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Shocking Truths About Three Factors That Influenced Computational Thinking (I Wish I Learned Earlier!)

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Abstract

Problem-solving mastery is deemed a key skill by the year 2025. In the future, the use of automation technology and machines are expected to completely replace existing jobs such as Industrial Revolution 4.0 (IR4.0) and 5G. This situation promotes computational thinking as a 21st-century thinking skill in education. However, research on the factors that influence students' computational thinking is still limited. Accordingly, this study aims to systematically analyze the factors influencing students' computational thinking through a systematic literature review and develop a conceptual framework based on the main factors outlined. A total of three databases such as Scopus, WoS, and ERIC were used in the screening of articles for a period of ten years (2022–2012). The PRISMA model used includes four levels comprising the identification, screening, eligibility, and data entry strategies. A total of 11 articles were identified from 111 articles, which met the specified criteria. The findings of the study showed 19 factors that influenced students' computational thinking. The conceptual framework was developed based on the most dominant approaches such as digital literacy, STEM awareness, and individual factors. This study has implications for teaching practices through the increased reinforcement of training techniques based on more effective computational thinking. In fact, the findings can provide expected data to design interventions that are more suitable for students at school. In addition, further research can also be done through the development of modules to train teachers and students to use computational thinking in the right manner so that thinking exercises can be carried out accordingly.

Keywords: Computational Thinking, Systematic Literature Review, Conceptual Framework, Students, Factors

Introduction

The history of computational thinking can be traced back to the 1950s, but most of the ideas were much older. Nevertheless, the essence of computational thinking was first used by Seymor Papert in 1980. This thinking can be interpreted as a process of building computing power and solutions, whether implemented by humans or machines (Lavigne et al., 2020).

The National Academic Press (2010) stated that computational thinking is a set of computer science concepts, applications, hardware, and skills that help people understand human behavior, solve problems encountered in everyday life, and design systems. Computational thinking is also a skill that can be used to understand how something can happen systematically and logically. Consequently, this helps humans in most problem-solving processes. In this regard, before a problem can be addressed, we need to first understand how it happened and the methods that can be used to solve the problem. The rapid development in the need for new skills necessitates the development of computational thinking and code literacy in student thinking. Evidently, economic and social development will utilize various complex computer technologies such as artificial intelligence, robotics, the Internet of Things (IoT), and analytics in making predictions and daily decisions. For instance, in 2017, the Department of Education in the United States created an initiative to encourage the learning of Computer Science among students. Hence, the White House government has spent nearly 200 million annually to support and ensure that all students in the United States learn Computer Science and acquire computational thinking skills.

In Malaysia, the government has taken the initiative by integrating computational thinking into the Malaysian education syllabus in 2017 through a new curriculum. Computational thinking is taught and applied to six levels of education in Malaysia, namely preschool, primary school, secondary school, higher education institutions, social media users, and elderly communities (Kusnan et al., 2020). The continuation of the development of computational thinking skills helps in producing individuals who are prepared to possess this skill. Computational thinking has also been applied since the beginning of education so that it can help build a foundation for students as well as apply a systematic problem-solving approach and foster higher-level thinking skills. In addition, this is also aimed at preparing students to become competent technology and workforce designers as well as encourage student initiative and innovation. Moreover, the programming approach was found to be the most widely applied computational thinking activity in Malaysia (Kusnan et al., 2020). This conceptual paper has two main objectives: (a) to identify the factors that influence students' computational thinking and (b) to build a conceptual framework based on these key factors.

Research Objectives

This study aims to

- Identify the most factors influencing students’ computational thinking
- Develop a conceptual framework model through the main factors that influence students' computational thinking skills

Methodology

This study uses a systematic literature review method or known as a systematic literature review (SLR), which aims to identify, select, critically evaluate, collect, and analyze data from relevant past studies (Moher et al., 2009). Booth et al (2016) asserted that a systematic literature review is conducted to identify complete knowledge about a study that is to be examined systematically and it can reduce the possibility of biased judgments. The selection of articles is carried out based on several criteria that have been set to ensure that they are of good quality for review purposes. In addition, the process flow diagram for the systematic literature review is contingent on Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA), which includes the four levels of the SLR method, namely identification, screening, eligibility, and inclusion, as suggested by (Menggist et al., 2019). SLR aims to identify, evaluate, and summarize the findings of all relevant individual studies on a given issue to make available evidence more accessible to decision-makers.

Stage One: Search Strategy

In selecting some suitable articles for this study, a systematic review process, namely the identification of keywords using English, was used through similar terms based on previous studies. After all the relevant keywords were decided, the search on the three main journal databases of Scopus, Web of Science (WOS), and ERIC (see Table 1) was carried out. The selection of these three databases was based on the factor coverage, citation data, and metrics. Scopus covers more journals and records than the Web of Science. In terms of citation data, Scopus provides citation data from a wider range of sources than the Web of Science. In terms of metrics, Scopus provides a wider range of metrics to evaluate research impact than the Web of Science.

The use of several databases can lead to accurate results, particularly in producing many articles, compared to using only one database covering various related research fields (Zhao, 2014). All articles related to the approach of computational thinking skills in IPT were viewed systematically to achieve the main goal of the study. The search strategy successfully retrieved 111 articles from all three databases. Several appropriate and related keywords were used to identify the articles relevant to this study, as shown in Table 1. The word AND was used to ensure a more comprehensive range of results. The search using keywords was limited to the year of publication from 2012 to 2022 to gain the latest articles. The ten-year range was chosen because it is deemed sufficient for acquiring the development pattern of publications in computational thinking.

Table 1
Search String

Database	Keywords
Scopus	TITLE-ABS-KEY (factor AND (influence OR predict) AND "computational thinking") AND PUBYEAR > 2011
Web of Science	factor AND (influence OR predict) AND "computational thinking" (All Fields)
ERIC	factor AND (influence OR predict) AND "computational thinking"

Stage Two: Selection Criteria

As for the selection criteria, several levels of article screening have been specified, resulting in the acceptance and rejection criteria. A total of 4 criteria were outlined in this study, particularly in terms of the year of publication, duplication of articles, language, and articles other than journals, as shown in Figure 1. The selected year of publication must be within the most recent ten years to ensure that the search topic is up-to-date, especially in terms of current issues and discussion topics. In addition, article screening was also conducted in the English language only. Figure 1 shows that 3 articles did not meet the main criteria and 39 research articles were removed because those articles were duplicates from the three databases used. As a result, there were 69 articles to be screened based on the next process. In the second screening process, as shown in Table 2, all selected articles must be fully accessible to facilitate the comprehensive and in-depth reading of the studies. The research context used should also involve studies on students' computational thinking.

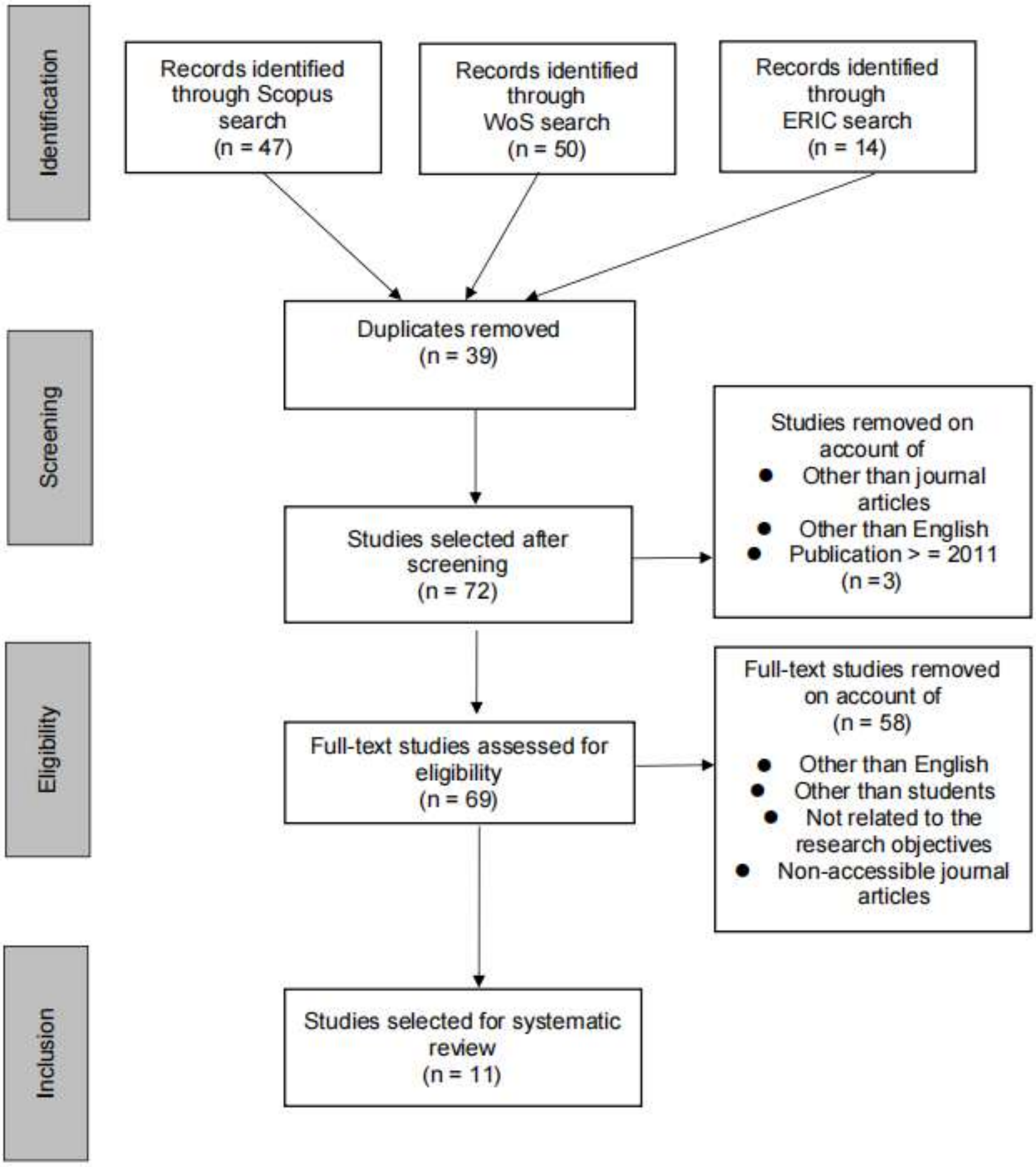

Figure 1: Systematic Literature Review Flow Chart (PRISMA)

Table 2
Inclusion and Exclusion Criteria

Criterion	Inclusion	Exclusion
Language	• English	• Other than English
Publication Year	• 2012-2022	• <= 2011
Document Type	• Journal articles	• Books, book chapters, theses, proceedings, conferences
Field of Article	• Computational thinking In the student context	• Other than computational thinking • Other than the student context
Keyword	• Use of complete keywords	• Use of incomplete keywords
Article	• Accessible	• Non-accessible

Based on Figure 1, a total of 58 articles did not meet the pre-specified criteria upon being carefully screened; thus, only 11 articles were selected and qualified to be used in this study. Table 3 shows the final results for the 11 previous research articles selected in this study, along with the names and countries of the authors. Accordingly, a conceptual framework based on past studies was developed based on the current SLR study.

Table 3
List of Research Articles Based on Suggested Search Criteria

No	Author(s)	Country	Title	SCOPUS	WOS	ERIC
1	Stewart *et al* (2021)	Korea	*Exploring Factors That Influence Computational Thinking Skills in Elementary Students' Collaborative Robotics*	/	/	/
2	Sun *et al* (2021a)	China	*Improving 7th-graders' computational thinking skills through unplugged programming activities: A study on the influence of multiple factors*	/	/	
3	Sun *et al* (2021b)	China	*Which way of design programming activities is more effective to promote K-12 students' computational thinking skills? A meta-analysis*	/	/	/
4	Sun *et al* (2021c)	China	*Educational games promote the development of students' computational thinking: a meta-analytic review*	/	/	
5	Gong *et al* (2020)	USA	*Exploring the key influencing factors on college students' computational thinking skills through flipped-classroom instruction*	/	/	
6	Sun *et al* (2020)	China	*STEM learning attitude predicts computational thinking skills among primary school students*	/		/
7	Valovicova	Slovakia	*Enhancing Computational Thinking through*	/		

	et al (2020)		*Interdisciplinary STEAM Activities Using Tablets*		
8	Ridvan Ata *et al* (2020)	Turkey	*Understanding predictor effects of computational thinking skills and media and technology use and attitudes of pre-service teachers for STEM awareness*	/	
9	Iwata *et al* (2020)	Finland	*Exploring Potentials and Challenges to Develop Twenty-First Century Skills and Computational Thinking in K-12 Maker Education*	/	
10	Chou (2019)	Taiwan	*Using ScratchJr to Foster Young Children's Computational Thinking Competence: A Case Study in a Third-Grade Computer Class*	/	
11	Pugnali *et al* (2017)	USA	*The Impact of User Interface on Young Children's Computational Thinking*		/

Findings and Discussion

The main objectives of this study are to (a) identify the factors that influence the computational thinking of students and (b) develop a conceptual framework based on the factors that often influence the students' computational thinking.

Findings for the first Objective

The findings for the first objective show 11 articles that met all the criteria based on the PRISMA flowchart guide. From the 11 articles selected, there were 19 factors that directly or indirectly influenced students' computational thinking. As shown in Table 5, the factors include appropriate curriculum, selection of learning methods or strategies, problem-solving skills, perception of efficiency or competence, motivation to learn, learning enjoyment, teamwork practices or group roles, parent involvement, unplugged programming activities, performance in Mathematics, awareness of Science, Technology, Engineering, Mathematics (STEM) subjects, and programming learning, among others.

Nevertheless, a study by Fahmi et al (2021) reported that these factors can be grouped and divided into several variables based on several dimensions of categories that have been examined through prior review as shown in Table 4, namely individual factors, social culture, learning environment, digital literacy, and student achievement. On the other hand, the current study lists eight categories of variables in which three new variables were added, namely curriculum structure, problem-solving skills, STEM subject awareness, and others, as demonstrated in Table 4. The findings also showed three main variables that were most frequently studied by researchers, namely digital literacy, STEM subject awareness, and individual factors, as depicted in Table 5. Therefore, the three main variables were used to form a conceptual framework for the factors that influence students' computational thinking in the current study.

Table 4
Variable and dimensional analysis mapping

Variable	Dimension
• **Individual factors**	• Self-efficacy • Student perception and motivation
• **Learning environment**	• Facilities and infrastructure • Educational materials and tools • Teacher involvement
• **Social culture**	• Family support • Language and social culture
• **Digital literacy**	• Learning skills • Literacy skills

Digital Literacy

To date, schools and educational institutions have been advised to implement innovative teaching methods based on the curriculum set by the Ministry. In this regard, new media literacy skills and diverse information technology learning environments have influenced students' computational thinking. For example, learning through programming project methods using the ScratchJr application can enlighten students on analytical analysis skills and further influence students' computational thinking (Chou, 2019). Furthermore, Sun et al (2021b) also asserted that the teaching design of programming code is carefully planned so that the use of technology can be used to encourage students' computational thinking skills more vigorously. In this vein, Sun et al (2021c) suggested that educational game process skills are planned rationally and that technology is fully used to develop students' computational thinking skills. In essence, the findings of this study play a crucial role in promoting the improvement of computational thinking skills. According to Pugnali et al (2017), students can learn computational thinking skills when equipped with the right tools in line with the development and teaching of the curriculum, such as the KIBO Robotics tool and ScratchJr iPad graphics application that allow students to learn basic computational thinking skills. Next, learning methods with new media methods, particularly through flipped classrooms, have also been widely used and have influenced students' computational thinking (Gong et al., 2020). Moreover, Iwata et al (2020) in their study showed that digital fabrication activities taught in schools can provide learning opportunities for 21st-century skills and computational thinking practices to students.

Awareness of STEM Subjects

Technology is one of the elements in STEM, which stands for Science, Technology, Engineering, and Mathematics in which learning is anticipated to be more meaningful to students because it applies various learning methods. STEM also emphasizes the 4C elements in 21st-century learning, comprising collaboration, creativity, communication, and critical thinking, which are all important for future career skills (Ministry of Education Malaysia, 2018). The findings reported by Ata et al (2020) showed the relationships between computational thinking, media and technology use, and attitudes and awareness of STEM subjects. Moreover, the level of students' awareness and knowledge of STEM subjects might also influence their computational thinking. As evidenced by Sun et al (2020), students' attitudes or learning methods toward STEM subjects can significantly influence their computational thinking skills. Since Mathematics is one of the STEM elements, Sun et al (2021a) reported that students' performance in Mathematics and prior programming experience can influence their computational thinking skills, and the study also found consistency before and after the research intervention was carried out.

Table 5
List of Articles Based on the Factors Influencing Students' Computational Thinking

No.	Factors/Authors	Stewart *et al* (2021)	Sun *et al* (2021a)	Sun *et al* (2021b)	Sun *et al* (2021c)	Gong *et al* (2020)	Sun *et al* (2020)	Valovicova *et al* (2020)	Ridvan Ata *et al* (2020)	Iwata *et al* (2020)	Chou (2019)	Pugnali *et al* (2017)	Total
	CURRICULUM STRUCTURE												
1	Appropriate curriculum											1	1
	PROBLEM-SOLVING												
2	The use of technology in the problem-solving process							1					1
3	Problem-solving skills	1											1
	INDIVIDUAL FACTORS												
4	Efficiency or competence	1											1
5	*Learning motivation*	1				1							2
6	Learning *enjoyment*	1											1
	PEER INTERACTION												
7	Feeling *toward group work*	1											1
8	*Student-to-student relationship*					1							1
	SOCIAL CULTURE												
9	Parent involvement										1		1
	LEARNING ENVIRONMENT												
10	*Unplugged programming activities*		1										1

	STEM AWARENESS											
11	Performance in Mathematics	1										1
12	Awareness of STEM subjects							1				1
13	Learning attitude towards STEM					1						1
	DIGITAL LITERACY											
14	Digital fabrication activities								1			1
15	Programming projects									1		1
16	*Programming instructional design*		1									1
17	Educational game			1								1
18	Use of appropriate technology learning tools										1	1
19	*Learning strategies* using flipped-classrooms				1							1

Individual Factors

According to Fahmi et al (2021), the variable of individual factors is formed through two dimensions that consist of self-efficacy as well as student perception and motivation. Evidently, student self-efficacy (Afshari et al., 2013) and perception in implementing programming exercises and lessons (Shamaki, 2015) were found to be able to influence students' interest in technology and computer science subjects. This also supports the study by Stewart et al (2021), which demonstrated significant relationships between efficiency or competence, student-oriented attitude to group work, learning enjoyment, learning motivation, and problem-solving skills with students' computational thinking. Stewart et al. (2021) also suggested that efforts are made to develop perceptions of competence and self-confidence among students so that their psychology can be prioritized for a collaborative learning environment where computational thinking skills serve as the desired outcome.

Findings for the Second Objective

The second objective of the SLR study is to develop a conceptual framework model through the main factors that influence students' computational thinking skills. As a result, three main components were selected after examining the similarity of meaning and the frequency of their use in previous studies pertaining to the factors influencing computational skills, namely digital literacy, awareness of STEM subjects, and individual factors.

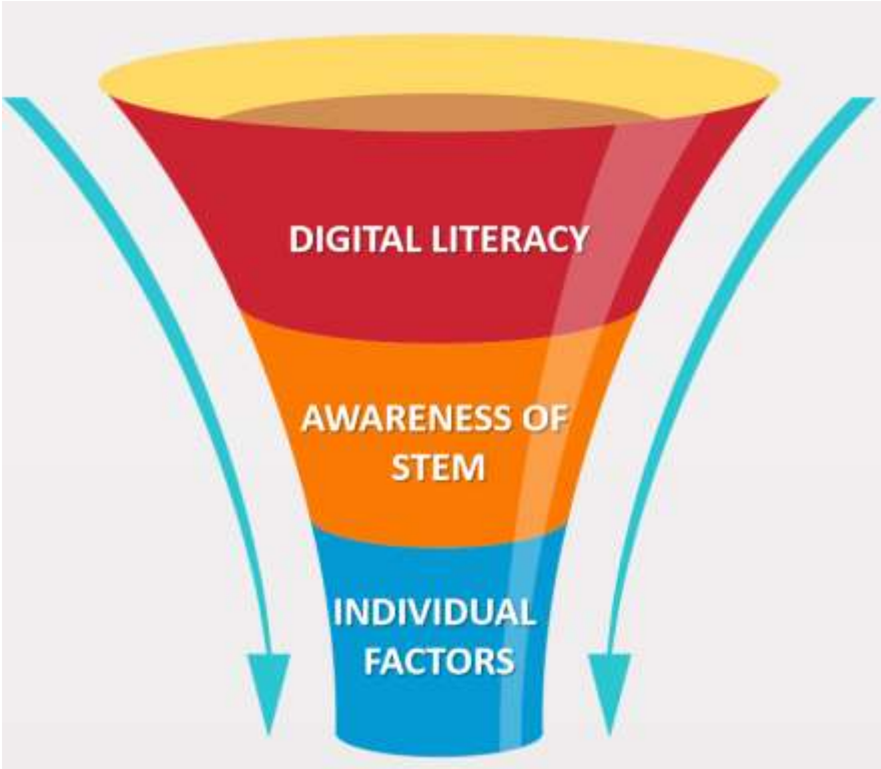

Figure 2: Conceptual framework of the factors influencing students' computational thinking

Figure 2 shows digital literacy where the skill of exploring new media technology is most often used in the literature, with a total of six articles. Previous studies also showed the awareness of STEM subjects with three articles, followed by individual factors with three articles. In Malaysia, the concept of integrating computational thinking at the Malaysian education system level is still new. In fact, its implementation started in 2017 in primary and secondary school institutions as a result of a new curriculum review of the Primary School Standard Curriculum (KSSR) and the Secondary School Standard Curriculum (KSSM) in the subjects of Fundamentals of Computer Science (ASK) and Computer Science (SK).

Discussion

Computational thinking is one of the problem-solving methods that involve decomposition, pattern recognition, algorithms, and generalization techniques (Csizmadia et al., 2015). Computational thinking skills are essential for all students to help them identify problems, break questions into small parts that are easy to solve, and subsequently solve the problem using a planned algorithm (Computational Thinking Skill Module IPGM, 2017). In essence, the skills are considered a special form of thinking that includes three important aspects in solving problems in the real world, namely identifying problems, designing systems that can be used by the community, and understanding human behavior (Kumar et al., 2020).

The first factor that influences computational thinking (CT) is digital literacy (DL). Digital literacy facilitates the exploration of new media technologies and helps influence the level of students' computational thinking. If students have these skills, then they will be more confident and readier to take on new challenges in the rapidly developing world of technology. As the world is moving towards 21st-century learning methods, students will always be exposed to new devices and software applications in learning sessions or in their employment. In addition, nowadays, most of the daily problems or user needs utilize technology as a solution to every problem. All problems can be solved innovatively and creatively using technology because it does not consume a lot of time, money, and energy. In the future, we need someone who not only knows how to use a tool or a technology but also understands the technology well.

Next, the second factor includes the awareness of STEM subjects, which helps influence the level of students' computational thinking and is very important in shaping students to become innovators in the future. Essentially, its integrated learning approach looks at real-world contexts, open-ended exploration, and hands-on learning methods. This can help students integrate STEM concepts to understand and solve problems creatively and innovatively. Problem-solving skills have a direct relationship with computational thinking skills. Computational thinking is one of the important 21st-century thinking skills for the next generation to face the challenges of the industrial revolution 4.0 (IR 4.0) (Chong et al., 2019).

The Future of Jobs through a survey of the world economic forum (2020) has reported that the demand for problem-solving skills in the marketability of the workforce is at the highest ranking. The boom in information technology has led to computational thinking as a new prerequisite in education and the job market. Accordingly, awareness of STEM subjects that lead to problem-solving skills is one of the main components that is needed by every student in order to influence their computational thinking. This has also helped students to be able to identify problems, plan, design, and implement work in a better and more organized way.

The third factor is an individual factor involving self-efficacy that can help improve the level of students' computational thinking. The very rapid development of globalization and digitalization with the need to improve one's ability with skills in the 21st century includes several aspects such as the ability to solve problems, think critically, collaborate, and so on. If the problems faced by a person become more complicated and complex, then there is a need to find a better solution to the problem-solving techniques obtained. As such, critical thinking is required in drafting and analyzing the amount of data and information obtained. The overflow of data and information that is not analyzed critically and managed well will increase the complexity of solving a problem. Critical thinking is also required in selecting relevant and appropriate data to solve increasingly complex problems. Meanwhile, the ability to collaborate or work in a group is required in the next action, which is attributed to problems that are increasingly complex and require various personal skills or individual factors to solve.

Since human skills often have limited expertise in only one field, they require problem-solving collaboration in such a case that the involvement of experts in other fields is warranted. Nevertheless, involvement in collaboration is not easy if a student does not have good competence and problem-solving ability. Therefore, self-efficacy or individual factors are necessary for developing mutual understanding and avoiding irrelevant actions during problem-solving or inconsistent understanding among group members. The implementation of collaborative relationships or group work can provide benefits to students such as increasing their efficiency, motivation to learn, learning enjoyment, and social skills. In this vein, the ability of students to be tolerant, have an open attitude in solving problems, and possess resistance or strong work pressure are among the skills needed in this digital era because a person's motivation and seriousness will decrease if an activity is not enjoyable.

Conclusion

The findings of this SLR study have shown three main factors that influence computational thinking, namely digital literacy, awareness of STEM subjects, and individual factors. In addition, a conceptual framework of the factors influencing students' computational thinking has been developed. The implications of this study are expected to improve teaching practices by strengthening training techniques based on computational thinking more effectively. In fact, the findings of this study also help provide expected data to design interventions that are more suitable for students at school, especially in the aspect of developing computational thinking skills.

Research suggestions can be made through a review of the implementation of teaching activities that involve computational thinking, especially among rural students. This is because internet access and infrastructure equipment or ICT hardware/software are very limited in rural areas and outdated pedagogical teaching methods will affect students' computational thinking. Therefore, policymakers in Malaysia should look at the method of unplugged programming activities that have been implemented in China as one of the alternatives for encouraging computational thinking among Malaysian students. With regard to the field of psychometrics, considerations on the aspects of the learning environment, especially those involving robotic activities, should be refined because they are expected to lead to a great influence of computational thinking skills on students. In addition to analytical analysis skills, student involvement in robotics activities can also help them find intrinsic satisfaction or certain psychological satisfaction (Stewart et al., 2021). Therefore, an effort should be implemented in developing the perception of competence and self-confidence in students from the primary school level so that there is a relationship that involves the learning environment that psychologically leads to the encouragement of computational thinking among students. This study also suggests that primary school students be exposed to team learning that involves interaction, which should be outlined in the education policy.

In addition, teachers are advised to identify and use various teaching techniques to improve students' computational thinking. Therefore, further research needs to be carried out to identify the difference in flipped classroom instructions such as learning outside and inside the classroom. Teachers, teaching staff, and module developers for teaching staff also need to encourage activities that involve communication between students, learning motivation, and student learning methods when making analysis, design, development, implementation, and evaluation in the process and subsequently observe how they impact students' computational thinking. Educational opportunities for parents, especially regarding the concept of computational thinking, must be considered because this concept is still new to parents and children. In fact, the role of parents is important in encouraging students' computational thinking. Ultimately, computational thinking skills are believed to be able to influence research in all disciplines and have the potential to drive student achievement, especially in the STEM field. In essence, this effort is important to ensure that students in Malaysia have competent knowledge and skills to enable them to compete at the global level.

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