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Review and Trend Analysis of Computational Thinking Research in Mathematics Education (2013-2023)

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Abstract: This research aims to examine the development of computational thinking research publications in mathematics education (ME) from 2013 to 2023 and explore information networks based on keywords and author collaborations. The methodology used in this research is descriptive bibliometric analysis. Data collection was carried out using the Scopus database with the keywords 'computational thinking' and 'mathematics education'. Data was collected via the Publish or Perish application, 99 publications were obtained for analysis using VOSviewer. Bibliometric mapping results reveal that CT in ME remains a continuously observed and evolving topic, with significant increases over the past 11 years. The most dominant country in this field of research is the United States. Bibliometric mapping identified collaborations between authors from various countries, with Chee-Kit Looi recognized as the most influential contributor. Mapping based on the occurrence of keywords identifies relationships between scientific concepts, forming several dominant groups. Keywords that appear limited include CT in teacher aspects through teaching practices, learning approaches, and assessment. Research on this topic is relatively scarce with respect to STEM education, providing opportunities for future research and broader development in this area.

Keywords: Computational Thinking (CT); Mathematics Education (ME); Review, Trend Analysis.

Tinjauan dan Analisis Tren Penelitian Berpikir Komputasi dalam Pendidikan Matematika (2013-2023)

Abstrak: Penelitian ini bertujuan untuk mengkaji perkembangan publikasi penelitian pemikiran komputasi dalam pendidikan matematika (ME) dari tahun 2013 hingga 2023 dan mengeksplorasi jaringan informasi berdasarkan kata kunci dan kolaborasi penulis. Metodologi yang digunakan dalam penelitian ini adalah analisis bibliometrik deskriptif. Pengumpulan data dilakukan dengan menggunakan database Scopus dengan kata kunci *'computational thinking*' dan *'mathematics education'*. Data dikumpulkan melalui aplikasi *Publish or Perish*, diperoleh 99 publikasi untuk dianalisis menggunakan VOSviewer. Hasil pemetaan bibliometrik menunjukkan bahwa CT dalam ME tetap menjadi topik yang terus diamati dan berkembang, dengan peningkatan yang signifikan selama 11 tahun terakhir. Negara yang paling dominan dalam bidang penelitian ini adalah Amerika Serikat. Pemetaan bibliometrik mengidentifikasi kolaborasi antara penulis dari berbagai negara, dengan Chee-Kit Looi diakui sebagai kontributor yang paling berpengaruh. Pemetaan berdasarkan kemunculan kata kunci mengidentifikasi hubungan antara konsep-konsep ilmiah, membentuk beberapa kelompok yang dominan. Kata kunci yang muncul terbatas meliputi CT dalam aspek guru melalui praktik mengajar, pendekatan pembelajaran, dan penilaian. Penelitian tentang topik ini relatif langka sehubungan dengan pendidikan STEM, sehingga memberikan peluang untuk penelitian di masa depan dan pengembangan yang lebih luas di bidang ini.

Kata Kunci: Berpikir Komputasi (CT); Pendidikan Matematika (ME); Tinjauan; Analisis Tren.

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INTRODUCTION

Mathematics education (ME) plays a central role in forming students' analytical, creative and logical thinking skills. In the era of advanced information technology, computational thinking (CT) is a key aspect that needs to be considered in mathematics learning. Schmidt et al. (2018) emphasized that effective ME in the digital era requires the development of strong CT skills. According to him, CT skills provide students with additional tools to solve mathematical problems efficiently and can expand their understanding of fundamental mathematical concepts. In addition, the National Council of Teachers of Mathematics (NCTM) also highlighted the importance of CT in their recommendations for innovative and relevant mathematics learning (NCTM, 2020).

CT refers to the ability to solve problems using algorithmic thinking and computer programming (Wing, 2006). It involves the ability to decompose a problem into steps or algorithms that can be executed by a computer or human. With CT, individuals can identify patterns, analyze data, and formulate efficient solutions (Grover & Pea, 2013; Shute, et al., 2017). In addition, CT enables the development of deep analytical skills and the ability to understand and design complex algorithmic structures (Resnick, 2017). Thus, it would not be wrong to say that this approach plays an important role in preparing students to face challenges in the modern world which is increasingly closely related to technology and computing.

In the context of ME, CT is becoming increasingly important because technology and computing play a significant role in solving mathematical problems. Brown & Sedgewick (2012) highlighted that modern technology has provided the ability to visualize, analyze, and solve complex mathematical problems through advanced computational tools. CT, according to Sheppard (2012), opens the door to a more systematic and structured approach in solving mathematical problems, especially in dealing with large-scale and complex problems. Buckley (2012) emphasized that CT is not just about solving problems, but also about developing efficient algorithms to solve those problems. Therefore, the integration of CT in mathematics learning becomes imperative in preparing students to face the demands of an increasingly computerized world.

Previous studies have highlighted the benefits of integrating CT in ME. Jones, et al. (2017) stated that students who engage in mathematics learning that integrates aspects of CT tend to show increased ability to solve complex problems and understand mathematical concepts more deeply. This indicates that CT not only enriches the learning experience, but also can improve students' academic achievement in mathematics (Jones, et al., 2017).

In recent years, there has been an increasing interest in the integration of CT in mathematics learning at various levels of education (Fitriyah, et al., 2023). This reflects an awareness of the importance of teaching computational skills as an integral aspect of ME. Grover & Pea (2013) state that incorporating computational elements into the mathematics curriculum helps students develop analytical thinking and problem solving skills with a more structured approach. The development of information and communication technology enables the use of computational tools in solving mathematical problems more effectively and efficiently. Sentance & Csizmadia (2017) added that introducing computing in mathematics learning also has the potential to increase students' interest and engagement with the learning material.

Through bibliometric analysis, we can identify the main research that has been conducted in this field, as well as evaluate the extent to which these contributions have influenced approaches to mathematics learning at different levels. Bibliometric analysis allows us to measure the impact and relevance of research in academic and practical contexts (Baraibar-Diez et al., 2020; Ellegaard & Wallin, 2015). In addition, we can identify collaborations between researchers and institutions in various countries involved in these studies. By measuring the number of citations and authorship frequency of key works, we can understand the extent to which particular research has influenced developments and approaches in ME. In addition, bibliometric analysis can also help identify important trends and patterns in ME research, providing valuable insights for the improvement and development of more effective learning methods (Glänzel & Moed, 2002). Thus, this study can provide an in-depth view of the dynamics and developments in integrating CT in mathematics learning.

Bibliometric analysis not only allows us to understand recent contributions in the scientific literature, but also opens up potential for further development. By gaining insight into the latest trends and contributions, we can identify areas that require further research or even require new approaches in the integration of CT in ME (Glänzel & Moed, 2002). Related studies have been conducted by Tekdal (2021) in the context of CT research trends with a very wide range of subject areas, as well as research conducted by Putri, et al. (2023) by focusing on the context of learning in general. In this study, we analyze the development and trends of research related to CT with a focus on the field of ME. based on the findings of the results of research conducted by Subramaniam, et al. (2022) that research related to CT in ME has been carried out throughout 2016-2022. Therefore, the data and findings from the bibliometric analysis in this study can provide a solid foundation to support the development of related studies, as well as provide a comprehensive view of the dynamics of research in the field of ME.

Specifically, this study aims to answer four main research questions, namely (1) what is the development of research publications related to CT capabilities in ME in 2013-2023? (2) which authors and research groups had the greatest impact on the study? (3) which countries have the most influence in research publications related to CT in ME? (4) what are the most essential research topics in research related to CT in ME during 2013-2023?

METHOD

This research is a bibliometric analysis conducted using the Publish or Perish and VOSviewer applications. This series of research was carried out from November 1, 2023 to November 25, 2023. This research uses quantitative analysis of the literature to understand trends and structures of new knowledge structures in the field of research known as scientometrics. Scientometrics more commonly known as bibliometric analysis, has become the most common method for assessing the performance of researchers, departments, colleges, universities, countries, and academic journals in recent years (Konur, 2012).

This research uses co-cite analysis to assess correlation between literatures. Co-cite analysis is used to find the most influential literature by analyzing the frequency with which the literature is cited by other literature. Furthermore, co-word analysis was performed to assess the affinity-disaffinity relationship among the words appearing in the literature group obtained from the statistics of the word pair. Co-word analysis can effectively map the correlation between information items in the form of keywords in literature text data and can directly see the interaction of these keywords. Therefore, the keywords used to summarize the content of publications can be used as a basic foundation for the knowledge structure of a research field (Fraley & Raftery, 2002).

In addition, cluster analysis was conducted in this study. Basically, cluster analysis is the process of grouping objects to be more uniform than other groups (Fraley & Raftery, 2002). It evaluates how close variables or samples are based on their numerical characteristics and groups similar objects into one category, so that the results are easy to understand and the conclusions are simple and clearer. Cluster analysis in this study was used to distinguish the results from co-cite analysis and co-word analysis as different knowledge domains. Subsequently, these findings were used as the intellectual foundation and main focus for future research.

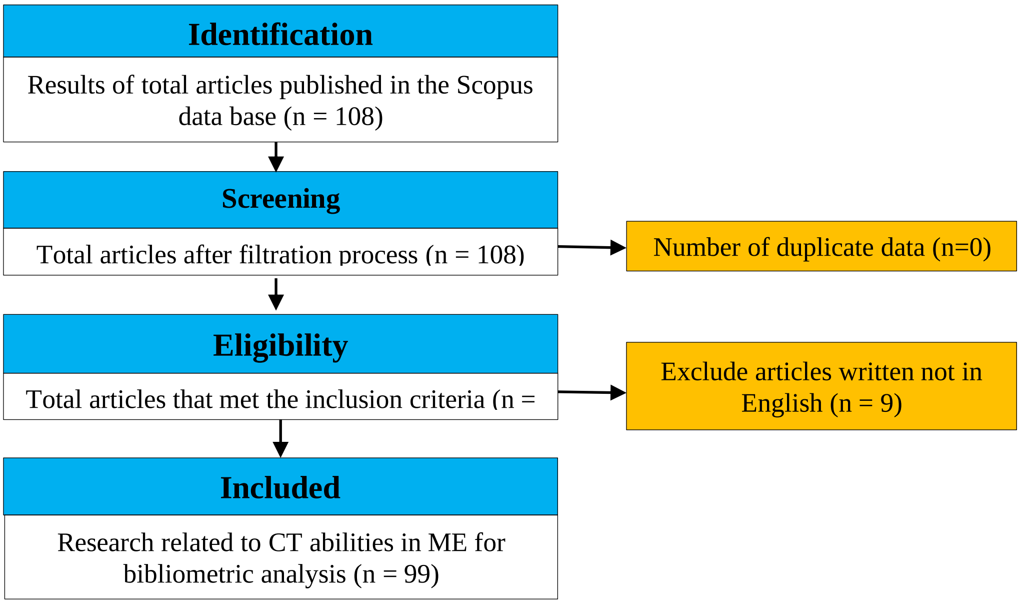

Figure 1. Data collection process using the PRISMA flow

This bibliometric analysis uses Scopus as the largest credible international database. In the data collection process, this study used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Sarkis-Onofre et al, 2021) as illustrated in Figure 1. The search used the publish or perish application by limiting the range of years (2013-2023) using two keywords namely 'computational thinking skills' and 'mathematics education'. The search results at the identification stage obtained 108 articles. Furthermore, for the accuracy and reliability of the clustering analysis, important data such as keywords from journal articles were completed using the Mendeley application. In addition, the inclusion criteria added were that the type of publication selected was a journal article or proceedings article written in English. In the end, 99 most relevant papers were obtained and met the inclusion criteria that had been set previously stored in the form of RIS files. Furthermore, the data was analyzed using VOSviewer to create and view bibliometric maps.

RESULT AND DISCUSSION

The analysis using the PRISMA method involved four main steps in research on CT in ME in the Scopus database in the last 10 years (2013-2023). The search results obtained 99 publications in that time span. The types of publications are divided into 65 (65%) journal articles and 35 (35%) proceedings articles. From the data, it can be seen the development of research publications related to CT in ME in the period 2013-2023 which is presented through the graph in Figure 2.

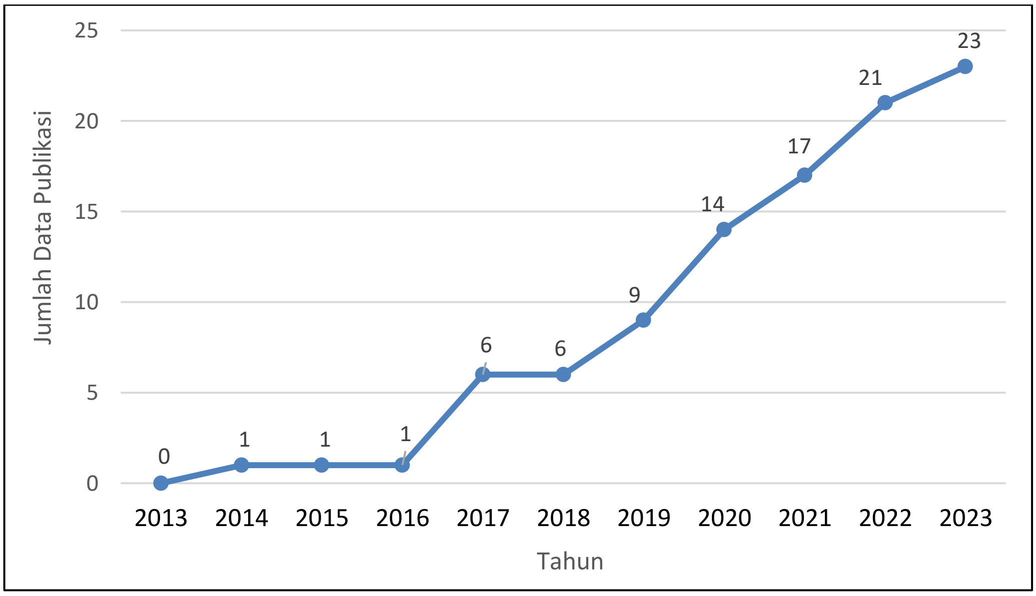

Figure 2: Publication trends (2013-2023)

In Figure 2, it is known that the number of research publications related to CT in ME is still very small in 2014 to 2016, even no related research was found in 2013. However, the number of research publications related to CT in ME began to grow significantly from 2017 to 2023. This finding is in line with the results of research conducted by So et al. (2020), that developed countries in Asia have started to include computer programming elements in the basic education curriculum since 2012. Likewise with Malaysia since 2017 (Ling, et al., 2018). This indicates that there is an increased awareness and interest in the topic within the academic community.

In the context of research development, it is seen that there is a development of research every year. Data related to research on CT in the last 10 years shows relatively positive progress. This provides a challenge for researchers in the future to innovate research given the potential for improving problem solving skills through CT.

A number of countries identified based on the country of origin of the journal in which the article was published are spread across several continents. This can be seen from the network visualization results depicted from the VOSviewer results in Figure 3. Through the analysis in Figure 3, it can be seen that the United States has a node with the largest size, while four other countries with a fairly large node size include the United Kingdom, Germany, the Netherlands, and Switzerland. This shows that these four countries also have a significant influence on related research related to CT in ME from 2016 to 2023.

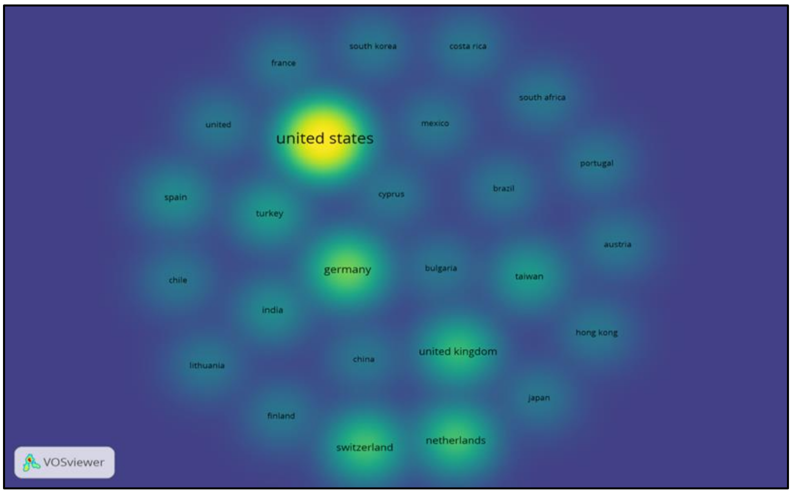

Figure 3. Density visualization based on country

More clearly, the geographical distribution of publications is shown in Figure 4 Based on the figure, a total of 27 countries were obtained. It is known that the United States is the most influential country in this field as it has published 27 articles which means more than 25% of the total publications. Furthermore, other countries such as the UK, Germany, the Netherlands, Switzerlands, Taiwan, India, Spain, and Turkey, have more than one publication with the total publications from these countries being 32% of the total publications during 2013 to 2023. Meanwhile, there are ten countries with more than one publication.

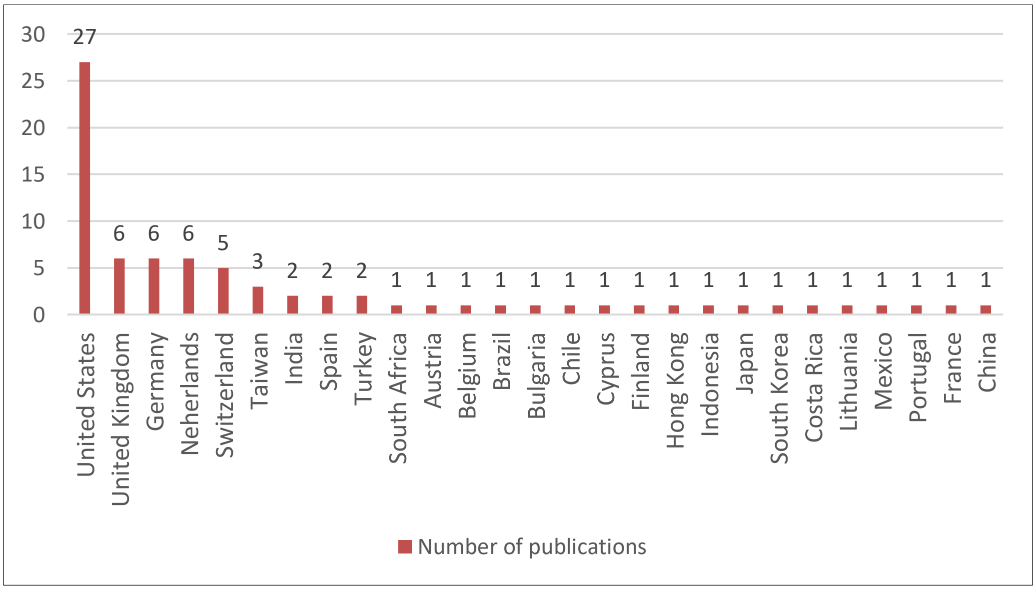

Figure 4: Number of publications based on country

The United States is one of the countries with high research interest in CT, because this thinking skill is an important skill taught in American schools. In addition, the fact that CT was first initiated in the country by a computer scientist who served as a professor at Columbia University and then at Harvard University named Jeannette Wing in 2006. This finding is in line with the research results of Mannila, et al. (2014), which shows that there is significant research interest in CT in learning in general in the United States. This means that the United States has fully realized that the importance of CT is integrated in every subject in school. Similarly, the UK has included programming material in the primary and secondary school curriculum since 2014 in order to introduce CT massively (Marifah et al., 2022; Mauliani, 2020). Meanwhile, Asian countries that still have few publications related to CT in ME, for example Indonesia, do not mean that they do not realize the importance of this CT ability, because specifically the Ministry of Education, Culture, Research and Technology (Kemendikbudristek) in Indonesia in 2022 has officially launched a media curriculum in which there is an integration of CT in learning at every level starting from elementary school (Marifah, et al., 2022).

Furthermore, data analysis was carried out using the VOSviewer application by selecting the data option 'create a map based on bibliographic data' to see the author collaboration map on research related to CT in ME. From 99 total publications, there are ten most influential authors, the visualization image of the publication bibliographic pairs is shown in Figure 5.

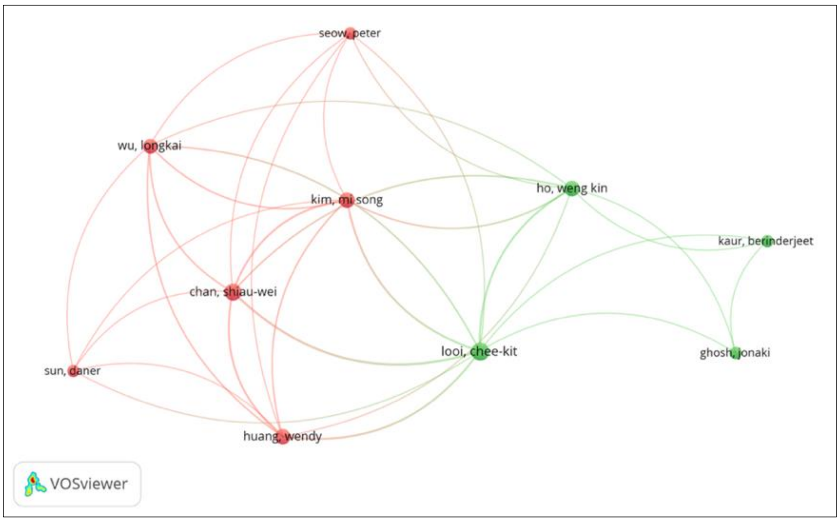

Figure 5. The pattern of relation between authors

In Figure 5, the network visualization of co-authorship is characterized by the presence of nodes that represent authors or researchers, as well as edges (networks) that represent the relationship between authors or researchers (Van Eck & Waltman, 2014). A set of nodes equipped with edges explains that there is a correlation between researchers in research on CT in ME. Bibliometric analysis based on authors or researchers centered on Chee-Kit Looi. Chee-Kit Looi is an author affiliated with the Education University of Hong Kong and is the author with the highest number of documents, indicating a significant strength of relationship with other authors. If connected to the previous findings, that although the United States is the most influential country in the publication of research related to CT in ME, the collaboration between authors from the country is still very minimal. In addition, the mapping results also indicated that most authors (92.9%) had only one published article, while a small proportion (4.28%) had two articles, and only 2.72% of authors had more than two articles. This shows that there are few authors who conduct continuing research from previous publications on CT in mathematics learning.

The network shows the relationship or collaboration of the authors, such as the network (edge) that connects Chee-Kit Looi with 6 other authors directly including Shiau-Wei Chan, Weng Kin Ho, Mi Song Kim, Wendy Huang, Jonaki Ghosh, and Berinderjeet Kaur. These authors are affiliated with universities from developed countries such as Hong Kong, Singapore, Malaysia, India, and the United Kingdom. This shows that collaboration between authors occurs not only from one country but from various countries. Furthermore, this can be an opportunity for the development of research related to CT in ME to spread throughout the world.

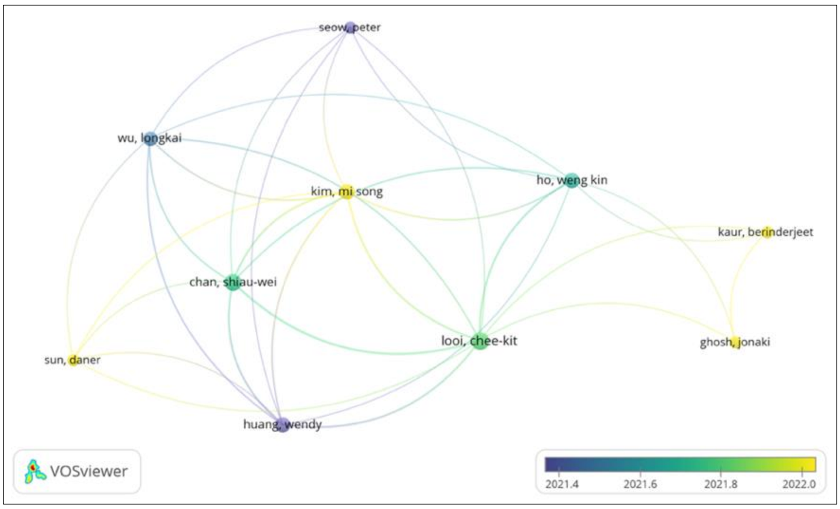

Figure 6. Overlay visualization of authors

In Figure 6, the data is displayed with an overlay visualization, there are several articles that are purple, green and yellow. These colors indicate the time of publication of the article from the corresponding author. The yellow color explains that the article was published around 2022. Then the green color is published around the end of 2021, the purplish green color is published around the middle of 2021, and the purple color is published around 2021 early. Interpretation of the network visualization in Figure 6 shows Chee-Kit Looi citing other authors including Shiau-Wei Chan, Weng Kin Ho, Longkai Wu, Wendy Huang, and Peter Seow, because the color of his research is lighter than the color of their research. However, other researchers Daner Sun, Mi Song Kim, Jonaki Ghosh, and Berinderjeet Kaur cited Chee-Kit Looi because her research color is darker than theirs. Mi Song Kim, Daner Sun, Jonaki Ghosh, and Berinderjeet Kaur are authors with yellow color, meaning that all four have published several articles around 2022. Furthermore, articles that have been published for a long time are written by Longkai Wu, because his node color is darkest than the others.

Next, a co-citation analysis was conducted using VOSviewer. Journal co-citation occurs when two documents from two different journals receive citations from the same document in another journal (Boyack & Klavans, 2010). The co-citation map of journals related to CT in ME is shown in Figure 7. When the occurance threshold was set to at least 2, a total of 89 nodes were generated for the map. The size of the circle indicates the relevance of the topic (Kurniawati & Wahyuni, 2023). The lines between the circles indicate the co-citation relationship, and the number and thickness of the lines indicate the strength of the relationship between journals. The top ten journals with the highest number of co-citations are listed in Table 1.

Table 1. Journals or conferences with the most co-published articles

No	Journal or Conference	Country of Origin	Total Citations
1	Technology, Knowledge and Learning	Netherlands	78
2	Journal of Science Education and Technology	United States	72
3	Mathematical Thinking and Learning	United States	61
4	International Journal of Information and Learning Technology	United Kingdom	44
5	Journal for Research in Mathematics Education	United States	39
6	Computer Applications in Engineering Education	United States	35
7	International Journal of Mathematical Education in Science and Technology	United Kingdom	33
8	ZDM - Mathematics Education	Germany	31
9	Proceedings of the ACM on Programming Languages	United States	24
10	Educational Technology Research and Development	United States	23

Table 1 shows that the most influential journal in terms of total citation frequency is Technology, Knowledge and Learning, which has a strong authority in the field of CT in ME. Six of the ten most cited journals are published in the United States and the other four are in the UK, Germany and the Netherlands, indicating that the main research areas of CT research in ME are still in the United States and Europe.

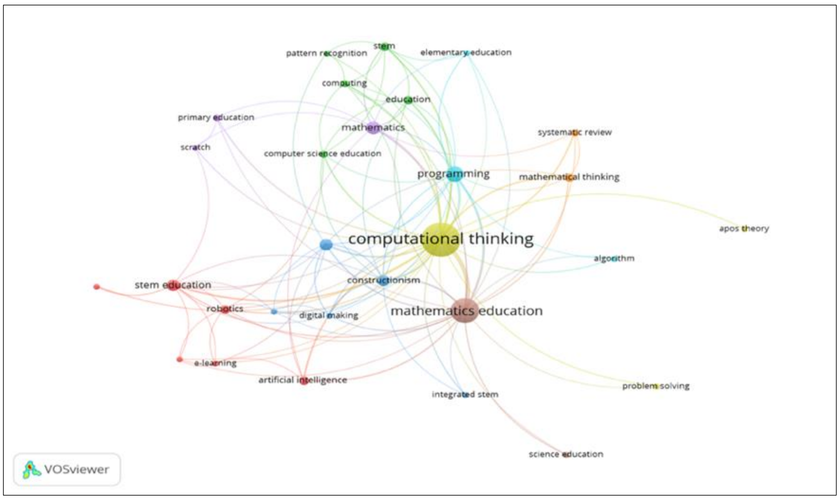

Figure 7. Network visualization of keyword pairs with number of occurrence of keywords: at least 2 times

In the results of mapping the development of research publications on CT in ME based on keywords. Extraction results with the minimum number of keywords that appear is 1 obtained 234 keywords. However, the keywords that appear are too common, so the data is too much and the mapping is too large, so re-extraction is carried out by changing the minimum number of keywords that appear is 2. The results obtained from the process, there are 29 keywords that meet the minimum threshold based on the mapping, as shown in Figure 7.

Co-keyword analysis using VOSviewer associates keywords with corresponding documents. Figure 7 shows the co-keyword network of the data synthesized in this study. The size of the nodes reflects the frequency of occurrence of the keywords in the data of CT in ME publications in this study. The five keywords with the most occurrences besides 'computational thinking' and 'mathematics education' are 'programming' 13 times, 'constructionism' 6 times, 'mathematics' 9 times, 'problem solving' 7 times, and 'stem education' 7 times.

The network visualization of co-occurrence shown in Figure 7 explains the relationship of one term to another in the research on CT in ME in the period 2013 - 2023. From Figure 7, there are 9 clusters that can be seen based on the color of the nodes. Cluster 1, marked by red nodes, consists of artificial intelligence, e-learning, educational robotics, engineering, robotics, and stem education. Cluster 2, marked with green nodes, consists of computer science education, computing, education, pattern recognition, and stem. Cluster 3, marked with dark blue nodes, consists of constructionism, digital making, integrated stem. Cluster 4, marked with yellow nodes, consists of apos theory, computational thinking (CT), problem solving. Cluster 5, marked with purple nodes, consists of methematics, primary education, scratch. Cluster 6, marked with tosca blue nodes, consists of algorithm, elementary education, programming. Cluster 7, marked with orange nodes, consists of mathematical thinking. Cluster 8, marked by brown nodes, consists of mathematics education (ME) and science education.

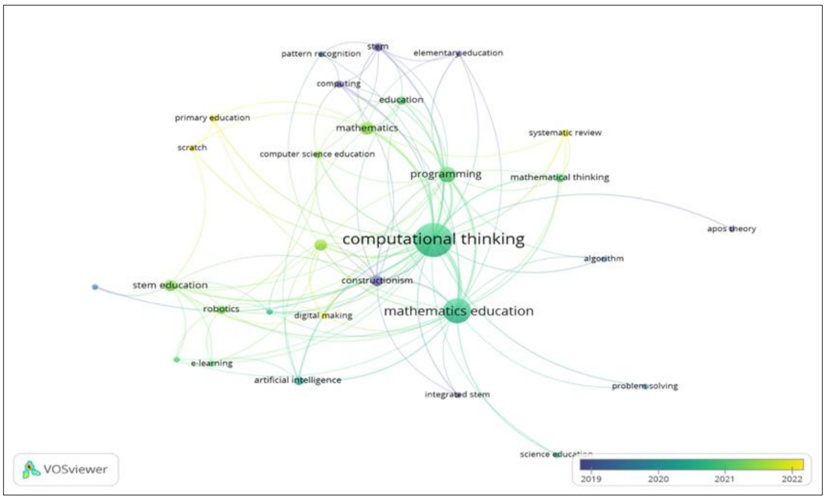

Figure 8. Overlay visualization of keyword pairs

In this visualization, the color of the nodes indicates the keywords and the year of publication. The keywords 'Computational Thinking' and 'Mathematics Education' have green nodes, which means that the articles containing these keywords were published around 2020 - 2022. While the term 'STEM Education' which in the Overlay visualization is depicted as having light green nodes, this means that the term in research on CT in ME with STEM education integration was published by researchers in 2022. Based on Figure 8, it is known that the publication of CT in ME is a renewable research as seen from the year of publication, namely the range 2020 - 2022, the most in the 2020.

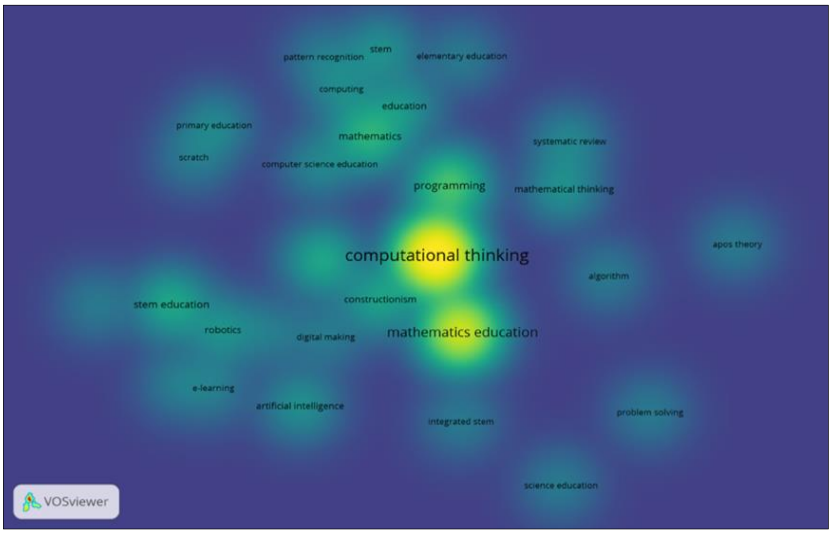

Figure 9. Density visualization of keyword pairs

Bibliometric analysis uses density visualization. From the visualization results shown in Figure 9, it can be identified that there are dense areas or those with high density between one node and another. The level of saturation identified in the number of keywords marked in yellow means that the region is a topic that has been widely researched and indexed by Scopus, for example, the keyword Computational Thinking. While nodes marked with dark colors indicate that these topics are still not widely researched. This can be an opportunity to conduct research on these topics, for example, the keyword collaborative knowledge construction which is connected to omputational thinking. Bibliometric analysis on collaborative knowledge construction shows a low stretch and intensity, indicating that research on collaborative knowledge construction related to CT is still relatively low, which makes research on this topic still very broad to be researched. In addition, it can also be seen that research on CT in ME with digital competence is still relatively low, which can be a topic that can be researched and developed more broadly.

CONCLUSION

Based on the results of bibliometric mapping using VOSviewer using network, overlay, and density visualization, it can be concluded that in the period 2013-2023, CT research in ME continues to grow significantly, this can be interpreted that this research is a topic that continues to be observed and developed in all countries in Europe, America, and Asia. In addition, bibliometric mapping identifies collaboration between authors who take the theme of CT in ME from various countries in Asia and the United Kingdom, where Chee-Kit Looi is the most influential author in research related to CT in ME with the highest number of citations.

The United States is the country with the highest interest in related research. The fact that CT was first initiated in the country by Jeannette Wing in 2006. In addition, the United States has fully realized that the importance of CT is integrated in every subject in school. Likewise with other countries in Europe and Asia. Mapping the development of CT in ME based on co-occurrence (keywords). This mapping identifies the relationship between scientific concepts with several dominant clusters, such as computational thinking (CT) in the aspect of teachers through teaching practice, learning approaches such as Rasch models, the use of tools such as geogebra, spreadsheets or scratch, and assessment with a more limited number of keyword occurrences. Then, it can also be seen that there is still relatively little research on CT in ME associated with STEM education then it can be a topic that can be researched and developed more broadly.

This study has several limitations, including the filtering of search results where the search process is still limited to the last 11 years. Further research should consider making a longer year coverage considering the history of CT was first officially introduced by Jeannette M. Wings in 2006 (Wing, 2006). Another obstacle is the limitation of the Scopus account used in the extraction of metadata by the author. Therefore, future related research can add a wider range of databases such as Google Scholar, Web of Science, or Dimensions so that it can describe research trends more comprehensively.

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