Malaysian Journal of Social Sciences and Humanities (MJSSH), Volume 6, Issue 3, (page 272 - 289), 2021
DOI: https://doi.org/10.47405/mjssh.v6i3.706

Malaysian Journal of Social Sciences and Humanities (MJSSH)

Volume 6, Issue 3, March 2021

e-ISSN : 2504-8562

Journal home page:
www.msocialsciences.com

The Big Why of Implementing Computational Thinking in STEM Education: A Systematic Literature Review

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Abstract

Computational Thinking (CT) has been increasingly embraced as a reformation in STEM education. This paper discusses why the implementation of CT would have a considerable effect on STEM education. The first objective of this systematic literature review is to identify the subjects that incorporate the most elements of CT in STEM education. Secondly, it aims to provide an overview of CT practices in the classrooms. Finally, the major findings of this study seek to discuss the benefits and challenges of the use of CT in STEM education. Fifteen articles were methodically selected from Scopus, Web of Science, Dimensions, and Google Scholar databases as the relevant studies to be discussed in this systematic study, based on the PRISMA Statement (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) review technique. This review identifies current research gaps and directions for the practice and implementation of CT in STEM education. Further analysis of the articles has contributed to a conclusion that CT has become more widespread and multi-disciplinary and seems to have propagated improvements in STEM education. Still, a new study is required, especially on long-term implications.

Keywords: STEM education, computational thinking, systematic literature review

Introduction

Over half a century ago, people laughed at Seymour Papert when he triggered ideas to use computers as learning tools to stimulate classroom creativity and innovation. In the 1980s, Papert broadened his ideas by bringing the fundamental idea of CT to the world. Papert focused on two dimensions of CT: firstly, how to use technology to develop new knowledge; and secondly, how to utilize computers to build understanding in education. Later on, Wing (2006), proposed a revised approach to CT in her papers. Wing stated that CT is not the act of thinking like a computer, but an approach to solve problems by using the concepts and ideas of computer science. CT has attracted significant interests in science, technology, engineering, and mathematics (STEM) education after Wing laid it forward. Henceforth, Wing (2016), defined six major steps for developing strategies in the problem-solving process: determining the problem; sensibly organizing and analyzing data; representing data through abstractions; automating solutions through algorithmic thinking; identifying, analyzing and implementing possible solutions to achieve the most efficient and effective combination of steps and resources; and generalizing and transferring solutions to a wide variety of problems. All six strategies are widely used in computer science and can also be used to solve all sorts of other problems. These strategies could be presented in a way that could be interpreted by the computer and the user, or both. By applying these strategies in the classroom, students would develop and adapt a new way of thinking. This statement is supported by a previous study conducted by Liu & Wang (2010), where computational thinking is asserted as a hybrid

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of other ways of thinking, such as abstract thinking, logical thinking, modelling thinking, and constructive thinking. Liu & Wang refined the idea of the six strategies of CT by developing a problem-solving model that shows the connection between critical thinking and computational thinking. At the same time, existing knowledge forms the relationship between them that can be applied to solve problems. Through integrating these three elements: knowledge, computational thinking, and critical thinking to solve problems, students may seek appropriate solutions to any problems found.

The growth of computational thinking and problem-solving skills are the most critical goals in the sense of STEM education. Embedding the problem-solving model into STEM education may provide a meaningful way to educate new generations of students who will become skilled at using technologies and build them. Students of today will then go on to lead a life greatly influenced by technologies, and most will work in fields that include or are affected by computing (Barr & Stephenson, 2011). Despite this, all significant elements should be identified, including the appropriate type of practices to trigger CT in the students and the limitations that may be present in the process. Thus, there is a need to introduce CT to students in-depth, especially in STEM education, earlier and more often.

Therefore, a systematic review of the implementation of CT in STEM education is required to understand why it is essential to include CT in STEM education by looking deeply at the subject and practices used in its implementation. This systematic literature review will further explore the importance of CT in STEM education, along with examples of CT activities carried out by previous researchers.

Research Questions

RQ1: What subjects have used CT in STEM education?
RQ2: What activities have been used to develop CT in STEM education?
RQ3: What are the benefits of applying CT in STEM education?
RQ4: What difficulties exist in introducing CT in STEM education?

Methodology

In this section, the method used to retrieve the articles related to CT in STEM education is discussed. The reviewers used the technique called PRISMA where a few database resources (Scopus, Science Direct, Google Scholar and Dimensions) are used to run the systematic review, while observing the eligibility and exclusion criteria, steps of the review process (identification, screening, eligibility), and data abstraction and analysis. Systematic literature reviews involve reviewing documents according to clearly formulated questions and using systematic and explicit methods to select and critically appraise relevant research (Higgins & Green, 2008; Petticrew & Roberts, 2002).

PRISMA

The review was guided by the PRISMA Statement (Preferred Reporting Items for Systematic reviews and Meta-Analyses), and by referring to the PRISMA checklist, reviewers follow the systematic review protocol by completing all the sections; title, abstract, introduction, methods, results, discussion and main findings from the articles. The PRISMA gives specific features, which is defining clear research questions that cater for systematic studies; identifying requirements for inclusion and exclusion; and attempting to analyse massive scientific literature databases in a specified period of time frame (Moher et al., 2014). The PRISMA Statement allows for a rigorous search of terms related to the integration of CT in STEM education. The methodology can be used for obtaining the implementation of CT that can be used in a fascinating variety of disciplines.

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Resources

The review focused on four primary sources of publications: Scopus, Science Direct, Google Scholar, and Dimensions. Scopus contains three types of sources: book series, journals, and trade papers. All articles included in the Scopus database are reviewed annually to ensure the retention of high-quality standards (Kulkarni et al., 2009). Next, Science Direct is a website that provides access to an extensive scientific and medical research database based on subscriptions. It focuses on empowering users to stay ahead in the field, discover more breakthroughs, accelerate the pace of discovery, and manage research within the research world (Harnegie, 2013). For all newbies scholars, Google Scholar is the most popular database search engines (Jean-François et al., 2013; Mayr & Walter, 2007). Google Scholar is a freely accessible web search engine that indexes academic literature's full text and metadata across a range of publication formats and disciplines. Dimensions comprises over 100 million publications ranging from articles published in scholarly journals, books, and chapters in books to preprints and conference proceedings (Thelwall, 2018). All Dimensions database publications are contextualized with related data sets, funding, articles, patents, clinical trials, and policy documents.

Eligibility and exclusion criteria

Several conditions for eligibility and exclusion were identified. First and foremost, a set of literature was chosen. To ensure the articles chosen are in the STEM education field, a search string was used for the systematic review process. Each database used a specific search string, as shown in Table 1.

Table 1: Keywords and search strings

Databases	Keywords used
Scopus	TITLE-ABS-KEY ("computational thinking" AND "STEM EDUCAT*")
Science Direct	Title, abstract, keywords: computational thinking AND STEM education
Google Scholar	allintitle: ("computational thinking") ("STEM Education*")
Dimensions	Article Publication Type: computational thinking AND STEM education

Systematic Review Process

The systematic review process involved four phases. Keywords for the search process were identified in the first phase. Based on previous findings and thesaurus, similar keywords related to CT and STEM education were used. At this phase, some duplicated articles have been removed after a stringent screening.

The second phase is the screening process. At this phase, a total of 7,331 articles were excluded from the 7,393 publications chosen for the next screening. The third phase is eligibility, where the whole documents were accessed. Upon careful examination, a total of 62 articles were omitted, some of which did not focus on STEM education at the school level.

Only journal articles with empirical findings were picked, by excluding all articles in review, book chapters, and conference proceedings. Secondly, the search strategies excluded non-English articles and concentrated exclusively on articles published in English to avoid misunderstanding and translation issues. Thirdly, as a concern to the timeline, a five years period has been designated (between 2015 and 2019), a suitable period of time to see research and related publications development. As the review process focused on the application of CT in STEM education, articles indexed in educational social science-based indexes were solely selected. Lastly, in line with the objective, which focuses on CT in STEM education, only articles concentrated on STEM subjects in the school environment were chosen, as shown in Table 2.

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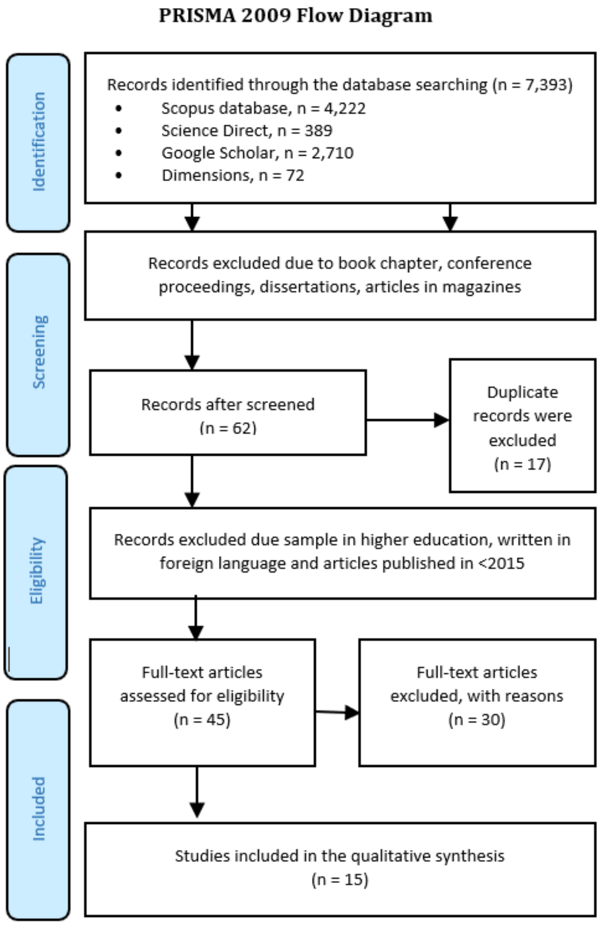
Table 2: The inclusion and exclusion criteria

Criteria	Eligibility	Exclusion
Search string in	Title and abstract only	In full text
Literature type	Articles	Proceedings, book chapters
Language	English	Other than English
Time span	2015 - 2019	Article publish before 2015
Grade of participants in study	Primary level, elementary level, middle school, secondary school only	Higher education
Subjects	STEM subjects	Non-STEM subjects

This final phase of the study resulted in 15 articles that were used for the qualitative analysis, as shown in Figure 1. All four phases in this systematic review process are summarized by a flow diagram detailing the application of PRISMA to the qualitative synthesis of published studies for computational thinking in STEM education.

Figure 1: A flow diagram detailing the application of PRISMA to the qualitative synthesis of published studies for computational thinking in STEM education. Adapted from Moher et al. (2009).



Data abstraction and analysis

The identified papers were then evaluated and analyzed. The focus was on specific articles related to the issues of study. Data were gathered through reading the abstracts; then, the entire articles were analyzed

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in-depth to identify suitable themes and sub-themes. Each article's abstract was then reviewed and judged for its theoretical robustness and contribution to the current discussion. A qualitative analysis was performed using the method of content analysis to identify themes related to the implementation of CT in STEM education. The authors then organized sub-themes around the themes established by categories. The articles listed have also been demographically checked.

Result

As part of the systematic search, more than seven thousand published studies were identified along with a final set of 15 qualitative synthesis studies (details for each review are presented in Tables 4). Table 4 provides a narrative summary to guide the reader through studies on features, designs, and main findings of the study (four main themes).

The articles were evaluated to address several points: the subjects involved, the activities used in practising CT, and the benefits and limitations of implementing CT in STEM education across the world. Three studies are from the European continent, eight studies from the North American continent, three studies from the Asian continent, and one study was from the Australian continent, as shown in Table 3.

Table 3: Selected articles summarize by continents and year of publication

Continent	Author(s), year of publication
Europe	Bermúdez, Casado, Fernández, Guijarro, & Olivas, 2019; Città et al., 2019; Martín-Ramos et al., 2017a
North America	Basu et al., 2016; Eguchi, 2016; Jaipal-Jamani & Angeli, 2016; J. Leonard et al., 2016, 2017; Serrano Pérez & Juárez López, 2018; Taylor & Baek, 2019; Tran, 2018
Asia	Kong & Lao, 2017; Kopcha et al., 2017; Yu & Guo, 2018
Australia	Miller, 2019

Furthermore, eight studies applied a quantitative approach while three studies used the qualitative analytic methods. The remaining four studies employed a mixed methods (qualitative and quantitative) approach. Regarding years of publication, four articles were published in 2019, three articles were published in 2018, four studies were published in 2017, and four studies were published in 2016. The analyses tabulated in this section were fixated on four main themes, including the subjects that applied CT, the activities used to apply CT in STEM education, the benefits of applying CT, and the difficulties in applying CT. They are presented as a rigorous analysis of current CT practices in STEM classrooms (see Table 4). A thorough discussion of the findings in Table 4 would be described in the following section. The study reviewed the research design and the main findings for the implementation of CT in STEM education to answer the research questions mentioned in the preceding section.

Table 4: A narrative summary to guide the reader through studies based on research questions

Author(s) and year	Subjects involved	Activities used to apply CT	Benefits of applying CT	Difficulties exists in in applying CT
Bermúdez et al., 2019	Computer programming and robotics	Game-based learning, drone programming competition	• An ideal way to incorporate various types of computer coding and aerial robotics in secondary schools. • CT skills can also be used in engineering studies to endorse artificial intelligence fields.	The computational power is necessary to finish the simulation.
Città et al., 2019	Computers	Unplugged learning activities, game-based tasks	• The algorithm's concept is also introduced to children referring to real-life examples such as dressing orders pattern, food preparation, and construction activities. • It can improve reasoning skills, mental rotation, and mathematical ability.	The hurdle of thought process involving problem-solving as instruction code sequences and the importance of specific instructions is also clarified.
Miller, 2019	Mathematics	Coding	• Students collaborate to fix their codes. • It will be able to get a more genuine and implemented approach to teaching mathematics to primary school students, promoting STEM interest.	• The willingness of educators to 'see' mathematics in coding classrooms needs to be upgraded. • School systems have made little effort to provide teachers an opportunity to grow and promote the implementation of emerging technology and computer-based skills.
Taylor & Baek, 2019	Robotics	Robotics music composing project	• Maximizing the current lease of teamwork robotics projects by recognizing strategies to enable all group students to contribute similarly. • Supporting one another's student achievement in the task and improving attitudes towards the team project.	• The standards for best practice are not explicitly outlined. • Although appointed fixed roles enhance student value in robotic performance scores, CT skills, and learning motivation for computer programming, they do not guarantee that all students are equally involved.

Serrano Pérez & Juárez López, 2018	STEM education	Robot-based educational activities	• Allowed students to develop their creativity and sensory imagination using a 3D geometric ecosystem. • It can significantly raise knowledge and develop student technical skills, including the use of circuit boards and sensors, three-dimensional models, studying with software animations and embedded systems, and so on.	• Students make theoretical calculations without going further than the principle in the classroom. • These experience-based computing methods are typically is not enough to attract students to engineering, and many of them eventually decline to the social world. • The expenses for the development of the educational robot are too high. • Students have less experience with the use of electronic devices, such as installing electronic training kits that need soldering and electronic welding components on a circuit board.
Tran, 2018	Computer science	• Coding Unplugged activities	• Rises in the implementation of the real world of coding concepts. • Encourage and scaffold the understanding of introductory CS ideas among elementary-age students. • Improved problem-solving skills and built interest in CS in everyday life. • Students engaged in and driven by activities and managed to learn to operate collaboratively in groups by posing questions regarding unplugged activities.	• Restrictions such as access to technology, source materials, duration, student demographic data, etc. should be tolerant of processes at the micro and macro level to cater to the increase in CT in schools. • Teachers may be less content-based knowledge, skills, and strategies that merge virtual and analogue parts to expose and enhance student critical thinking abilities.

Yu & Guo, 2018	Computer science	"STEM+ Computational Thinking" model workshop	• The students' desire to study computer science increases dramatically. • Students think like computer scientists through the implementation of the CT model. • Encourage students as rigorously as a professional to solve issues, improve critical thinking, improve technical abilities, innovation capacity and creative ability, self-regulation, and co-regulation in students.	There are some issues, such as technology challenges, creative capabilities, discovering research issues, and insufficient time for classrooms.
Kong & Lao, 2017	Robotics	• Programming robotics	• Proposed innovative problem-solvers to nurture the next generation. • It helps students' ability to deduce causality. • By involving students in problem-solving activities, informal or non-formal programmable robotics, student science knowledge must be applied.	• Teachers have to direct students to learn with codes from the beginning of the process, as students are not prepared to generalize a pattern to the stage of development of coding. • Students need several attempts, for instance, to adjust the techniques before they can program the model as per the guidelines.
Kopcha et al., 2017	Robotics	Robotics	• Students can strengthen the higher-order thinking skills and problem-solving abilities. • Involve students' indirect knowledge. • Students will be introduced to deep science and mathematical reasoning. • Knowledge and skills gained during training with robotics shifted after training has been finished. • Students enjoy the problem-solving part of the syllabus when working together to solve the problem.	• During the assessment, most teachers and students had little to no previous experience in coding robotics and incorporated them into the classroom. • Teachers found the content and pedagogy are the trickiest. • No adequate time for completing the courses.

J. Leonard et al., 2017	Robotics	• Robotics Game design	• Students are capable of engaging across four levels of the revised evolution of learning: sequence, causal inference, proportional reasoning, and conditional reasoning. • Students participated in intermediate CT activities during robotics as they accomplished different challenges. • Students showed high CT rates in robotics classes.	• Game design was harder to learn and facilitate by teachers. • Students struggled to encode and debug but had minimal use of game design with only society and blended robotics and computer design perspectives.
Martín-Ramos et al., 2017	Programming	Hands-on projects	• Students are driven to step by step to increase complexity. • Students' interest in computer technology has boosted. • Provide a meaningful learning experience for the students.	• Most students were not exposed to any platform of embedded systems at all. • The cost of microcontrollers and programming tools are expensive.
Jaipal-Jamani & Angeli, 2016	Science, robotics	• Robotics intervention	• Robotic learning experiences will enhance the confidence and interest of students in STEM education. • By improved self-efficacy for the use of robotics in the science curricula, a better comprehension of the concepts of basic science and computational thinking.	Pedagogical factors such as classroom management, evaluation methods, differentiation for learning needs, technical skills, and logistics, such as access to computers, need to be considered while executing the robotics. This information may have affected the stated self-efficacy.
Basu et al., 2016	Science, biology, mathematics	Constructing simulation models	• The participation of students in the development of computer conceptual design activities is very directly associated with the growth of the CT skills of students. • Programming as a tool of inquiry to create models of scientific phenomena, which in turn allows students to gain a deep understanding of applicable science concepts.	• For an interpretation of scientific phenomena, students need to organize their reasonings on observations or data comparisons with the results of findings. • Planning experiments and organized practice are methods that are complicated for students. • Students had trouble understanding the meaning and use of visual primitives and computational constructs.

Eguchi, 2016	Educational robots	Robotic competitions	• Students have positive attitude in technology. • The hands-on, project-based, and goal-oriented learning experience generated by an educational robotics competition has long-lasting impacts on student learning and encouragement to pursue in STEM-related fields	Communication between teams from various countries can be a major obstacle
J. Leonard et al., 2016	STEM education	• Robotics Game design	• Some students were able to develop imaginative and interesting scaffolded games while others followed the tutorial without much adjustment. • Students may incorporate certain aspects of culture and game design • Students had a clear chance to generate critical thinking skills by rising STEM competences.	Students may not want to further studies because of lack of awareness on career, its consequences, and the job description.

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Findings

The analysis shows that most of the study reviewed utilized game-based learning and coding approaches to implement CT among students. However, from the articles chosen, an approach like programming workshops, model simulation construction, and robotics competition were also parts of the strategies adopted for introducing CT in STEM education. A few studies added CT in their studies by using hands-on projects and an unplugged approach. The tools used in each study are developed/adopted to build problem-solving, algorithmic, and programming knowledge among novice students and teachers - some of the tools leveraged on standard software such as Arduino. However, many of the studies did not specify the name of the machine or technology utilized.

Discussion

A selection of scholarly articles on the implementation of CT to either teachers or students in the STEM classroom was evaluated. This section discusses the findings presented in Table 4 on the implementation of CT skills and the consequences of such studies on students in the scope of this review. Along with the findings on the usages of CT in programming and robotics activities, this study has also shown that CT programs have been designed and taught to students to prepare them for potential jobs requiring rigorous technical skills and excellent thinking skills in the future.

For instance, CT approaches and tools such as Arduino, MATLAB, Scratch, and robotics programming (Karaahmetoğlu & Korkmaz, 2019; Noh & Lee, 2020; Pala & Mıhçı Türker, 2019), have been used to introduce novice students to CT through problem-solving. The preference for the technology form that will be used depends on the subject. The benefits of each approach used in the subject areas are indeed how students could use CT in their learning process. Nevertheless, certain constraints and limitations faced throughout the implementation of the activities should be taken as a challenge to ensure that students have learned CT and can apply them in their daily lives.

Subjects which applied CT in STEM education

Computational thinking is inter-disciplinary in nature (Yadav et al., 2017), so it makes good sense to continue practicing it in primary school or even early education, where all subjects are naturally blended together in the same environment for students. CT skills are widely used in various subjects such as arts and linguistic studies (Cheng et al., 2008; Grover & Pea, 2013; Sáez-López & Sevillano-García, 2017), social studies (Güven & Gulbahar, 2020; Hammond et al., 2020), music (Essl, 2007; Moore, 2015; Shafer & Skripchuk, 2020), STEM subjects (Basu et al., 2016; Jaipal-Jamani & Angeli, 2016; J. Leonard et al., 2016; Miller, 2019; Serrano Pérez & Juárez López, 2018), and physical education (Leonard et al., 2020; Parmar et al., 2017).

STEM is synonymous with science, technology, engineering, and mathematics, which also corresponds to the topic areas within these four disciplines. Instead of teaching the four components as distinct and separate subjects, STEM blends them into a coherent, real-world learning paradigm. It is applicable in multiple fields across STEM education as computer science, programming, robotics, engineering, science, and mathematics. A total of ten studies focused on computer, programming, and robotics-based subjects from all the studies selected in this systematic review. In comparison, five studies focused on science and mathematics subjects. From the findings, CT was more implemented in robotics and programming subjects. However, in STEM education, science and mathematics are the core subjects that need to be focused on. Students who can apply CT in science and mathematics will have an advantage in mastering the technological part as well.

In implementing CT in STEM education, the students became aware of the application of CT to their learning experience, rather than just using computers and technology (Yada et al., 2011). Majority of the countries in the world have already integrated CT-based learning programs in the curriculum. Towards

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embracing this awareness, Malaysia has also opted to incorporate CT into the national educational system. Since January 2017, the Malaysian Ministry of Education (MOE) has declared that the CT approach would be included in the National Education Curriculum for the primary and secondary classrooms (KPM, 2017). MOE has taken several efforts in implementing CT in education by training teachers on how and where to apply CT in the academic subjects for both the primary and secondary schools. Initially, CT is only assigned to the computer science field, but it has been slowly extended into other syllabuses through stages.

As an effort to improve CT among students, the CT element continues in other syllabi as well. To increase students' access to digital technology, MOE is introducing design and technology (RBT) in primary schools in 2020 (KPM, 2017). The goal is to prepare students for the fourth industrial revolution (IR4.0). By increasing the use of all these technologies, students' ability to think creatively later will hopefully also increase. The MOE worked with the Malaysia Digital Economy (MDEC) to train a cohort of teachers to master CT and also to display to school students how their creativity, critical thinking, problem-solving, collaboration, and communication skills can be cultivated through their activities using digital technology. Students are given the opportunity, via coding, application development, 3D printing, robotics, embedded programming, and data analytics, to develop their digital technology-based inventions.

Activities for developing CT in STEM education

Teaching computational thinking has been typically seen primarily as a constructivism attempt. Based on Dewey, Piaget and Bruner 's work on constructivist theory, learning is a continuous and active process. Constructivist learning theories tend to underline the dynamic, subjective, and constructive dimensions of understanding, putting students at the centre of the learning process. Coding and programming activities, for example, encourage students to engage in CT throughout the activity actively and are facilitated by the teacher. As a result, students improve their knowledge and skills, particularly in problem solving and critical thinking via CT-integrated activities.

CT allows us to overcome any particular challenge with an empirical and methodical approach. As students are taught CT, they gain skills that are useful not just for STEM subjects, but also in the areas of social sciences (Hammond et al., 2020; Leonard et al., 2020). By applying CT, students can articulate a problem and critically think. These skills enable them to break down the problems and foresee what will change in the real situation. A variety of activities and strategies can be set up to help students improve their CT skills (Bers et al., 2019; Rossano et al., 2018; Sharma et al., 2019; Tonbuloğlu, 2019).

Game-based learning approaches are ideal ways to incorporate various types of coding and robotics in secondary school. As the name implies, game-based learning is game playing with structured learning objectives and is intended to present subject areas in the form of games that would assist students' understanding. Before using it in the real world, students gain insights into the functioning of the simulation environment. Students indirectly utilize vital CT elements such as decomposition, pattern recognition, abstraction, and algorithms throughout game-based learning. Such components evolve with their daily life activities, such as clothing arrangements, preparing meals, and others.

As Città (2019) and Bermúdez (2019) have mentioned in their studies, abstract concepts can be hard to teach. Games can be used to give such concepts a tangible form so that students can look at them from a different point of view. Bermudez used drone games in his study to teach students about navigation that are used in the aviation field. Students were introduced from the very early stages to the navigation system, and this can encourage students' motivation in space-related professions (Razali et al., 2020).

Città used the 'Robot-Tino Walk' mental rotation game, where the activity includes an algorithm, coding and debugging process using large chessboard tiles consisting of path tiles, target tiles and obstacle tiles. The students physically move across the chessboard and carry out a sequence of simple instructions written in sheets featuring the chessboard. Both activities allow students to progress within their tempo and thus make learning a personalized experience. In turn, it will strengthen the CT skills of students in many other STEM subjects.

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Benefits of implementing CT in STEM education

Problems solving, analysis of the validity of strategies and patterns in data are all critical working skills and are already taught in schools clustered under the term, CT. By engaging CT in the school environment, students are capable of making complex problem-solving issues more visible and can be systematically resolved. CT would also help students to explore higher order thinking skills questions (Zaharin et al., 2018), and other problem-solving questions (Kong & Lao, 2017; Kopcha et al., 2017; Martín-Ramos et al., 2017; Serrano Pérez & Juárez López, 2018; Yu & Guo, 2018).

With the integration of CT in STEM education, students would not only have participated in and driven by activities but managed to work together in groups solving issues on CT activities (Jaipal-Jamani & Angeli, 2016; Kopcha et al., 2017; J. Leonard et al., 2016; Miller, 2019; Taylor & Baek, 2019). From the studies, collaborative work and CT in an education robotics context are significantly linked. Robotics is an immersive activity in a possible multi-disciplinary problem with planning, construction, and environmental aspects. Due to this broadness, robotics is an activity which is ideal for working with a team, where students take up different roles in a team to solve the problem with robotics, such as coder, constructor, and analyst. Besides, the current literature review of robotics studies found that it is a collaborative activity which can develop the computational skills of students (Sullivan & Heffernan, 2016).

At the beginning of the robotic activities in Taylor & Baek (2019), students were all randomly assigned a role. Each role had a description and guiding issues to sustain discussion among students and to facilitate the team in the task given. These roles were not coding particular to one person but working as a team. All students, regardless of their positions, were invited to help with the coding. The functions are intended to supplicate the project component with mutual support while simultaneously providing opportunities to code and test the code across all students. Through cooperative learning in such activities, students work together to deal with the problems. They identify tactics to allow all group members to make similar contributions and encourage each other's work. Then, it also improves teamwork attitudes (Taylor & Baek, 2019), and students additionally enjoy solving the problems (Kopcha et al., 2017; Martín-Ramos et al., 2017), in the their field of learning. CT also allows students to develop their creativity and spatial intuition as well as to improve technical skills in learning (Serrano Pérez & Juárez López, 2018). Thus, students had a strong opportunity to improve critical thinking skills through increasing STEM skills.

With the technological growth over the years, the skill to code is increasingly necessary. Coding is the primary way to communicate with a computer. It uses a language to provide a computer with commands for specific functions. Coding allows creating stuff such as software, webpages, apps, and so forth. For students, there are plenty of benefits of coding that go way beyond technology access. Coding and programming can foster logical thinking in students. It also helps students to start showing their creativity (Serrano Pérez & Juárez López, 2018), develop resilience and persistence, as well as to communicate effectively. Besides that, coding will help students to solve problems (Kong & Lao, 2017; Kopcha et al., 2017), and also learn algebra (Miller, 2019), which will be more gratifying for students in the process of learning. CT skills in STEM learning can be strengthened through coding, programming, and robotics. Robotics activities, therefore, enhance CT as students boost their confidence via robotics. Students have greater confidence, particularly once they have met the solutions to various challenges. They will be courageous to face a new challenge as they have a greater level of confidence.

Challenges of implementing CT in STEM education

Throughout the attempts for schools to implement CT to all students, especially in STEM education, there are various constraints and limitations which have become hurdles that need to be overcome. A recent study outlines several gaps in the integration of CT in STEM education that proposes steps to remedy the route. From the articles chosen for this study, a list of difficulties is listed: lack of time; teachers' lack of quality, and students have no experience, lack of thinking skills, cost of technologies

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used too pricey for computer-based activities, technological limitations due to demographic factors, and communication between multiple nations become major obstacles when involving cross-country participation.

A lot of time is needed for robotics and programming as its content and pedagogy are the toughest (Angeli & Giannakos, 2020). The latter implies that students may not feel that they have sufficient time to complete the coursework. However, a framework that leads teachers to prepare CT activities may solve these issues (Curzon et al., 2014; Kotsopoulos et al., 2017; Perković et al., 2010; Swaid, 2015). As an example, the computational thinking pedagogical framework (CTPF) developed by Kotsopoulos (2017), consists of four educational perspective, namely unplugged, tinkering, making, and remixing. Unplugged perspective focuses on the activities conducted without computer usages. Tinkering experiences involve mainly activities that separate people and turn or modify existing objects. Making perspective includes actions where the main focus is the construction of new objects. Remixing refers to those experiences involving the allocation of objects or components of objects to be used and for other purposes. Such experiences reflect distinct and yet redundant CT experiences, which are also considered necessary to experience CT truly. The proposed CTPF could also be a useful structure for the development of teachers. Curzon (2014), recommended that the workshops for teachers should begin with unplugged activities to narrow the knowledge gap in the CT idea and use the skills in their classrooms.

Even though the use of computer programming is the main approach for students to develop CT, educators also use the unplugged approach as an alternative approach. An unplugged activity is a non-technology activity – which is, 'unplugged' from a computer or machine. Unplugged activities might substitute computer-based activities which could take ages. As well-known, the implementation of CT in STEM education through unplugged activities is believed to help in cross-disciplinary activities without subject limitations. Students can better see how different subjects and fields engage with one another. Unfortunately, unplugged activities are not just about "playing." Students have to have a strong and stable basis. Generally, students would give teachers a great deal of work. Not only in planning the activities, but for the teacher, they can also be obstructed in the process. Maintaining the focus and managing time seems to be a tough graft. However, although unplugged activities could be a great tool for students to access CT, it seems obvious there are restrictions to this approach (Brackmann et al., 2017; Tonbuloğlu, 2019). Further research is needed to explore the efficacy of the unplugged approach. The use of current technologies is required in order to preserve CT development in STEM education.

The quality of professional development in the STEM classroom is important to help students come up with the CT. However, numerous classrooms are still filled with an under-prepared teacher due to various minimal skills or none. Over the past decades, several scholars have investigated the correlation between inadequate teaching practices in STEM to student achievement (Han et al., 2013; Nadelson et al., 2013; Stohlmann et al., 2014). Both variables, the readiness of the teacher and the student experience are dependent of each other. To further develop CT in STEM education, teachers should be adequately equipped for the design of CT activities, strategies, including the use of technologies to explore the CT ideas. This suggests that teachers must be continuously trained with new skills including CT (Bower et al., 2017; Wang et al., 2018). Alongside the growing role of teachers, students may increase their abilities. Once students are provided with CT, they will be more confident to utilize them specifically in STEM classroom.

Issues such as the restriction of technology due to demographic conditions are not really a major problem currently as there are numerous available access to STEM education (Brannon & Novak, 2019; Croff, 2017). In their respective countries, all authorities are very concerned about STEM education implementation to improve students' understanding and thinking skills. Giants such Arduino, and others, particularly in the rural areas, are also doing community programs. Arduino Education Classroom advances students from elementary schools to universities via the STEAM and increases their sophistication by developing new skills. It is all at your fingertips. Today, technological development has reduced the interaction gap between countries (Bybee, 2010). Facilitating the application of language technology helps many international-country communication issues. Consequently, today we can claim that CT could carry so much in STEM education and spread its awareness to the world in one go.

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Conclusion

This systematic review underlined the current research gaps and directions for practicing and implementing CT in STEM education. The benefits and difficulties of integrating CT in STEM education are described in the scope of thinking skills. The main goal has been highlighted through four sub-themes based on the systematic reviews carried out, including the advantages of CT in STEM education by identifying subjects and practices that incorporate CT into their classrooms, along with the issues and challenges associated with CT in STEM education.

The review proposes a couple of suggestions for future studies. Firstly, more qualitative studies are necessary as they provide a comprehensive overview and clear description of strategies for improving CT in STEM education. Secondly, the application of a standardized and common structural approach to lead a systematic review in the sense of computational thinking is recommended, and thirdly, the use of complementary methods of searching, such as reference identification, and snowball may be beneficial.

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