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Mapping the Integration of Computational Thinking in Mathematics Education: A Scopus-Based Bibliometric Analysis (2015–2025)

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Abstract: *This study presents a comprehensive bibliometric analysis of research on Computational Thinking (CT) in mathematics education, based on Scopus-indexed publications from 2015 to 2025. CT—encompassing higher-order cognitive skills such as decomposition, pattern recognition, abstraction, and algorithmic thinking—has gained increasing relevance in 21st-century mathematics instruction. The study aims to map the development of research in this domain by analyzing seven key aspects: publication trends, author productivity, institutional productivity, journal productivity, international collaboration patterns, co-word relationships, and thematic evolution. A total of 165 English-language journal articles were analyzed using RStudio in conjunction with the Bibliometrix package. The results indicate a rapid annual publication growth rate of 23.11%, reflecting heightened global interest in the topic. Most publications resulted from collaborative research, with notable international partnerships, particularly involving Southeast Asian countries such as Indonesia. Frequently occurring keywords included "computational thinking," "students," and "engineering education," highlighting the emphasis on student-centered and interdisciplinary approaches. The co-word network and thematic mapping revealed strong linkages between CT and STEM education, project-based learning, curriculum development, and educational equity. Digital tools, including Scratch, robotics, and gamified learning platforms, shape the research landscape. However, persistent challenges remain, including limited teacher preparedness and unequal access to resources. This study contributes to educational innovation by illustrating how CT transforms mathematics pedagogy into a more contextual, technology-integrated, and collaborative practice. The findings are intended to inform educators, policymakers, and researchers in advancing curriculum reform and strategic research planning to enhance CT implementation across diverse educational contexts.*
Keywords*: computational thinking, mathematics education, bibliometric analysis, 21st-century learning.*

Abstrak: Penelitian ini menyajikan analisis bibliometrik komprehensif mengenai kajian *Computational Thinking* (CT) dalam pendidikan matematika, berdasarkan publikasi terindeks Scopus periode 2015–2025. CT yang mencakup keterampilan kognitif tingkat tinggi seperti dekomposisi, pengenalan pola, abstraksi, dan berpikir algoritmik semakin relevan dalam pembelajaran matematika abad ke-21. Tujuan penelitian ini adalah memetakan perkembangan kajian pada bidang tersebut dengan menganalisis tujuh aspek utama: tren publikasi, produktivitas penulis, produktivitas institusi, produktivitas jurnal, pola kolaborasi internasional, keterkaitan kata kunci, dan evolusi tematik. Sebanyak 165 artikel jurnal berbahasa Inggris dianalisis menggunakan RStudio dengan paket *Bibliometrix*. Hasil penelitian menunjukkan laju pertumbuhan publikasi tahunan yang pesat, yaitu 23,11%, mencerminkan meningkatnya minat global terhadap topik ini. Sebagian besar publikasi merupakan hasil kolaborasi riset dengan kemitraan internasional yang menonjol, khususnya melibatkan negara-negara Asia Tenggara seperti Indonesia. Kata kunci yang sering muncul antara lain *"computational thinking," "students," dan "engineering education,"* yang menegaskan fokus pada pendekatan berpusat pada siswa serta bersifat interdisipliner. Jaringan kata kunci dan pemetaan tematik mengungkap keterkaitan kuat CT dengan pendidikan STEM, pembelajaran berbasis proyek, pengembangan kurikulum, dan kesetaraan pendidikan. Alat digital seperti Scratch, robotika, dan platform pembelajaran berbasis permainan turut membentuk lanskap riset ini. Namun, tantangan masih dihadapi, termasuk keterbatasan kesiapan guru dan ketidakmerataan akses sumber daya. Penelitian ini berkontribusi pada inovasi pendidikan dengan menunjukkan bagaimana CT mentransformasi pedagogi matematika menjadi lebih kontekstual, terintegrasi teknologi, dan kolaboratif. Temuan ini diharapkan dapat menjadi rujukan bagi pendidik,

pembuat kebijakan, dan peneliti dalam mendorong reformasi kurikulum serta perencanaan riset strategis untuk meningkatkan implementasi CT di berbagai konteks pendidikan.
Kata kunci: berpikir komputasional, pendidikan matematika, analisis bibliometrik, pembelajaran abad ke-21.

INTRODUCTION

In today's increasingly complex digital landscape, Computational Thinking (CT) has emerged as a fundamental skill set for 21st-century education. CT encompasses higher-order cognitive abilities, including decomposition, abstraction, pattern recognition, and algorithmic thinking. These skills equip students to approach problems systematically and creatively, making CT particularly relevant in mathematics education, where logical reasoning, structured analysis, and precision are essential (Angeli & Giannakos, 2020; Kafai et al., 2020). In the context of 21st-century learning, CT supports students in developing mathematical problem-solving and abstraction strategies. The application of CT within constructivist mathematics curricula has been shown to promote high-order thinking skills. For example, (Angraini et al., 2024) found that using a constructivist approach effectively supported students' ability to decompose complex problems, which is a core skill in CT. The integration of CT into mathematics pedagogy thus represents a paradigmatic shift from traditional instructional approaches toward more contextual, student-centered, and collaborative methods.

Across various educational levels, CT has been integrated into mathematics curricula through diverse instructional strategies. In primary and secondary education, gamified learning environments, mobile applications, and interactive platforms have been utilized to enhance conceptual understanding and engagement. These tools foster links between computational and mathematical reasoning, leading to improved student motivation and participation (Yadav & Chakraborty, 2023; Juškevičienė et al., 2020). Moreover, the use of CT has shown measurable gains in mathematics achievement. For instance, (Zulfa & Andriyani, 2023) reported an increase in student test scores from a 20–30 range to 50–60 after implementing CT-based strategies in arithmetic sequence problems.

At the tertiary level, CT has gained prominence within engineering, technology, and applied science disciplines. University curricula are increasingly integrating mathematical theory with computational modeling and data analysis to meet labor market demands for graduates who are proficient in coding, abstraction, and complex problem-solving (Liu et al., 2023; Zhang et al., 2023). Nonetheless, empirical evidence reveals persisting gaps in CT competencies among university students, underscoring the need for more substantial foundational exposure at earlier stages of education. (Liu et al., 2023).

The integration of CT in mathematics instruction has yielded notable improvements in student learning outcomes. Digital learning environments support autonomous exploration and foster deeper engagement with mathematical content. (Alghamdi, 2025). For instance, Scratch-based project learning not only enhances programming skills but also strengthens mathematical reasoning (Liu, 2024). Furthermore, educational robotics and gamified platforms promote abstract thinking and effective problem-solving, while also alleviating math-related anxiety (Yolcu & Demirer, 2023). Significantly, CT contributes to equity in education by mitigating gender and socioeconomic disparities in mathematics achievement (González-Pizarro et al., 2024).

To support the implementation of CT in mathematics education, a range of tools and instructional approaches have been adopted. Block-based programming platforms, such as Scratch and Pencil Code, have demonstrated efficacy in cultivating algorithmic thinking and student engagement. (Liu, 2024; Deng et al., 2019). Physical computing and robotics tasks help apply mathematical concepts such as measurement and geometry—through hands-on activities (Hangün & Türel, 2025; Adnan et al., 2023). Likewise, gamified environments like BlocklyScript enable students to design and debug algorithms, thus aligning instruction with student interests and intrinsic motivation. (Rijo-Garcia et al., 2022).

Despite these advances, integrating CT into mathematics classrooms presents ongoing challenges. One of the most pressing issues is inadequate teacher training. Many educators report limited familiarity with CT concepts and insufficient pedagogical support (Tedre et al., 2021). Furthermore, technological disparities and entrenched social biases such as gender stereotypes continue to obstruct equitable access and implementation (González-Pizarro et al., 2024; (García-Pérez et al., 2025). Additionally, the dominance of traditional mathematics curricula, which emphasize procedural fluency and standardized assessments, often clashes with the open-ended and exploratory nature of CT instruction. (Angeli & Giannakos, 2020; Durak & Bulut, 2023).

Over time, the scope of CT research in mathematics education has broadened. Initial efforts focused on basic programming and problem-solving skills (Juškevičienė, Stupurienė, et al., 2020). Contemporary studies now explore issues of social inclusion, technological innovation, and interdisciplinary integration, such as simulation and modeling in STEM education (Dolgopolovas & Dagienė, 2024; Hangün & Türel, 2025). Increasingly, longitudinal methodologies are employed to investigate the development and application of CT competencies across diverse educational contexts (Liu et al., 2023).

Although the literature on CT in mathematics education is expanding, bibliometric studies that systematically map its development remain limited. Previous reviews tend to generalize CT in STEM or computing contexts without highlighting mathematics-specific dynamics. To address this gap, the present study undertakes a bibliometric analysis of Scopus-indexed publications to explore the evolution and structure of research on CT in mathematics education. Specifically, the study seeks to answer the following five research questions:

1. What are the trends in the development of research topics related to Computational Thinking in mathematics education over the past decade?
2. Who are the most productive authors, institutions, and journals in publishing works on this topic?
3. What are the dominant keywords in these publications, and how are they thematically organized?
4. What is the structure of conceptual relationships between topics or keywords within the literature?

5. What are the patterns of international collaboration in CT-related mathematics education research?

Through this bibliometric investigation, we aim to offer a comprehensive overview of the intellectual landscape of CT in mathematics education. The findings will serve as a reference for curriculum developers, teacher educators, and policymakers in identifying thematic priorities, fostering international collaboration, and guiding data-driven reform in mathematics pedagogy.

METHODS

This study employed an exploratory quantitative approach using bibliometric analysis. Bibliometrics is a quantitative method used to systematically examine scientific literature to identify publication trends, collaboration patterns, and the developmental trajectory of a particular field (Chen et al., 2020). Pritchard (1969), a pioneer of this approach, defined bibliometrics as the application of mathematical and statistical methods to books and other communication media to assess the structure of scientific knowledge (Zuo et al., 2023).

The primary data source for this study was the Scopus database. Articles were retrieved using a query in the TITLE-ABS-KEY field with the following terms: ("computational thinking" OR "CT skill" OR "mathematics" OR "mathematical thinking" OR "mathematics education"). The data retrieval was conducted on July 1, 2025. A publication year filter was applied to restrict the results to the period from 2015 to 2025, yielding 373 documents. The dataset was then refined by document type to include only journal articles, resulting in 171 entries. A final language filter was applied to include only English-language publications, producing a total of 165 articles for analysis.

Data processing and analysis were conducted using RStudio, supported by the *Bibliometrix* and *Biblioshiny* packages. These tools enabled the structured extraction of data and the advanced visualization of scientific outputs. Moreover, *Bibliometrix* facilitated the analysis of intellectual structures, the identification of thematic areas, and the mapping of scientific collaboration networks (Hira et al., 2020; Wang & He, 2024).

RESULT AND DISCUSSION

1. General Information and Publication Trends

Figure 1 summarizes the bibliometric profile of 165 journal articles on Computational Thinking (CT) in mathematics education published between 2015 and 2025. These publications appeared in 111 different academic sources and involved a total of 536 contributing authors. Notably, only 21 articles were single-authored, highlighting the predominance of collaborative research in this domain. The data were processed using Bibliometrix's *biblioAnalysis()* function in RStudio, which calculates descriptive indicators of publication productivity and co-authorship patterns.

The annual growth rate of publications reached 23.11%, calculated using the *annualGrowthRate()* function in Bibliometrix, indicating a significant rise in scholarly attention. International co-authorship accounted for 15.76% (computed via *collaborationIndex()*), suggesting a moderate yet meaningful level of global research engagement. On average, each document had 3.48 authors, underscoring the collaborative nature of CT research in education.

The dataset included 481 unique keywords, reflecting conceptual richness and thematic variety. A total of 8,518 references were cited, further demonstrating the academic depth of the publications. The mean age of documents was 2.85 years, indicating the field's recency and current relevance. Each article received an average of 17.86 citations, indicating the research's influence and visibility within the academic community.

Figure 1. Main Information About Data

2. General Information and Publication Trends

Figure 2 illustrates the development of emerging research themes in CT and mathematics education from 2017 to 2025. The most recurrent keywords students, computational thinking, and engineering education appeared prominently between 2020 and 2023, reflecting a growing emphasis on learner-centered and technologically integrated pedagogies. Despite the appearance of "engineering education" as a keyword, many of the associated studies explicitly focus on mathematical contexts, such as algorithmic problem-solving, modeling, and numeracy (Liu et al., 2023); (Yolcu & Demirer, 2023).

Other frequently occurring terms, such as teaching, education, and educational computing, highlight the intersection of CT with educational methods and technology. More recent keywords, such as robotics and science technologies, point to a shift toward experiential learning and STEM-based instruction. The consistent appearance of "STEM" from 2019 onward signals the field's expansion into interdisciplinary territories. Overall, these trends suggest a transition from theoretical exploration to practical, cross-disciplinary applications supported by digital tools.

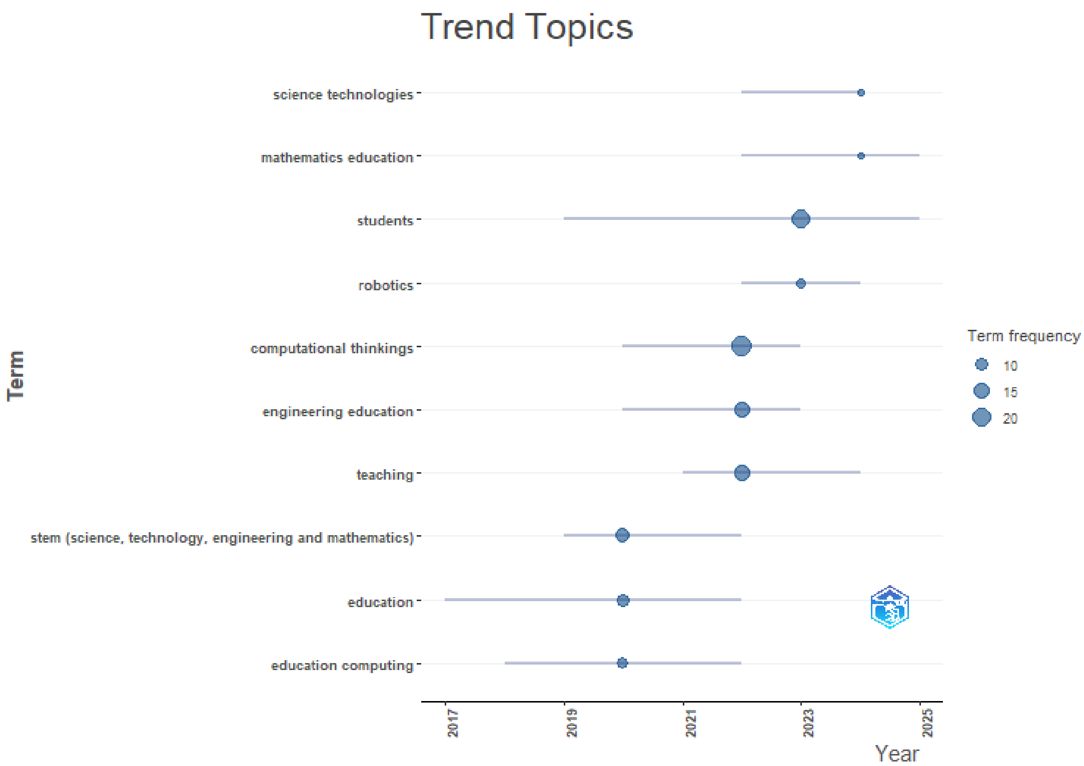

Figure 2. Trend Topics

3. Institutional, Author, and Journal Productivity

As shown in Figure 3, the Three-Field Plot illustrates the relationships among institutions, authors, and journals that contribute to CT research. Noteworthy institutions include Oslo Metropolitan University, Northwest Normal University, the University of Riau, Universitas Pendidikan Indonesia, and the Education University of Hong Kong.

Prominent authors such as Bai Y, Jin Z, and Dagienė V are closely associated with these institutions and are frequently published in high-impact journals. Indonesian researchers, such as Juandi D, Hidayat R, and Helša Y, are also prominent, reflecting strong national involvement in the global CT discourse.

Leading journals in this field include *Education Sciences, Journal on Mathematics Education, and Educational Technology Research and Development.* The prominence of the *Journal on Mathematics Education* affirms the thematic alignment of the dataset with mathematical pedagogy, distinguishing it from more general STEM or CS education studies.

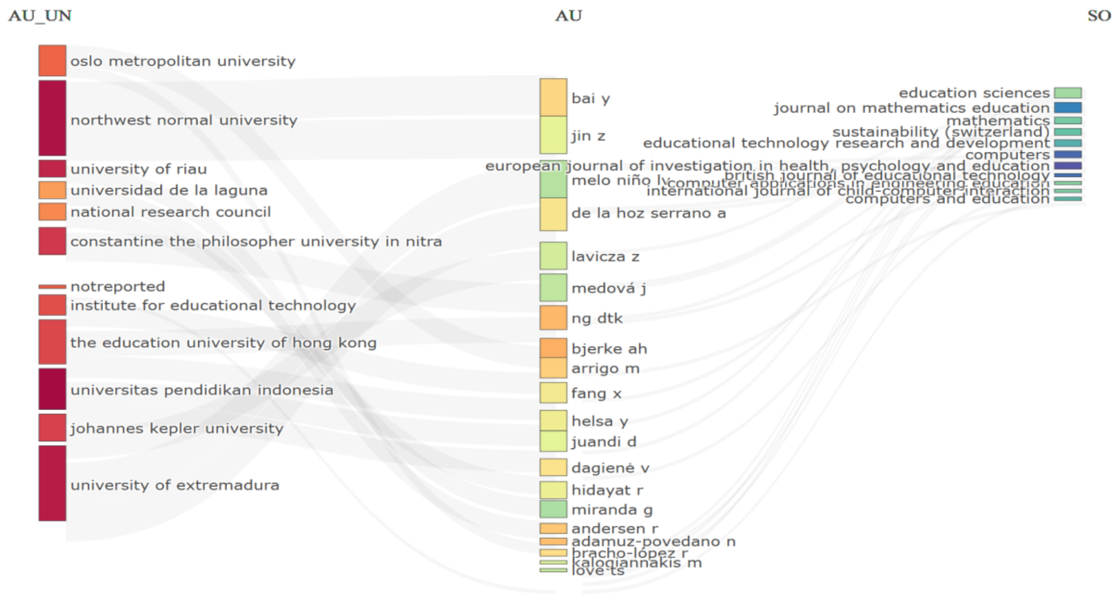

Figure 3. Three-Field Plot

4. Keyword Distribution and Frequency

Figure 4 presents a TreeMap depicting the frequency and thematic clustering of keywords across the dataset. The keyword *"computational thinking" appeared most frequently (24 times), followed by "students" (20 times) and "engineering education" (15 times). While "engineering education" appears frequently, many of these publications target CT skills development in mathematics classrooms through programming, robotics, and integrated numeracy tasks* (Hangün & Türel, 2025)*;* (Yolcu & Demirer, 2023).

Technological and interdisciplinary terms such as *robotics*, *mathematics education*, and *STEM* highlight the integration of CT with hands-on and applied learning environments. Keywords like *thinking skills*, *problem-solving*, and *integration* reflect a sustained focus on cognitive development and instructional design. Collectively, the treemap indicates that CT research spans pedagogical, cognitive, technological, and sociocultural dimensions.

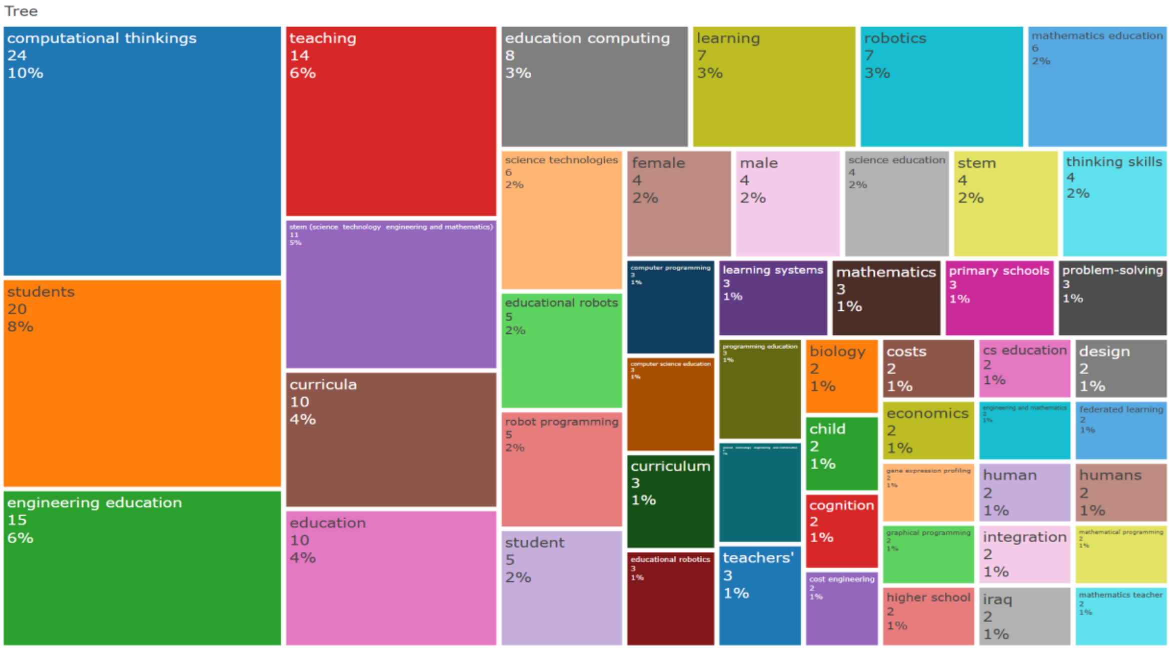

Figure 4. ThreeMap

5. Conceptual Structure and Co-Word Network

The co-word network in Figure 5 visualizes the semantic relationships between frequently co-occurring keywords. Node sizes represent keyword frequency, while colors denote thematic clusters.

Central keywords such as *students*, *computational thinking*, and *teaching* underscore a strong focus on learner-centered approaches and pedagogical strategies. The green cluster groups terms such as robot programming, CS education, and mathematical programming, reflecting the integration of technology. The blue cluster includes *mathematics education*, *science technologies*, and *federated learning*, indicating innovation in STEM pedagogy. The red cluster highlights *education*, *cognition*, *curriculum*, and gender-related terms, addressing the sociopsychological facets of CT. This co-word network affirms the multidimensional nature of CT research in mathematics education, bridging educational theory, technology, psychology, and social inquiry. These clusters confirm that although some terms appear technology-oriented, their functional roles in supporting mathematical learning are prominent across the literature.

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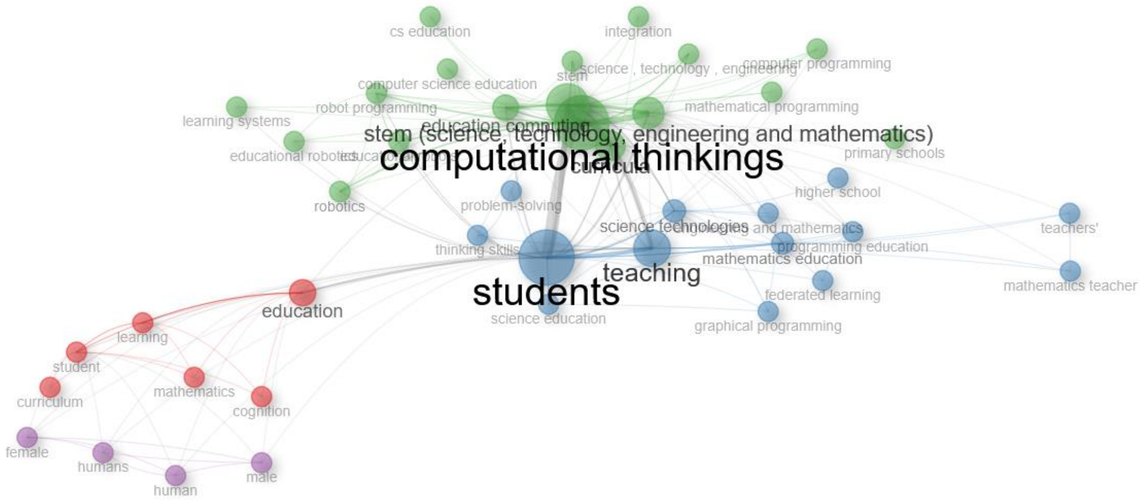

Figure 5. CoWordNet

6. Conceptual Structure and Co-Word Network

Table 1 outlines bilateral collaborations between countries involved in CT-related mathematics education research. Indonesia ranks among the most active contributors, collaborating with Germany, Japan, Malaysia (four times), New Zealand, and the United Kingdom. Other notable partnerships include those with China and Hong Kong, as well as the UK, and Italy, with Hungary, Lithuania, and Mexico. The United States collaborated with China and Australia, while European alliances featured countries such as Norway, Slovakia, Cyprus, and the Czech Republic.

These patterns underscore the global character of CT research, with strong intercontinental academic networks linking Asia, Europe, and the Americas.

Tabel 1. CollabWorldMap

From	To	Frequency
CANADA	BRAZIL	1
CANADA	SINGAPORE	1
CHINA	HONG KONG	2
CHINA	UNITED KINGDOM	1
GERMANY	SWITZERLAND	1
INDIA	THAILAND	1
INDONESIA	GERMANY	1
INDONESIA	JAPAN	1
INDONESIA	MALAYSIA	4
INDONESIA	NEW ZEALAND	1
INDONESIA	UNITED KINGDOM	1
ITALY	BELGIUM	1
ITALY	HUNGARY	1
ITALY	LITHUANIA	1
ITALY	MEXICO	1

JORDAN	SAUDI ARABIA	1
JORDAN	UNITED ARAB EMIRATES	1
LITHUANIA	BELGIUM	1
MALAYSIA	CANADA	1
MALAYSIA	SINGAPORE	1
NORWAY	CYPRUS	1
NORWAY	GERMANY	1
SLOVAKIA	CZECH REPUBLIC	1
SLOVAKIA	UNITED KINGDOM	1
TURKEY	KUWAIT	1
UNITED ARAB EMIRATES	SAUDI ARABIA	1
USA	AUSTRALIA	1
USA	CHINA	1

7. Interpretation and Implications

This bibliometric analysis confirms that research on CT in mathematics education has expanded rapidly in both volume and thematic scope. The growing emphasis on student-centered learning aligns with constructivist principles, which prioritize exploration, engagement, and collaboration.

CT equips learners with critical analytical and problem-solving abilities—skills essential in mathematical thinking and problem-solving contexts. When applied through digital tools and project-based tasks, CT enhances student motivation and engagement in mathematics classrooms (Juškevičienė, Dagienė, et al., 2020; (Ng & Chan, 2018).

Southeast Asia, particularly Indonesia, is becoming increasingly visible in the global research landscape. However, the low proportion of single-authored articles suggests that individual researchers may still face challenges in mastering bibliometric methodologies.

As highlighted by Akrami et al. (2023). Bibliometric analysis plays a vital role in mapping the evolving landscape of scientific inquiry, including the identification of publication patterns, dominant themes, and unaddressed research gaps. This method not only provides a descriptive overview but also offers strategic direction for future research, promoting broader international collaboration Sim et al. (2024). Visualization tools, such as Bibliometrix, enhance the ability to represent the intellectual structure of a research domain, thereby strengthening literature reviews through systematic, transparent, and reproducible processes (Hira et al., 2020; Wang & He, 2024). Moreover, co-word analysis supports the identification of complex thematic relationships within the literature, clarifying how emerging topics are interconnected and evolving. (Aoujil et al., 2023; Trinidad et al., 2021).

Therefore, this study makes a strategic contribution to data-driven educational policy, curriculum development that integrates Computational Thinking, and the expansion of global research collaboration in 21st-century mathematics education. As an objective and scalable tool, bibliometric analysis serves as a critical instrument in shaping research agendas that are relevant, adaptive, and innovation-oriented across various disciplines, including technology-enhanced learning and STEM education. (Khalili & Breyer, 2022; (Dabbagh et al., 2019).

CONCLUSION AND SUGGESTIONS

This study presents a comprehensive bibliometric analysis of research on Computational Thinking (CT) in mathematics education, based on Scopus-indexed publications from 2015 to 2025. The analysis highlights key developments in thematic focus, collaboration patterns, and research productivity. While international collaboration is expanding, there is a need for capacity building in bibliometric literacy among individual researchers, particularly in emerging research contexts.

The co-word network and thematic mapping reveal strong interconnections between CT, STEM education, curriculum development, and innovative instructional strategies. These insights confirm CT's transformative potential in supporting mathematical reasoning, collaborative learning, and problem-solving through digital and contextual approaches.

Based on these insights, future research should focus on developing scalable, curriculum-aligned strategies to integrate CT into mathematics instruction at primary, secondary, and tertiary levels. For teachers, training programs and professional development initiatives must emphasize practical strategies to embed CT in problem-solving, reasoning, and modeling activities. For policymakers, the integration of CT into national mathematics curricula should be accompanied by investments in infrastructure, teacher readiness, and inclusive access to technology. For researchers, capacity-building in bibliometric methods and collaborative publishing networks is essential to sustain contributions in global research communities. Such coordinated efforts will ensure long-term, meaningful integration of CT in mathematics education that is equitable, data-informed, and contextually relevant.

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