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Tren Computational Thinking in Mathematics Education: A Global Bibliometric Analysis 2016-2025

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ABSTRACT

This study aims to identify the trends of annual publications, the linkages of keywords and thematic clusters, the patterns of collaboration between authors and institutions, as well as the most prolific and influential authors in the study of Computational Thinking (CT) in the field of mathematics education over the past decade. Data is collected from the Scopus database using relevant keywords, then analyzed through the VOSviewer software to map the relationships between keywords, authors and documents. The results of the analysis showed a significant increase in the number of publications from year to year, with the five most prolific authors being Ng, Oi-Lam; Barendsen, Erik; Drijvers, Paul; Gadanidis, George; and Maharani, Swasti. The focus of the research is divided into five main thematic clusters, namely the perspective of students and teachers on CT, the development of CT assessment instruments, the integration of CT in mathematics learning, systematic studies related to CT-based learning models, as well as publication trends and bibliometric studies. These findings confirm the important role of CT in improving the quality of 21st century mathematics learning. Recommendations for further research include the development of CT-based pedagogical models for different levels of mathematics education, the exploration of students' affective and metacognitive aspects in CT learning, as well as the development of more specific and contextual CT assessment instruments for mathematics learning.

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1. INTRODUCTION

The 21st century demands high-level thinking skills that include not only literacy and numeracy, but also computational thinking (CT). CT is defined as the ability to solve problems, design systems, and understand human behavior using a computer science approach (Lee, 2020; Lockwood, 2021; Wing, 2006). In mathematics education, CT plays an essential role in encouraging abstraction, problem decomposition, and algorithmic reasoning, thereby strengthening students' understanding of mathematical concepts (Khoo et al., 2022; Suarsana et al., 2024; Surahman et al., 2020). The integration of CT into mathematics learning is also aligned with current curriculum demands that emphasize digital literacy and the development of 21st-century skills (Maharani et al., 2020; Yuntawati et al., 2021).

Recent studies highlight that embedding CT into mathematics not only enhances students' problem-solving abilities but also prepares them to face increasingly complex technological challenges (Grover, 2021; Sengupta et al., 2018) However, despite its importance, the application and understanding of CT in the context of mathematics education—especially in school-level classrooms—remain limited and underexplored (Katuk et al., 2020; Yadav, 2018). This indicates a significant research gap that needs to be addressed to support effective pedagogical strategies. Therefore, examining how CT can be strengthened through mathematics learning is both timely and urgent. This effort is a strategic step to equip the younger generation with adaptive thinking patterns required in the digital era (Ismarmiaty et al., 2022; Romandoni et al., 2023; Suparman et al., 2024).

Several studies have highlighted the importance of computational thinking in education as well as its relationship to mathematics learning. For example, Weintrop (2016) developed a framework for the integration of CT in STEM subjects, including mathematics, by highlighting aspects such as data, modeling, and algorithm-based computing. On the other hand, a research review by Shuter et al. (2021) showed that CT learning had a positive impact on improving problem-solving and logical thinking skills. Additional studies, such as those by Lee et al. (2019); Rich et al. (2022); Sengupta et al. (2013) have also examined how CT can be embedded into classroom practices, teacher training, and curriculum development. These studies have largely discussed pedagogical approaches, program effectiveness, and curriculum integration, but they tend to focus on specific case studies or qualitative syntheses rather than providing a macro-level view of the field.

Atmatzidou (2017) also traced the effectiveness of CT programs in high school, but without a bibliometric approach. Even though the volume of research on CT in mathematics education continues to grow rapidly, there is still a lack of studies that comprehensively map the knowledge structure, thematic evolution, and author collaboration patterns in this area. This shows that although systematic and narrative studies have been carried out extensively, bibliometric approaches that can describe knowledge structures and collaborative networks in this field are still very limited. Therefore, this study aims to fill the research gap by conducting a global bibliometric analysis of CT in mathematics education from 2016 to 2025. Unlike previous works that focus on content-based reviews, this study offers a quantitative visualization of publication trends, influential authors, co-authorship networks, and thematic developments using bibliometric tools. This provides a distinctive contribution to the field by offering a holistic overview of how research on CT in mathematics education has evolved and where it is heading.

Although attention to computational thinking in mathematics education continues to increase, there have not been many bibliometric studies that map the development of this research globally. So far, the majority of studies are still narrative or systematic with a focus on pedagogical implementation, while studies that present trend mapping, collaboration, and research direction are still limited. In fact, bibliometric analysis is very useful for identifying knowledge structures, influential authors, and emerging topics in a research field (Donthu et al., 2021; Hodiyanto et al., 2024; Mangiri & Prabawanto, 2024). With this approach, mapping the CT literature in mathematics education can provide a comprehensive picture of the scientific dynamics that have occurred over the past decade. The absence of bibliometric studies on this topic confirms the urgency of conducting this research (Eck & Waltman, 2009; Maharani, 2023).

This study aims to conduct a global bibliometric analysis of publications that discuss computational thinking in the context of mathematics education in the period 2016 to 2025. In particular, this study aims to address key research questions regarding CT in mathematics education. Specifically, it aims to identify the trends in the number of publications each year from 2016 to 2025, explore the dominant keywords and thematic clusters within the literature, examine the collaboration networks between authors and institutions, and identify the most productive and influential authors and institutions in this field. By analyzing these indicators, this study is expected to provide a comprehensive overview of the development of CT research in mathematics education. The findings are intended to serve as a strategic reference for researchers, educators, and policymakers in shaping future research directions and enhancing teaching practices in alignment with current trends in CT (Maharani et al., 2024).

To achieve this goal, this study is designed to answer several key questions. First, what are the annual publication trends related to computational thinking in mathematics education from 2016 to 2025? Second, what dominant keywords and thematic clusters emerge from the existing literature during that period? Third, how are collaboration patterns formed among authors and institutions in this research field? Fourth, who are the most productive and most cited authors contributing to the development of computational thinking in mathematics education? These four questions will be addressed through bibliometric analysis based on data extracted from a reputable international database, with the aim of mapping global research directions, collaboration networks, and key contributors in the field (Rafiq et al., 2023; Romandoni et al., 2023).

2. METHODS

This study employs a descriptive quantitative research design using a bibliometric approach. Bibliometric analysis is widely used to systematically identify patterns, structures, and developments in scientific publications within a specific research domain (CheshmehSohrabi & Mashhadi, 2022). The purpose of using this method is to quantitatively map the growth, collaboration, and influential contributions in the field of computational thinking (CT) in mathematics education. Data for this study were obtained from the Dimensions.ai database, a global scholarly database that indexes a wide range of academic publications, including journal articles and conference proceedings. Dimensions was selected due to its broad multidisciplinary coverage, access to citation metrics, and its compatibility with bibliometric tools such as VOSviewer. The data collection process was carried out using the main keywords: “computational thinking” AND “mathematics education”. The search was restricted to publications from January 2016 to March 2025, aiming to capture research developments over the last decade. This search produced 267 publications that were then exported in CSV format for further processing and analysis.

To ensure the quality and relevance of the dataset, a number of inclusion and exclusion criteria were applied. The inclusion criteria consisted of several points: (1) articles must be published in English; (2) the content must focus on computational thinking within the context of mathematics education; (3) the publications must contain complete metadata, including author names, institutional affiliations, keywords, and reference lists; and (4) only journal articles and conference papers were included in the analysis. Conversely, the exclusion criteria covered publications such as editorials, short notes, book reviews, or non-peer-reviewed materials, as well as articles that lacked complete metadata or were duplicated. After applying these criteria, a thorough screening of titles and abstracts was conducted to ensure that the final dataset accurately represented the research focus.

The collected data were then analyzed using two main tools: VOSviewer and Microsoft Excel. VOSviewer was employed to construct bibliometric visualizations such as keyword co-occurrence networks, authorship collaborations, and institutional mapping, while Microsoft Excel was used to perform descriptive statistical analysis. This study specifically focused on four key indicators: first, annual publication trends were analyzed to observe the progression and dynamics of research from 2016 to 2025; second, keyword co-occurrence and thematic clustering were examined to identify the most frequently used terms and emerging research themes; third, authorship and institutional collaboration were mapped to reveal patterns of cooperation and active contributors in the field; and fourth, the most productive and top-cited authors were identified based on their publication output and citation impact. Altogether, these indicators provide a comprehensive overview of the evolution, influence, and collaboration trends in computational thinking research within mathematics education.

3. FINDINGS AND DISCUSSION

A total of 178 publications were selected based on the inclusion criteria during the data screening stage, covering the period from 2016 to 2025. These publications consisted of 155 journal articles and 23 conference proceedings, all of which were deemed relevant to the topic of computational thinking in mathematics education.

3.1 Annual Publication Trends

The annual publication trends show a consistent increase in the number of studies on computational thinking in mathematics education between 2016 and 2025, indicating growing research interest in this field. The graph can be seen from the following image.

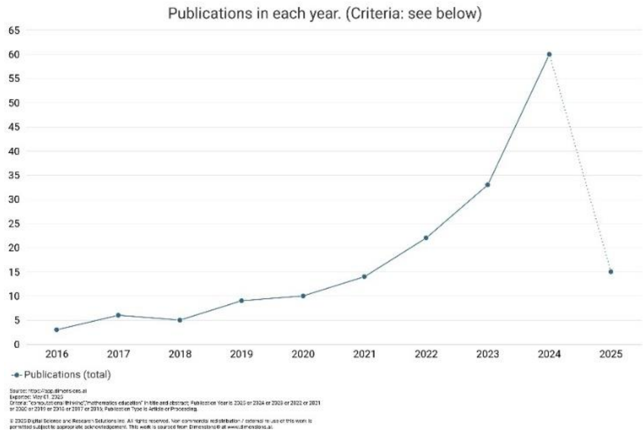

Figure 1. Annual Publication Trends

The trend of publications on computational thinking in mathematics education shows a significant increase over the past decade. Based on data from 2016 to 2025, it was recorded that the number of publications increased from only 3 publications in 2016 to a peak of 60 publications in 2024. Although 2025 is not yet over, as of the data collected there have been 15 publications, which shows that the trend remains high compared to the early years. The increase began to be seen since 2020 with 10 publications, followed by a gradual increase to 33 in 2023 and a drastic spike to 60 in 2024. This trend shows an increasing global attention to the importance of CT in the context of mathematics education, along with the increasing need for the integration of technology and computational thinking in mathematics classrooms.This phenomenon is in line with the findings Allsop (2019); Maharani et al. (2020); Wing (2006) which emphasizes that computational thinking is a basic 21st century skill that needs to be taught from an early age, including through mathematics education. In addition, a study by Bocconi et al., (2016) also mentioned that the explicit implementation of CT in the curriculum has increased globally since 2020, especially in countries with national digital literacy strategies. Overall, this data indicates that within a decade, there has been a paradigm shift in the world of mathematics education that has begun to adopt the CT approach as an important part of learning that is relevant to the challenges of the times.

3.2 Keyword Co-occurrence and Thematic Clusters

The analysis of the co-occurrence of keywords from 177 publications analyzed resulted in a number of main thematic clusters that show the research focus in the study of computational thinking (CT) in mathematics education. Visualization using VOSviewer groups keywords into five different interrelated color clusters, representing dominant themes that emerged in the literature over the past decade. The visualization can be seen in the following image.

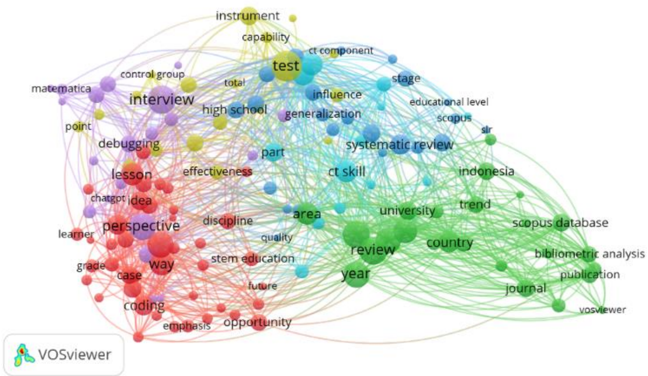

Figure 2. Keyword Co-occurrence and Thematic Clusters

The red cluster shows themes around learning approaches and implementable practices such as lessons, coding, perspective, way, and emphasis. These words highlight CT-based learning approaches, the use of coding in mathematics classrooms, and various perspectives in the application of CT. This is in line with the findings (Fitriani et al., 2023; Grover, 2019; Huang & Qiao, 2022) which emphasizes the importance of integrating coding in mathematics education to foster computational thinking skills.

The green cluster reflects methodological and bibliometric dimensions such as review, country, trend, publication, and bibliometric analysis. This shows that a large number of publications focus not only on the implementation of CT, but also on the mapping of studies and research trends themselves, as done by Nijenhuis-Voogt et al. (2020) which reviews the importance of systematic studies in the development of CT in education. The blue cluster shows a focus on CT ability and education level such as CT skill, generalization, educational level, and systematic review. This suggests that the research is not only focusing on practice, but also on the measurement, assessment, and review of CT capabilities themselves.

The yellow cluster appears to highlight data collection methods such as tests, instruments, and interviews, indicating the research's focus on instrument validation and intervention effectiveness. Meanwhile, the purple cluster shows a connection with early learning issues such as debugging, grade, and learner, leading to the importance of implementing CT since primary education. The results of this analysis show that the trend of CT research in mathematics education is growing and covers pedagogical, methodological, and bibliometric dimensions broadly (Haydar, 2023; Haydar et al., 2023; Refvik & Bjerke, 2022). The clusters that emerge provide a comprehensive overview of the main focuses of researchers in the past decade.

The findings confirm that the current direction of CT research is no longer limited to instructional or media development, but rather leads to skills evaluation, literature mapping, and integration of CT in national and international curricula. The research gaps identified include the need for more longitudinal studies on the effectiveness of CT at various levels of education, as well as the limitations of interdisciplinary approaches in linking CT with non-STEM subjects. Authors such as O.-L. Ng et al. (2023); S. Y. Ng (2022) menekankan bahwa "CT is not only a tool for digital learning, but a way of thinking applicable across disciplines," while Kallia et al. (2021) adding that "explicit teaching of CT components should be integrated systematically in mathematics education." As such, CT has a globally important role as a transdisciplinary pedagogical approach that strengthens problem-solving, critical thinking, and innovation in mathematics education.

3.3 Authorship and Institutional Collaboration

In the analysis of the authors' collaboration in 177 publications related to the topics analyzed, a visualization of the collaboration network was obtained which showed the existence of collaborative groups that are limited to a limited connection between authors. From the mapping results (Figure 3), it can be seen that some authors have strong collaborative relationships, such as Barendsen, Erik; Floats, Paul; and Tolboom, Jos. The three form a solid collaborative group, characterized by a close connection between them.

In addition, some writers are seen standing alone (isolated nodes), such as juandi, dadang; Maharani, Swasti; Bjerke, Annette Hessen; and son, Zedra Hainul. This shows that they do not have significant collaborations with other authors in this network. Other authors who form a two-way but limited collaboration between two individuals, such as ng, oi-lam and ye, huiyan, also appear in the visualization. The mapping of institutional collaboration (Figure 4) shows that the institution with the most publication contributions is the Indonesia University of Education, which is connected to several other universities both from within and outside the country. Overseas institutions such as Western University, Oregon State University, and Utrecht University also appeared in the network, indicating the existence of international collaboration, although the intensity of collaboration was still limited. Meanwhile, other institutions in Indonesia such as the University of Muhammadiyah Malang and the University of Jember do not seem to have strong collaborative connections with other institutions in this network. This fact indicates that research collaboration on this topic is still fragmented and a broad and solid network of cooperation between institutions in Indonesia has not been built.

In general, the authorship and institutional collaboration analysis shows that most research is conducted by small groups with limited collaboration. This is an important input to encourage more cross-author and cross-institutional cooperation so that research in this field develops more broadly and in-depth. Figures 3 and 4 are presented below.

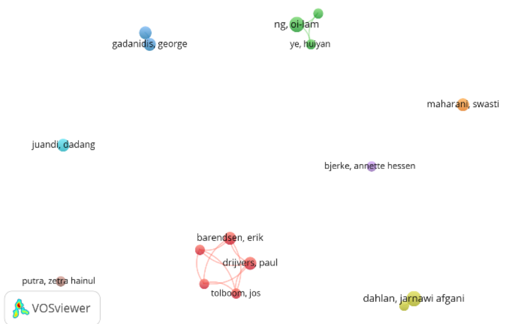

Figure 3. Authorship

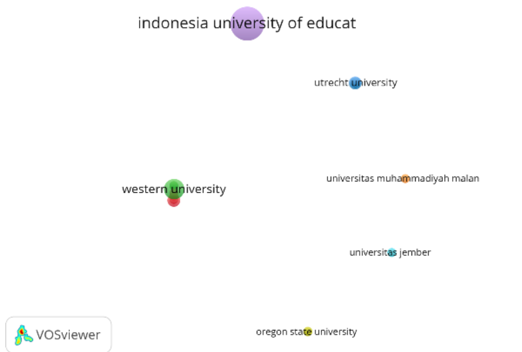

Figure 4. Institutional Collaboration

3.4 Productive and Top-Cited Authors

An analysis of the most prolific and most cited authors in related publications shows five prominent names, as shown in Figure 5 below.

Selected	Author	Documents	Citations	Total link strength
☑	ng, oi-lam	5	176	3
☑	barendsen, erik	4	118	11
☑	drijvers, paul	4	118	11
☑	gadanidis, george	4	166	5
☑	maharani, swasti	4	36	2

Figure 5. Productive and Top-Cited Authors

The author with the highest number of publications is Ng, Oi-Lam, with a total of 5 documents and a total of 176 citations, showing significant contributions both in terms of quantity and scientific influence. Next, Barendsen, Erik and Drijvers, Paul each have 4 documents and 118 citations, with the highest total link strength (TLS) of 11. This shows that they are not only actively writing, but also have a strong collaborative network with other writers in this field.

Gadanidis, George is also one of the most influential writers, although the number of documents is only 4, he has obtained 166 citations, making him one of the authors with the highest citation ratio among the top five. Meanwhile, Maharani, Swasti, who is from Indonesia, was also included in the top five with 4 documents and 36 citations. Despite having the lowest total link strength (2), its presence among the top authors demonstrates the potential contribution of local researchers in global research on this topic. These findings show that the dominance of authors in this field is spread across several countries, including contributions from Indonesia, although it still needs to be improved in terms of influence and collaborative networking.

Discussion

The results of this study align with the main objectives outlined in the introduction, which aim to explore the trends, dominant keywords, collaboration networks, and influential authors and institutions in the study of Computational Thinking (CT) in mathematics education over the past decade. The analysis of annual publication trends revealed a consistent increase in publications from 2016 to 2025, signaling the growing academic interest in CT as an essential component of 21st-century mathematics education. This finding supports Angraini (2024); Rianto et al. (2024) who argues that CT is a fundamental competency that should be introduced at the elementary education level. Additionally, it is reinforced by van Borkulo et al. (2021), who highlight the importance of integrating CT into mathematics learning to strengthen students' problem-solving and algorithmic thinking skills. The rising publication trend further reflects the increasing recognition of CT's relevance in modern educational frameworks.

The keyword mapping analysis revealed five primary thematic clusters: (1) student and teacher perspectives on CT, (2) development and validation of CT assessment instruments, (3) integration of CT within the context of STEM and school curricula, (4) systematic studies and CT-based learning models, and (5) publication and bibliometric trends. These thematic clusters build on the work of Gadanidis (2017); O.-L. Ng et al. (2023) who argue that CT extends beyond programming to include mathematical representations, patterns, and logical thinking. For example, Gadanidis et al. (2016) assert that "mathematics and computational thinking are mutually reinforcing domains," meaning that mathematics education can be enriched through explicit and applied CT approaches. The findings of this study reinforce this perspective, showcasing the multifaceted nature of CT and its critical role in enhancing mathematics education.

In the realm of authorship and institutional collaboration, the study visualized a collaboration network that revealed a concentration of prominent researchers, such as Ng, Oi-Lam, and Barendsen, Erik, who lead the field. However, the collaboration between institutions across different countries remains limited, indicating a gap in research dissemination from developing nations. This finding contrasts with the call by (Angeli & Giannakos, 2020; Nordby et al., 2022) for a more global approach to CT application. The study confirms that research from local contexts, particularly from developing countries, is still underrepresented in the global literature. This highlights the need for more collaborative research strategies that involve diverse countries and socio-cultural contexts, fostering a richer, more inclusive global dialogue on CT in mathematics education.

Regarding productive and top-cited authors, the study identified key contributors whose work focuses on CT assessments Aydeniz, (2018); Chytas et al. (2024) the integration of CT in curricula (O. L. Ng, 2021) and the exploration of CT-based learning design (Hasanah & Masduki, 2024). These findings are consistent with previous research but offer an updated and more comprehensive understanding through the visualization of trends and scientific relationships in CT research. This approach provides new insights that have not been explored in depth before, offering a clearer view of the field's development and the contributions of influential authors.

The implications of this study emphasize the necessity of developing educational policies that support the integration of CT into the basic mathematics curriculum. Furthermore, the study highlights the need for improving teacher training in CT-based pedagogy to ensure effective implementation in classrooms. Future research should focus on longitudinal studies that examine the effectiveness of CT applications in real classroom settings, especially in developing countries, which are currently underrepresented in the literature. Additionally, extending bibliometric analysis to include data from multiple scientific databases would enhance the global understanding of CT research dynamics and provide a more comprehensive picture of the field’s growth and challenges.

4. CONCLUSION

This study shows a significant increase in publications related to Computational Thinking (CT) in basic mathematics education during 2016-2025, with exponential growth especially since 2018, reflecting the global recognition of the importance of integrating CT in mathematics learning. The bibliometric analysis identified five main thematic clusters: student and teacher perspectives, the development of CT assessment instruments, the integration of CT in mathematics curriculum, CT-based learning models, and research methodology trends, with dominant keywords such as "computational thinking" and "mathematics education". The pattern of researcher collaboration forms five main networks dominated by institutions from developed countries, with prominent contributors such as Ng, Oi-Lam and Gadanidis, George. These findings have implications for the need for mathematics curriculum reform, teacher professional development, innovative learning design, and educational policies that support CT integration, as well as recommend future research focusing on longitudinal studies and contextual expansion to developing countries. In addition, further research is also recommended to develop CT assessment instruments specifically designed for the context of mathematics learning, so that students' ability in computational thinking can be measured validly, reliably, and according to curriculum needs.

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