming by teachers Pörn et al (2021). The development of CT teaching materials and assessment instruments, which are resources for teachers and schools, can later be used as curriculum development materials. These resources provide them with a more precise and concrete set of practices to guide curriculum development and application of CT concepts in the classroom Chan et al (2021).

Overcoming these challenges, reported by Van Borkulo et al (2021), can be done through training and mentoring to use ICT and CT tools so that the implementation of learning in the classroom becomes more effective. Other things that can be done to help teachers integrate CT in the classroom are conducting workshops and designing integrated curricula that have proven useful.

3. **Teachers must prepare and design didactic sequences and consider other aspects because the teaching and learning process is very complex and involves many variables.**

Teachers' challenge in implementing CT is preparing and designing the correct didactic sequence. The teaching and learning process is very complex and involves many variables, so teachers must consider various aspects in designing CT lessons. In addition, the teacher must understand the student's competency level, prepare appropriate materials, and consider how best to present the material to students.

The challenge regarding the need to prepare this didactic sequence was reported by Seckel et al (2022). Of course, preparing a didactic sequence is not easy. In addition to considering mediation criteria (use of resources), other aspects must be considered because the teaching and learning process is very complex and involves many variables.

Discussion

According to theory, the reported advantages of CT are not necessarily in accordance with those found through empirical experience. Theoretically, with CT skills, student performance in learning will be better. It is also in line with the results of Kong & Kwok (2021) research that CT can significantly improve students' understanding of particular mathematical topics. However, the results of Chan et al. (2021) showed no significant difference between students who received learning using CT and students who did not. The possibility of incompatibility with the theory is due to the short time of conducting research in class, so students have yet to be able to utilize CT for their performance in class. The problem of time utilization turns out to be quite a serious challenge because research by Van Borkulo et al (2021) also reports the same thing. Sufficient preparation is needed before the implementation of learning to face these challenges. The duration of CT implementation is also a consideration to obtain good results.

Besides the duration problem, CT can improve student performance in mathematics classes. When viewed personally by students, although performance, in general, did not differ significantly in the study by Chan et al. (2021), several students in the experimental class experienced a drastic increase in performance when compared to the performance of students in the control class. It is in line with the findings of Bers et al., (2022), which state that in the learning process, the practice of CT can encourage students to be actively involved in fostering students' critical aspects.

Another advantage found is that learning involving CT can positively influence higher-order thinking skills (logic, algorithmic, and problem-solving views). The results found by Pörn et al., (2021) support the findings of previous research by Relkin & Bers, (2018), which showed that CT practice could improve children's problem-solving skills, and the findings of Saidin et al. (2021), which states that CT can improve students' critical and analytical thinking skills.

With CT, students can solve the problems they face. Components in CT, namely generalization, and algorithmic thinking, can help students solve computational problems well. Findings by Van Borkulo et al (2021) show that students who have CT skills can solve computational problems using GeoGebra. Sunendar et al. (2020) also reported similar benefits because they can finally solve problems students encounter after being given CT-related supplies. Related to the effectiveness of using internet quota. This advantage is in line with the results of the research found by Weintrop et al., (2016), which stated that with CT, students can deal with practical problems they encounter but still need to be supported by proficient teachers.

The proficient teacher problem turned out to be an essential challenge to solve. Based on the findings in this study, resource problems, one of which is teacher ability, were reported to be a problem in the research of Chan et al (2021), Van Borkulo et al (2021), Pörn et al (2021), and Nordby et al (2022). This finding reinforces previous findings by Saidin et al. (2021), which state that the challenges of implementing CT in the classroom are teachers' understanding of CT, teachers' lack of confidence in using CT, and teachers' lack of skills to implement CT.

Computational thinking is a way of solving problems, designing systems, and understanding human behavior that draws on concepts fundamental to computer science. It involves breaking down complex problems into smaller, more manageable parts and finding ways to solve them through algorithms, data analysis, and other techniques. Here are a few strategies that might help a teacher overcome the challenges they might face in incorporating computational thinking into their classroom: the following steps can be taken, namely: Provide training and available learning resources for teachers. It includes providing professional training, providing access to online learning resources, and providing practical materials to help teachers understand CT principles; Encouraging teachers to keep their knowledge and skills updated by attending seminars and conferences, online courses, or attending additional relevant classes; Facilitating the exchange of ideas and best practices between teachers. It can be done through discussion forums with fellow teachers and by bringing in experts from universities. This practice allows teachers to learn from one another's experiences and develop new ideas; it Encourages teachers to try and develop projects that use CT in the classroom. It can help teachers become more familiar with CT principles and find effective ways to teach them to students; Provide appropriate support and guidance to teachers still learning about CT. It can be done through mentors or consultants who can help teachers develop the right skills and strategies for teaching CT to students. These steps can also be taken to overcome the third challenge in this study, related to the preparation and design of didactic sequences.

Rich et al. (2022) suggest that CT has the potential to allow teachers to produce more complicated math assignments that concentrate on important ideas, anticipate students' thought processes, and contemplate the correlation between math and the way students think. Furthermore, training programs created to assist teachers in using CT as a means to establish and execute math tasks that require high cognitive ability. CT is becoming increasingly critical in math as it prepares students for obstacles and competition in a world that is quickly evolving technologically, where technology is increasingly prevalent in a variety of domains.

CONCLUSION

Based on the literature study that has been done, there are several benefits of computational thinking in mathematics class, namely CT can improve students' mathematics learning achievement; CT skills, namely generalization and algorithmic thinking, can help students solve computational problems well, as well as learning that involves CT has the potential to have a positive influence on higher-order thinking skills (logic, algorithmic, and problem-solving views), as well as helping students solve real problems that he found. However, several challenges need to be faced, including the need to pay attention to the duration of learning to improve CT skills, the need for resource readiness which includes teacher competence, teaching materials, and assessment instruments, and teachers need to prepare and design didactic sequences by considering other aspects of the learning process. Some ways teachers can overcome these challenges include providing training and learning resources available to teachers, encouraging teachers to keep updating their knowledge and skills, facilitating the exchange of ideas and best practices between teachers, and encouraging teachers to try and develop new projects using CT in the classroom, and providing appropriate support and guidance to teachers who are still learning about CT.

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