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A bibliometric analysis of computational thinking skills: definition, components and assessment tools

Ahmad Sarji Abdul Hamed [1], Su Luan Wong [1*], Mas Nida Md Khambari [1], Nur Aira Abd Rahim [1], Fariza Khalid [2] and Priscilla Moses [3]

*Correspondence:
suluan@upm.edu.my
Department of Science and Technical Education,
Universiti Putra Malaysia,
Serdang, 43400, Selangor,
Malaysia
Full list of author information is available at the end of the article

Abstract

This paper provides an in-depth analysis of computational thinking (CT) skills and their assessment. It discusses the definition and components of CT. Various assessment tools, such as surveys, exams, self-assessment instruments, and performance tests, are explored. A bibliometric analysis reveals a growing trend in publications related to CT skills since 1993. The study employs citation analysis, co-citation analysis, and co-keyword analysis, identifying clusters of related work and emphasizing the core ideas of CT skills, their components, and their assessment. The findings highlight the intellectual synergy between publications, particularly the strong conceptual and thematic links between works that often cite each other. The discussion underscores the importance of CT components like abstraction, decomposition, and algorithms, as foundational elements across disciplines, particularly in education and computer science. Additionally, the integration of CT into educational curricula, such as robotics, programming, and STEM, demonstrates its growing significance. The conclusion identifies several gaps in the current understanding of CT, particularly the need for a standardized, widely accepted definition that encompasses all aspects of CT. It also emphasizes the limited focus on the assessment of CT skills and calls for the development of validated and reliable assessment tools. Furthermore, the paper highlights the need for more research on the impact of teacher training programs on CT development, to ensure effective integration at the school level.

Keywords: Computational thinking (CT), Definitions, Components of CT, Measurement, Assessment tools

Introduction

Computational thinking (CT) has become essential in the 21st century, enhancing individual capabilities to tackle problems, design systems, and comprehend human behavior. These skills are foundational cognitive abilities in the digital age, enabling people to address complex issues methodically and logically. The industrial revolution 4.0 underscores the necessity for students today to master these skills. Technological advancements have introduced intricate new challenges and cultural contexts, requiring critical thinking skills, specifically CT (Voskoglou & Buckley, 2012). Computational thinking is a problem-solving approach that leverages fundamental computer science concepts and techniques, allowing individuals to analyze situations, design systems, and understand human behavior (Grover & Pia, 2013; Haseski et al., 2018). The term “computational thinking” has gained popularity and can mean different things to different people based on the context and field of study. These skills represent a person’s intellectual ability to solve complex problems by creating adaptable systems and processes using computers, focusing on key components like decomposition, pattern analysis, abstraction, and algorithms (Tykhonova & Koshkina, 2018). Istenic (2020) highlights that these skills are a modern educational trend crucial for learning in science, technology, engineering, and mathematics (STEM). At the heart of CT is computer literacy, which Istenic (2020) describes as the technical use of computer technology and its applications. However, computational thinking extends beyond mere computer operation; it involves the critical analysis and structured resolution of problems, applicable across various fields.

Aminah et al. (2022) describe computational thinking as an analytical and systematic problem-solving approach. It involves breaking down problems into smaller parts, solving each part individually, and then combining these solutions to address the entire problem. As these skills evolve, there is a pressing need for a clear framework that can operationalize and evaluate computational thinking in educational settings (Hurt et al., 2023). Although Grover and Pia (2013) note that there isn’t a universally accepted definition of computational thinking yet, the core concepts of computer science are widely recognized as essential skills for today’s students. Research has identified various domains and components of computational thinking, highlighting their multifaceted nature. These skills blend critical thinking, problem-solving, and creativity, becoming increasingly vital in our digital society (Gao & Chen, 2022). Understanding these domains helps educators and students effectively apply computational thinking in different contexts, enhancing problem-solving abilities. One of the main components of computational thinking is abstraction. As Csizmadia et al. (2019) explain, abstraction involves identifying the important features of a problem while ignoring irrelevant details, simplifying complex problems, and focusing on critical aspects. This simplification aids in understanding and developing effective solutions. Another crucial component is decomposition. According to Tsai et al. (2022), decomposition is the process of breaking a complex problem into smaller, more manageable parts or sub-processes. This approach allows individuals to tackle each sub-problem efficiently, leading to a more systematic and focused problem-solving strategy.

Pattern recognition is another crucial element of computational thinking. It involves identifying similarities, patterns, and trends within data or information. Recognizing these patterns enables individuals to make informed decisions and develop strategies for solving problems more efficiently. This skill requires analyzing data and identifying relationships between significant pieces of information (Silva Junior et al., 2022). Algorithms also play a vital role in computational thinking. An algorithm is a set of step-by-step instructions that outline how to solve a problem. Dagienė and Sentance (2016) note that the algorithm component provides a systematic approach to problem-solving by detailing the actions and processes required. Algorithms are essential for designing solutions, implementing them through programming languages, and automating tasks. In addition to these core components, computational thinking encompasses several other approaches, including generalization and systems thinking. Generalization involves applying solutions from one problem domain to another similar domain (Tsai et al., 2022). Systems thinking requires understanding the interconnections and dependencies within systems to solve problems effectively (Kong & Abelson, 2019). Based on previous studies, the primary components of computational thinking include abstraction, decomposition, pattern recognition, algorithmic thinking, generalization, and systems thinking. Developing and nurturing these skills can significantly enhance individuals' problem-solving abilities, enabling them to thrive in a technology-driven world.

Computational thinking are critical cognitive abilities for problem-solving and decision-making in today's digital age. To accurately evaluate individual CT abilities, effective assessment tools are essential (Csizmadia et al., 2019). Numerous assessment tools have been developed and utilized to gauge the various components of computational thinking. These tools include questionnaires, test papers, self-evaluation instruments, and performance tests, each targeting different domains and components such as pattern recognition, abstraction, teamwork, data analysis, and algorithms. The development and implementation of these assessment tools are crucial for evaluating computational thinking across different contexts and fields of study (Oluk & Korkmaz, 2016). A comprehensive and multidimensional assessment approach provides a clear and valuable understanding of individual skill levels, identifies knowledge gaps, highlights areas needing further study, and measures the effectiveness of educational interventions (Usman et al., 2018). In 21st-century education, computational thinking has become increasingly important as a problem-solving domain. To enhance the understanding and application of these skills, comprehensive research is needed to define terms, determine components, and develop assessment tools with validated reliability and validity. This study aims to discuss the definition of computational thinking, their components, and the assessment tools used, based on previous research. The investigation is guided by two research questions:

RQ1: What is the past research trend related to computational thinking based on citation and co-citation analysis?

RQ2: What is the future research trend related to computational thinking based on keyword analysis?

Literature review

Computational thinking is a term with varied definitions and interpretations across different fields of study. Wing (2006) initially defined computational thinking as a set of skills to solve problems, design systems, and understand human behavior through computer science components. Later, in 2011, Wing refined this definition, describing computational thinking as a cognitive skill for problem-solving that involves breaking down complex problems into manageable parts, abstracting critical information, thinking generally, making structured connections, and evaluating efficient solutions for effective problem-solving. Tsai et al. (2021) classified the definition of computational thinking into two categories: the specific domain category and the general domain category. In the specific domain category, computational thinking refers to the knowledge required to systematically solve problems within the realms of computer science or computer programming. In the general domain category, these skills refer to the ability to systematically solve problems in everyday life.

Haseski et al. (2018) define computational thinking as basic social skills that enable individuals to solve problems and make accurate, systematic decisions using information and computer technology collaboratively in the real world. Various studies (Brennan & Resnick, 2012; Chang, 2014; Chen, 2009; Furber, 2012; Grover & Pea, 2013; Jacobson & Wilensky, 2006; Jenkins, 2015; Kafai, 2016; Lu & Fletcher, 2009; Park & Jeon, 2015; Sullivan & Heffernan, 2016; Voogt et al., 2015; Williamson, 2016; Yadav et al., 2014) consistently describe computational thinking as a systematic problem-solving process using core components of computer science and technology. The definitions across these references highlight the importance of problem-solving, system design, and the application of computer science concepts in a systematic problem-solving process. Computational thinking has practical applications in many fields, including education, science, and technology. A deeper understanding of the conceptual definition and operation of computational thinking provides a clear picture of their application across disciplines, fostering critical thinking and problem-solving abilities.

Computational thinking is cognitive abilities that encompass various components essential for problem-solving and analytical tasks. Numerous studies have analyzed and conceptualized these components. Sholihah and Firdaus (2023) identified key components such as decomposition, pattern recognition, abstraction, and algorithm design. These components are crucial for breaking down complex problems into manageable parts, recognizing patterns in data or problems, extracting important details, and designing step-by-step solutions. Mukasheva and Omirzakova (2021) introduced four levels of computational thinking: phenomenological, analytic-synthetic, set-prognostic, and axiomatic levels. These levels help in understanding the development and progression of computational thinking. Current research trends have increasingly focused on integrating these components across various disciplines. For instance, Pan et al. (2016) emphasized the application of computational thinking in teaching subjects like Photoshop. Lyon and Magana (2020) highlighted the growing need for more studies and reflections on the concept of computational thinking and their components within the context of digital education. Many past studies provide insights into the fundamental components of computational thinking, including decomposition, pattern recognition, abstraction, generalization, and algorithm design (Dagienė et al., 2017; Gao & Chen, 2022; Rosali & Suryadi, 2021; Sholihah & Firdaus, 2023). These components play a vital role in enhancing problem-solving and analytical abilities across various fields. Further research and exploration into these components will contribute to a deeper understanding and more effective integration of computational thinking in education, fostering better problem-solving and analytical skills in students.

Effective assessment tools are crucial for accurately evaluating an individual's computational thinking abilities. Numerous studies have delved into the various tools and methodologies used to assess CT. Among these, questionnaire instruments, test papers, self-assessment instruments, and performance tests have been commonly employed. Romero et al. (2017) conducted a study on the development of computational thinking through creative programming in higher education. This research integrated automated and observational analysis tools to evaluate CT scores in creative programming projects, providing a comprehensive assessment of CT skills. Tsai et al. (2021) introduced the Computational Thinking Scale (CTS), a tool developed to assess thinking processes in CT across general and specific problem-solving contexts. CTS consists of five dimensions: abstraction, decomposition, algorithmic thinking, evaluation, and generalization, allowing for a multidimensional assessment of individual CT skills. Moreno-Leon et al. (2016) compared assessment scores for computational thinking provided by Dr. Scratch, a free software evaluation tool for Scratch, with predefined software complexity metrics. Their findings highlighted a potential correlation between CT scores and software measurements. Papadakis and Kalogiannakis (2022) focused on assessing computational thinking in early childhood education using the Bee-Bot educational robotics platform. Their study showed significant improvements in children's computational thinking based on comparisons of initial and final assessments. In conclusion, effective assessment tools are essential for accurately measuring computational thinking and providing valuable feedback to researchers. Various tools and methodologies, including automated analysis tools, scales, tests, questionnaires, and multidimensional assessments, contribute to a comprehensive understanding of individual CT abilities across disciplines. Further research and development of CT assessment tools will enhance our ability to evaluate and foster computational thinking in students of all ages.

Methodology

Bibliometric analysis, also known as citation analysis or scientometrics, is a research methodology that involves the quantitative evaluation of scientific literature (Donthu et al., 2021). By examining citation patterns and publication data, bibliometric analysis provides insight into the structure, impact, and development of research fields (Raisig, 1962). While meta-analysis and systematic literature reviews focus on synthesizing and analyzing research findings, bibliometric analysis offers a quantitative perspective on the characteristics and dynamics of scholarly publications within a field, providing valuable context for understanding research trends and impact. Bibliometric analysis provides a number of advantages and applications, including the identification of academic trends, research network mapping, research performance evaluation, and tracking collaboration patterns among researchers, institutions, and countries (Anand et al., 2020). In addition, bibliometric analysis helps to identify research gaps, emerging topics, and influential authors or publications in a particular field, which allows researchers to gain a holistic understanding of the state of knowledge in a particular field by examining key themes, historical trends, and publication and citation patterns (Boyack & Klavans, 2014; Van Eck & Waltman, 2014). Research topics related to computational thinking are increasingly popular and gaining ground among educational researchers; bibliometrics provide objective analysis by mapping scientific literature into the visualization of knowledge structures (Garfield, 1979).

There are three types of analysis used in bibliometric studies: citation analysis, co-citation analysis, and co-keyword analysis. This analysis evaluates cited articles by measuring the number of citations a publication receives. Citation analysis is important in mapping knowledge structures to identify quality contributions in specific fields (Sood et al., 2021). The higher a document is cited, the greater its importance in a certain field (Fauzi, 2022). Citation analysis in bibliographic analysis refers to the examination and evaluation of citations in a bibliography to gain insight into various aspects of research impact, quality, and information retrieval. It involves analyzing the pattern, frequency, and relevance of citations to understand the intellectual network, impact, and purpose of a research paper (Kostoff & Martinez, 2005). Citation analysis can be used as a tool to measure the impact or quality of research in a specific research field (Mishra et al., 2017). This analysis can also help identify current topics that need attention in addition to assessing the accuracy and quality of citations and reference lists.

Co-citation analysis in bibliographic analysis is a bibliometric method that examines the frequency of co-citations of two or more references to identify relationships and similarities between them (Chen et al., 2010). This analysis is also carried out to evaluate semantic similarities and identify clusters of knowledge in certain fields of study. When two references are often mentioned together, this indicates that the research conducted is likely to be semantically related or share the same concept (Chen et al., 2010). Co-citation analysis can be used to understand evolutionary trends, patterns, and levels of use of research literature in a specific field or topic (Hanoum et al., 2021). By analyzing co-citation patterns, researchers can gain insight into the structure and boundaries of a discipline, as well as identify influential authors and evaluate papers that have a major impact in the field of study. Co-citation analysis is a valuable tool for mapping the structure of scientific knowledge and identifying current research trends (Hanoum et al., 2021). The co-citation strength between publications and clusters is indicative of the degree of their thematic or conceptual connections. Strong co-citation links suggest that these works are frequently referenced together, signifying their substantial contributions to the same or closely related areas of study (Fauzi, 2022).

Co-keyword analysis in bibliometric analysis is a technique used to analyze the co-use of keywords or topic words in academic writing (Yang et al., 2019). This analysis helps to understand the interconnections and main topics in the research field (Coulter et al., 1998). The distance between nodes in the keyword analysis indicates how frequently they co-occur in the same context. Closer nodes within the same cluster suggest a stronger relationship and higher frequency of co-occurrence, indicating that these keywords are often discussed together in the literature (Fauzi, 2022). Co-keyword analysis is considered one of the most important methods in bibliometric analysis, where co-keyword analysis is used to explore research areas, visualize mapping, and understand the current state of the researched field. Therefore, co-keyword analysis is often used together with other bibliometric methods such as citation analysis, co-citation analysis, and co-author analysis to provide a comprehensive understanding of trends and relationships between researchers (Sedighi, 2016).

Despite all their advantages, bibliometric analyses often rely on data from one specific database, either the Web of Science or Scopus, which may not cover all disciplines or types of publications. This limited scope can lead to biases in the results, favoring certain fields or publication types over others. All documents used in this study include all forms of journal papers, conference proceedings, books, book chapters, letters, and notes. These sources may contain valuable insights and contributions that are not captured by traditional peer-reviewed publications. Another limitation of bibliometric analysis is that citation patterns can be influenced by factors other than the quality or impact of the cited work, such as self-citations. To overcome this issue, the number of citations stated in this study represents the number of citations without self-citation to ensure the quality of the data used.

Research Design and Data Collection Procedure

Data for this bibliographic study were obtained from the Scopus Core Collection database. According to Gonzalez-Serrano et al. (2019), the database is a collection center for extensive research materials and has been adopted in bibliometric analysis due to its impact factor and recognition as the best index. The following search string was performed on the 'topic' column in the Scopus document search (Table 1). The search document type is not limited; all types of journal documents, conference proceedings, books, book chapters, letters, and notes are taken into account in this study. The search was conducted on July 25, 2023. To avoid duplicate documents, all documents are downloaded into Excel software and filtered using several steps which are utilize Excel's built-in feature, the "Remove Duplicates" function (under the Data tab), to identify and eliminate exact duplicate rows or entries. For double confirmation, arrange the titles of all documents alphabetically from A to Z. Then, filter and remove all documents that have the same title. A total of 1,000 documents from the search data results were taken into account in this study, which were published between 1993 and 2022.

Designing effective search terms is crucial to ensure that the bibliometric analysis captures all relevant documents meeting the research requirements. Start by clearly defining the research objectives and questions to address. Understand the specific topics, themes, or areas of interest to explore through the bibliometric analysis. In this research, there are few keywords act as the basis of the search string ("Computational thinking's" OR "computational thinking" OR "teaching" OR "education" OR "students" OR "assessment"). These keywords and concepts should encompass the key themes and aspects of the research. The analysis tool utilized in this study is ViewVOS. ViewVOS enables users to import bibliographic data from diverse sources like the Web of Science, Scopus, or PubMed. Once imported, the data undergoes preprocessing to extract pertinent information, such as authors, publications, citations, and keywords. The primary feature of ViewVOS lies in its visualization capabilities. It employs techniques like co-citation analysis, bibliographic coupling, and keyword analysis to generate visual representations of bibliographic data.

Table 1 Search string in Scopus database

No.	Keywords
1	"Computational" AND "thinking" AND "tools" OR "Computational thinking's" OR "computational thinking" OR "teaching" OR "education" OR "students" OR "assessment"

These visualizations typically manifest as network graphs, wherein nodes denote entities and edges represent relationships. ViewVOS offers built-in metrics and analytics to aid users in evaluating the impact and significance of individual papers, authors, or keywords within the literature. These metrics may encompass citation counts, centrality measures, or clustering coefficients, among others. This study utilizes the Similarity-Based Clustering method to form effective clusters. This technique organizes objects (such as documents, authors, and keywords) based on their similarity or dissimilarity in a multidimensional space. By employing a similarity metric like cosine similarity or Jaccard similarity, this approach in VOSviewer calculates the pairwise similarity between elements. Distinct objects are grouped into discrete clusters, while items with greater similarity are clustered together. VOSviewer offers a built-in cluster analysis tool that enables users to conduct similarity-based clustering on the items extracted from bibliographic data. Users can specify the clustering method, similarity measure, and clustering parameters (threshold values) to tailor the clustering process. Figure 1 shows the steps taken to do the bibliometric analysis in this study.

Analysis data and result

Findings from the Scopus database show that the total number of citations in the publication (N = 1,000) is 9,928 times without self-citation, the h-index is 44, and the average citation for each publication is 9.93. Publications related to computational thinking began in 1993, but this topic gained a place in the field of educational studies and became more popular starting in 2016. The jump in publications from 49 publications (2016) to 90 publications

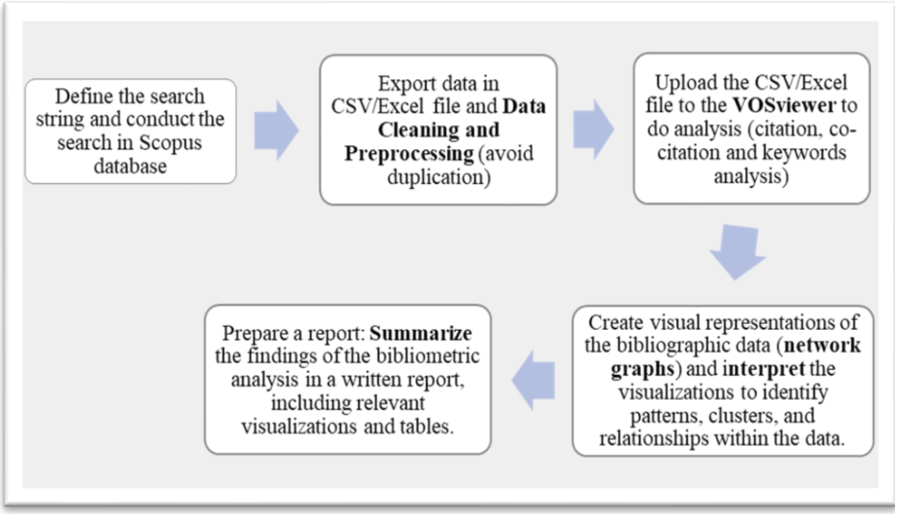

Fig. 1 Steps taken to do the bibliometric analysis

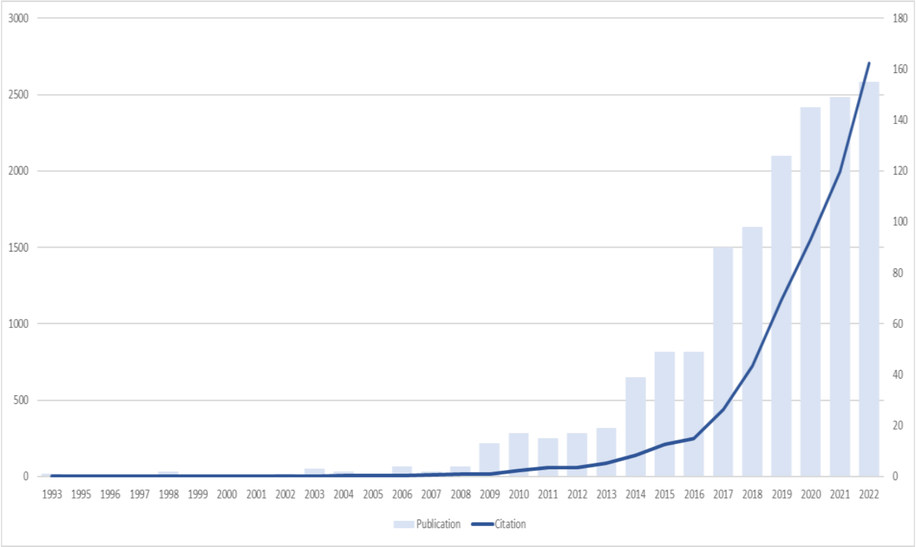

Fig. 2 Number of publications and citations from 1993 to 2022

(2017) continues to show an increase in the number of publications in the years. The next step is to prove that computational thinking is an important element in today's education. Figure 2 shows the number of publications and citations from 1993 to 2022.

RQ1: What is the past research trend related to computational thinking based on citation and co-citation analysis?

This part presents a citation analysis based on publications related to the topic of computational thinking. Table 2 is a list of ten publications with the highest number of citations. Seven of the articles with the highest citations discuss the method of applying computational thinking; one article discusses the components of computational thinking; and the rest discuss assessment tools to measure computational thinking. Based on the ten most cited publications, computational thinking has generally been defined as a branch of systematic problem-solving skills involving content from the domain of computer science. The method of teaching computational thinking is by integrating robotics knowledge, using problem-based and project-based learning approaches, using scalable game design, teaching computational thinking through programming, and then combining computational thinking across disciplines (Atmatzidou & Demetriadis, 2016; Bers et al., 2014; Buitrago Flórez et al., 2017; Hsu et al., 2018; Kirk & Hwu, 2013, 2016; Repenning et al., 2010). Atmatzidou and Demetriadis (2016), in their study, discuss the understanding and development of cognitive processes, namely abstraction skills, algorithms, reasoning, and generalization, which are important components in fostering computational thinking in students. Korkmaz et al. (2017) have developed a questionnaire assessment tool to measure

Table 2 List of ten publications with the highest number of citations

Author	Title	Year	Cited by
Bers, M. U., Flannery, L., Kazakoff, E. R., & Sullivan, A.	Computational thinking and tinkering: Exploration of an early childhood robotics curriculum	2014	595
Hsu. T.-C., Chang. S.-C., & Hung. Y.-T.	How to learn and how to teach computational thinking: Suggestions based on review of the literature	2018	400
Atmatzidou, S., & Demetriadis, S.	Advancing students' computational thinking skills through educational robotics: A study on age and gender relevant differences	2016	358
Korkmaz, O., Cakir, R., & Ozden, M. Y.	A validity and reliability study of computational thinking scales (CTS)	2017	287
Yadav, A., Hong, H., & Stephensson, C.	Computational thinking for all: Pedagogical approaches to embedding 21st century problem solving in K-12 classrooms	2016	255
Werner, L., Denner, J., Campe, S., & Kawamoto, D. C.	The fairy performance assessment: Measuring computational thinking in middle school	2012	238
Buitrago Flórez, F., Casallas, R., Hernández, M., Reyes, A., Restrepo, S., & Danies, G.	Changing a generation's way of thinking: Teaching computational thinking through programming	2017	215
Repenning, A., Webb, D., & Ioannidou, A.	Scalable game design and the development of a checklist for getting computational thinking into public schools	2010	196
Krik, B. D., & Hwu, W. M. W.	Programming massively parallel processor: A hands-on approach (3rd edition)	2016	193
Bers, M. U., González-González, C., & Armas–Torres, M. B.	Coding as a playground: Promoting positive learning experiences in childhood classrooms	2019	159

knowledge, skills, and attitudes towards computational thinking, while Werner et al. (2012) have developed a set of game-based assessment tools (game-programming courses) to assess aspects of computational thinking.

Citation threshold analysis for co-citation analysis was determined at 14, which resulted in the number of cited references being 46. Based on the cited references, a network analysis of computational thinking was constructed and presented in Figure 3. Ten documents with the highest total co-citation and total link strength are shown in Table 3. The top three cited publications are Wing (2006) (158 citations), Barr and Stephenson (2011) (81 citations), and Papert (1980) (111 citations). Co-citation analysis identifies related clusters of work and helps identify intellectual structure in a field (Kraus et al., 2012). Groups of publications that are often cited together indicate a strong relationship

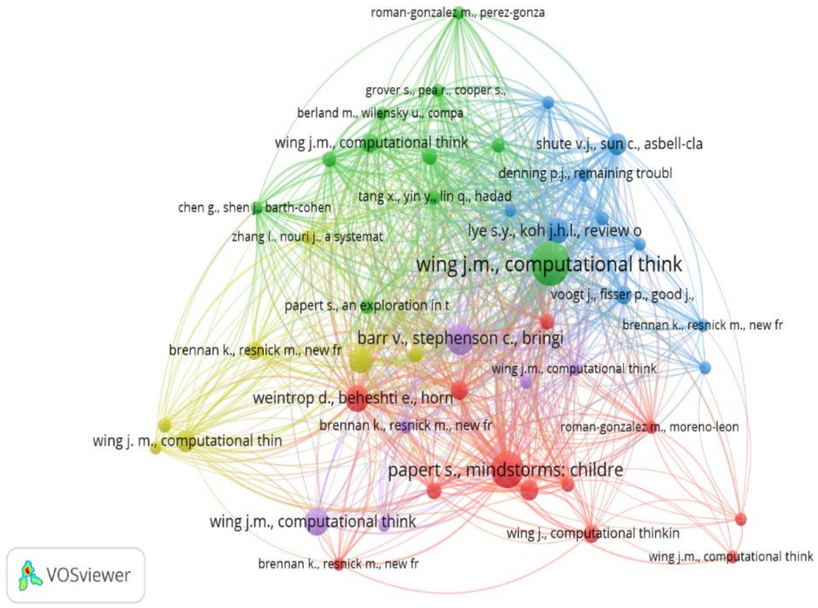

Fig. 3 Co-citation analysis

Table 3 Ten documents with the highest total co-citation and total link strength

Document	Citation	Total linked strength
Wing (2006), Communications of the ACM, Vol. 49(3), 33-35	158	428
Papert (1980), Basic Books, Inc.	111	275
Barr & Stephenson (2011), ACM Transactions on Computational Logic	81	327
Weintrop et al. (2016), Journal of Science Education and Technology, Vol. 25, 127-147	59	248
Grover & Pea (2013), Educational Researcher, Vol. 42(1), 38-43	57	211
Lye & Koh (2014), Computers in Human Behavior, Vol. 41, 51–61	53	262
Shute et al. (2017), Educational Research Review, Vol. 22, 142-158	41	206
Linn et al. (2010), National Research Council	34	102
Brennan & Resnick (2012), AERA, 1-25	28	71
Voogt et al. (2015), Education and Information Technologies, 715-728	26	145

between them. These clusters can represent different themes or areas of research within the field of study. The following describes each cluster and its labels based on co-citation analysis. A cluster represents a group of items in a particular theme. Items that appear in the same theme are located closer together and are shown with the same color code (Zupic & Cater, 2015). A summary of the joint citation analysis group is shown in Table 4.

Cluster 1 (red) has 12 publications and is labelled as the core idea of computational thinking. Papert (1980), in his study, stated the basis for the development and teaching of the basics of computer science, which are now known as computational thinking, and

Table 4 Co-citation cluster

Cluster	Cluster label	No. articles	Representative publication
1 (Red)	The core idea of computational thinking skills	12	Papert (1980), Weintrop et al. (2016), Brennan & Resnick (2012)
2 (Green)	Components of computational thinking skills	11	Wing (2006), Selby & Woollard (2013), Tang et al. (2020)
3 (Blue)	Assessment of computational thinking skills	10	Korkmaz et al. (2017), Brennan & Resnick (2012), Denning (2017)
4 (Yellow)	Development of computational thinking skills	7	Barr & Stephenson (2011), Grover & Pea (2013), Shute et al. (2017)
5 (Purple)	Teaching and learning	6	Barr & Stephenson (2011), Robins et al. (2010), Werner et al. (2012)

suggested that computers may improve thinking and change patterns of knowledge accessibility. Weintrop et al. (2016) suggested a definition of computational thinking for mathematics and science subjects in the form of a taxonomy consisting of four main categories, namely data practices, modelling and simulation practices, computational problem-solving practices, and system thinking practices. Next, Brennan and Resnick (2012) explain the definition and main dimensions of computational thinking based on the field of programming: the concept of computational thinking (concepts studied by designers when they organize ways, such as iteration and parallelism), computing practices (skills generated by designers as they engage with the concept), and the computational perspective (the perspective that designers form about the world around them and about themselves).

Cluster 2 (green) has 11 publications and is labelled as a computational thinking component. Wing (2006) discusses the basics of computational thinking and focuses on several components of computational thinking such as decomposition, pattern recognition, abstraction, and algorithms. Wing’s (2006) study is supported by Selby and Woollard (2013), who also suggested that the operational definition of computational thinking is the basic set of computer science, namely abstraction, analysis, algorithmic thinking, evaluation, and generalization. Tang et al. (2020) stated that the components of computational thinking are different based on computing and programming activities that require students to improve domain-specific knowledge and problem-solving skills.

Cluster 3 (blue) has 10 publications and is labelled as computational thinking assessment. Korkmaz et al. (2017) have developed a set of questionnaires containing 29 items that measure the level of computational thinking. The set of questions developed was tested for validity and reliability through factor exploratory tests and factor confirmation tests. Brennan and Resnick (2012) highlight the approach of project portfolio analysis, artifact-based interviews, and design scenarios to assess computational thinking in programming activities. Denning (2017) states that the assessment of computational thinking can be done through competency-based skills assessment, where this assessment measures student progress in designing useful and practical skills in various areas of interest.

Cluster 4 (yellow) has seven publications and is labelled the development of computational thinking. Barr and Stephenson (2011) stated that the development of technology and world progress increase the need for computational thinking to solve problems more efficiently and effectively. Grover and Pea (2013) urge the integration of computational thinking in K–12 education in an effort to equip students with important and relevant skills in today's technology-driven world. The development of computational thinking is still focused on the field of computer science or programming; this skill is very important in solving problems that can be applied across disciplines (Shute et al., 2017).

Cluster 5 (purple) has six publications and is labelled teaching and learning. Changes in the teaching and learning system need to be in line with current needs, where industry players and the administration need to understand the need to apply computational thinking in K–12 education (Barr & Stephenson, 2011). Werner et al. (2012) stated that the teaching and learning process based on computer games or online games can foster good computational thinking among students. Robins et al. (2010), in their study, found that teaching and learning in the field of programming are influenced by individual expertise factors and have an impact on competency and computational thinking.

RQ2: What is the future research trend related to computational thinking based on keyword analysis?

Keyword analysis identifies words that are frequently used together in the analyzed document (Kipp & Campbell, 2007). Pairs or groups of words that have a high frequency of being used together indicate relationships, themes, or concepts that are important in the field of study. The citation threshold analysis for co-keyword analysis was determined at 22, which resulted in the number of cited references being 59 publications. Table 5 presents the 10 keywords with the highest frequency. Figure 4 shows the analysis of the keyword network based on the total number of publications analyzed. Keyword analysis produced five clusters, and each cluster was analyzed based on research trends and related themes obtained from keywords and publications. Table 6 presents a summary of the keyword analysis cluster.

Cluster 1 (red) consists of 17 keywords and is labelled as assessment of computational thinking. The keywords underlying group 1 are "computational thinking", "assessment" and "assessment tool". This group discussed computational thinking assessment methods involving algorithmic thinking skills, computer learning, codes and symbols, assessment based on game-based learning, as well as questionnaires.

Cluster 2 (green) has 14 keywords labelled as components of computational thinking, and this group underlies exploration in determining the components of computational

Table 5 Ten keywords with the highest frequency

No.	Keyword	Frequency
1	Computational thinking	1288
2	Students	426
3	Teaching	212
4	Education	184
5	Education computing	179
6	Curricula	176
7	Engineering education	169
8	Computer programming	149
9	E-learning	93
10	Problem solving	86

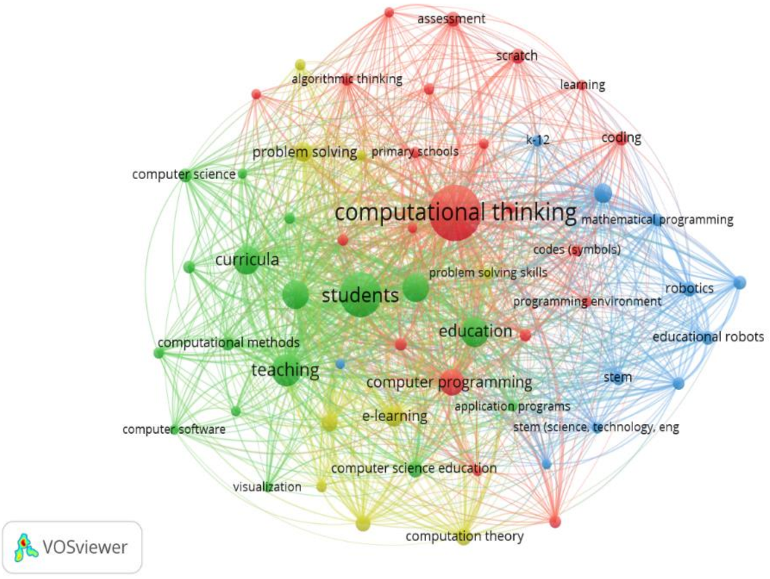

Fig. 4 Co-keyword analysis

Table 6 Keyword analysis cluster

Cluster	Cluster label	No. of keywords	Most frequent keywords
1 (Red)	Assessment of computational thinking skills	17	computational thinking, computational thinkings, assessment, assessment tools
2 (Green)	Components of computational thinking skills	14	students, computational tools, engineering research, curricula, computational methods
3 (Blue)	Teaching and learning	11	programming, robotic, K-12, stem, teaching and learning
4 (Yellow)	The core idea of computational thinking skills	9	computational theory, learning system, problem solving, e-learning, scaffold
5 (Purple)	Development of computational thinking skills	8	application program, scratch, computer science education, visual programming, education

thinking in various research fields. This group's main keywords include "students", "computational tools", "engineering research", "curriculum" and "computational methods".

Cluster 3 (blue) consists of 11 keywords and is labelled as teaching and learning. This group's main keywords are "programming", "robotic", "K-12", "stem" and "teaching and learning". Based on the list of keywords, this group discussed appropriate and effective teaching and learning methods to foster computational thinking among students.

Cluster 4 (yellow), labelled as core idea of computational thinking, consists of nine keywords. This group's main keywords include "computational theory", "learning system", "problem solving", "e-learning" and "scaffold". It can be concluded that this group discussed the core idea of computational thinking in various fields.

Cluster 5 (purple) has 8 keywords and is labelled as development of computational thinking. This cluster discusses the application of computational thinking in various fields that are increasingly gaining a place in 21st-century education. This group's main keywords include "application programme", "scratch", "computer science education", "visual programming" and "education".

Discussion

Based on citation and co-citation analysis, the past research trend related to computational thinking has focused on various aspects. The frequent co-occurrence of citations demonstrates the intellectual synergy between publication, underlining their collective impact on the development of specific research themes within the field of computational thinking. Nodes that are located closer together in the map have a stronger co-citation relationship. This means they are often cited together in the same publications, indicating a conceptual or thematic link between the works they represent. Researchers have explored the definition and conceptual understanding of computational thinking, emphasizing their importance in fostering critical thinking and problem-solving abilities. Based on different fields of study and publications, the definition of computational thinking varies slightly but generally includes similar components. In the field of education, Istenic (2020) defines computational thinking as the ability to use the basics of computer science effectively and the process of analyzing and solving problems critically in a structured way. This skill involves breaking a problem into smaller parts and finding a solution for each part before combining them to solve the whole problem. Computational thinking is seen as an analytical and systematic approach to solving problems in the field of education. Next, in the field of computer science, Grover and Pea (2013) emphasized the importance of computational thinking as an important skill that must be mastered by students. Although there is no widely accepted definition, core computer science concepts such as abstraction, decomposition, pattern recognition, and algorithms are considered important components of computational thinking.

Brennan and Resnick (2012) provide a definition of computational thinking as skills based in the field of programming. Their study describes computational thinking as a combination of concepts, computing practices, and computing perspectives. Concepts refer to the ideas and principles that designer's study when organizing ways to solve problems, such as iteration and parallelism. Computational practice is the skill that designers produce as they engage with these concepts. Computational perspective is the perspective that designers generate about the world around them and themselves. Definitions of computational thinking across different fields and publications highlight the importance of computational thinking components such as abstraction, decomposition, pattern recognition, and algorithms in the process of solving problems and applying the basics of computer science effectively. These components form the backbone of the framework to solve problems analytically, systematically, and creatively, are important, and can be applied in various fields. Computational thinking is seen as an important skill in today's digital society and are increasingly emphasized in education. The integration of CT into educational approaches such as robotics, programming, and STEM education illustrates its growing importance across various disciplines. Robotics education employs CT by having students tackle complex problems through hands-on interaction with programmable robots, while programming education uses both block-based and text-based languages to teach fundamental CT principles. STEM education incorporates CT through problem-based and project-based learning, supported by frameworks like the Next Generation Science Standards (NGSS) and the Common Core State Standards (CCSS) (Istenic, 2020). Collectively, these approaches demonstrate how CT enhances problem-solving skills and innovation, preparing students for a technologically advanced and multifaceted world.

The future research trend related to computational thinking is expected to focus on several key areas based on keyword analysis. Keyword analysis reveals important cross-disciplinary connections. Keywords from different clusters may co-occur in interdisciplinary research, demonstrating the integration of various themes across fields. For example, the keyword "assessment" from Cluster 1 may appear together with "curriculum" from Cluster 2 in studies that investigate the incorporation of assessment methods into educational curricula. This co-occurrence underscores the interdisciplinary approach often required to explore and implement computational thinking, as it necessitates blending evaluation techniques with curricular development. Researchers may explore the development of new assessment tools and methods to measure and evaluate students' computational thinking abilities. This includes the design and validation of assessment instruments that can effectively capture the multidimensional nature of computational thinking. In past studies, various instruments have been used to measure computational thinking. These instruments include the computational thinking scale (CTS). The CTS is a self-report questionnaire that assesses students' computational thinking across different dimensions, such as problem solving, pattern recognition, and algorithmic thinking (Korkmaz et al., 2017). Werner et al. (2012) have developed a set of performance assessments involving the assessment of students' computational thinking through direct assignments or projects. This assessment requires students to apply concepts and strategies of computational thinking to solve real-world problems. Repenning et al. (2010) have introduced a set of checklists used to assess students' computational thinking by assessing their ability to use certain concepts and strategies of computational thinking. This checklist provides a structured framework for assessing different components of computational thinking. Various assessment tools have been used to measure computational thinking. Each assessment tool that has been developed has its strengths and limitations, and researchers often use a combination of instruments to collect comprehensive data on students' computational thinking abilities. The choice of assessment tools depends on the specific research context and the desired assessment results.

The exploration of computational thinking has been a multifaceted journey, traversing various disciplines and perspectives. From educational to computer science domains, researchers have delved into defining and understanding the essence of computational thinking, highlighting its critical role in fostering problem-solving abilities and analytical thinking. While definitions may vary slightly across fields, common components such as abstraction, decomposition, pattern recognition, and algorithms form the foundational pillars of computational thinking. Looking ahead, the trajectory of computational thinking research is poised to enter new territories, driven by the need for robust assessment tools and methodologies. The future landscape of computational thinking inquiry is expected to pivot towards the development and validation of assessment instruments capable of capturing the multidimensional nature of these skills. This entails not only designing tools to measure problem-solving prowess but also evaluating students' ability to apply computational concepts in real-world scenarios. As the digital era continues to evolve, computational thinking stands as a cornerstone skill, indispensable for navigating the complexities of modern society. The observation that "Engineering education" appears more frequently than "computer programming" in discussions about computational thinking is indeed noteworthy. This trend indicates that CT is transcending its traditional roots in computer science and making significant inroads into other educational disciplines. The integration of CT into engineering education reflects a broader recognition of its value as a fundamental skill set that enhances problem-solving, innovation, and analytical thinking across diverse fields. This development underscores the evolving nature of education, where interdisciplinary approaches are increasingly embraced to equip students with versatile and adaptable competencies for the future. Its integration into educational curricula underscores its significance in preparing future generations for the challenges ahead. By advancing our understanding and assessment of computational thinking, we pave the way for a more adept and resilient workforce, equipped to tackle the intricate problems of tomorrow's world.

Conclusion

In conclusion, there are several gaps in the current understanding of computational thinking. One of the gaps identified is the lack of consensus regarding the definition and components of computational thinking. Although previous studies provide insight into various components, such as problem-solving approaches and the application of computational thinking, there is a need to find a standardized and widely accepted definition that encompasses all aspects of computational thinking. It is important for empirical studies to be conducted to establish a comprehensive and universally accepted definition of computational thinking. This research should involve input from experts in the field, educators, and stakeholders to ensure a holistic understanding of the components and their interrelationships. The findings of this research can be the basis for the development of a standard framework for computational thinking. The limited focus on the assessment of computational thinking is a gap that needs to be addressed in future research. Although there has been some discussion of the assessment of computational thinking, this has not been widely explored. The development of a computational thinking skill assessment set that has validity and reliability is important to effectively measure an individual's computational thinking. Empirical studies to develop and validate assessment tools that measure various aspects of computational thinking need to be conducted. The assessment tools developed should be usable in various educational settings and age groups. Next, there is a limited understanding of the impact of teacher training programmed on the development of computational thinking. The analysis revealed a lack of emphasis on the importance of applying computational thinking in teacher training programs. It is important to understand how teacher training programmed can equip educators with the knowledge and skills needed to teach and foster computational thinking in schools. This gap needs to be addressed to ensure the successful integration of computational thinking at the school level.

Abbreviations

CCSS: Common Core State Standards; CT: Computational Thinking; CTS: Computational Thinking Scale; NGSS: Next Generation Science Standards; No.: Number; STEM: Science, Technology, Engineering, and Mathematics.

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Authors' contributions

Ahmad Sarji Abdul Hamed played a pivotal role in data collection, assuming the role of the principal author of the paper and making substantial contributions to crafting the majority of the original manuscript. Prof. Dr. Su Luan Wong provided invaluable editing and guidance in the finalization of the manuscript. Dr. Mas Nida Md. Khambari, Dr. Nur Aira Abd Rahim, Dr. Fariza Khalid, and Dr. Priscilla Moses made crucial contributions by providing essential insights during the research conceptualization phase.

Authors' information

Ahmad Sarji Abdul Hamed is a doctoral student, majoring in Educational Technology at the Faculty of Educational Studies, Universiti Putra Malaysia, Malaysia. Email: gs64812@student.upm.edu.my

Prof. Dr. Su Luan Wong is a Professor at the Department of Science and Technical Education, Faculty of Educational Studies, Universiti Putra Malaysia, Malaysia. Email: suluan@upm.edu.my

Dr. Mas Nida Md. Khambari is an Associate Professor at the Department of Science and Technical Education, Faculty of Educational Studies, Universiti Putra Malaysia, Malaysia. Email: khamasnida@upm.edu.my

Dr. Nur Aira Abd Rahim is a Senior Lecturer at the Department of Professional Development & Continuing Studies, Faculty of Educational Studies, Universiti Putra Malaysia, Malaysia. Email: nuraira@upm.edu.my

Dr. Fariza Khalid is an Associate Professor at the Centre of Innovative Studies in Learning & Teaching, Faculty of Education, Universiti Kebangsaan Malaysia, Malaysia. Email: fariza.khalid@ukm.edu.my

Dr. Priscilla Moses is an Associate Professor at the Department of General Studies, Faculty of Creative Industries, Universiti Tunku Abdul Rahman, Malaysia. Email: priscilla@utar.edu.my

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Availability of data and materials

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Declarations

Competing interests

The authors declare that they have no competing interests.

Author details

[1] Universiti Putra Malaysia, Malaysia

[2] Universiti Kebangsaan Malaysia, Malaysia

[3] Universiti Tunku Abdul Rahman, Malaysia

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