

Programming Evolution through Computational Thinking Using The Bibliometrics Analysis

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Abstract

The increasing significance of programming in various fields has made understanding its evolution a crucial academic pursuit. Despite the growing importance of programming, there is a lack of comprehensive analysis that integrates programming evolution with the nuances of computational thinking. This study explores an in-depth examination of the developmental trajectory of programming, contextualized within the broader framework of computational thinking. The aim of the paper is to decode the patterns, trends, and shifts in programming paradigms, tools, and education, contributing to the academic discourse on the subject. Using bibliometric analysis, the study examines a broad array of academic publications and data from the past decade. Advanced data mining in Scopus database and VOSviewer 1.6.20 are employed to trace the progression of programming concepts and their educational implications. Findings indicate a major transition from traditional paradigms to more inclusive, intuitive approaches that emphasize real-world problem-solving and interdisciplinary applications. The analysis reveals a significant shift from traditional programming paradigms towards more inclusive and intuitive approaches, emphasizing real-world problem-solving and interdisciplinary applications. While, Educational trends show a gradual integration of computational thinking into curricula, reflecting the need to equip learners with relevant programming skills.

Keywords: Bibliometric Analysis; Computational Thinking; Digital Skills; Information Technology; Programming

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1. Introduction

In the ever shifting area of digital technology, the integration of programming and computational thinking stands as a cornerstone of innovation and education (Leifheit et al., 2020; Montiel & Gomez-Zermeño, 2021). The United Nations Sustainable Development Goals (SDGs), specifically SDG 4 for Quality Education and SDG 8 for Decent Work and Economic Growth has become imperative. The confluence of programming skills and computational thinking (CT) has not only revolutionized the way its approach problem-solving in various domains but also significantly influenced educational paradigms, prompting a re-evaluation of curricula across levels (Gaki & Jimoyiannis, 2023; Karaoglan Yilmaz et al., 2020; Shen et al., 2022). Computational thinking, a term coined by Jeannette Wing, encapsulates the essence of abstracting and solving problems in a manner akin to computer scientists (Lodi & Martini, 2021; Wing, 2014). It transcends basic coding abilities, integrating logical reasoning, algorithmic thought, and systematic problem-solving.

Measuring cognitive levels in programming and CT presents several challenges due to the complexity and multifaceted nature of these skills. CT comprises not only algorithmic processes but also abstract reasoning, pattern recognition, and problem-solving; all of which operate at both cognitive and metacognitive levels (Sudadi et al., 2023). Existing assessment instruments often lack comprehensive validity and tend to focus narrowly on observable behaviours such as code-writing or debugging while neglecting higher-order reasoning, self-regulation, and reflection. Moreover, validated and adaptable tools that can be calibrated across diverse educational contexts remain scarce. The assessment

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of CT is crucial for integrating it effectively into educational curricula, specifically in coding and programming, yet it remains a challenging task due to the lack of comprehensive and validated tools. Many existing tools focus on specific aspects, such as programming skills, while neglecting broader cognitive and meta-cognitive skills (Basso et al., 2018). Different studies propose varying components and skills that constitute CT, leading to inconsistencies in measurement approaches (Poulakis & Politis, 2021; Tsarava et al., 2022). Studies such as (Korkmaz et al., (2017) and Sovey et al., (2022a) have highlighted the need for rigorous psychometric models such as Rasch analysis or many-faceted measurement models to address variance stemming from raters' teaching experience, assessment training, and subjectivity. A significant progress has been made in developing tools and frameworks for assessing CT, challenges remain in achieving a universally accepted and comprehensive measurement approach. The integration of CT into educational curricula necessitates ongoing research to refine assessment tools and ensure they are adaptable to diverse educational contexts and age groups. Additionally, the relationship between CT and other cognitive abilities, such as numeracy and reasoning, suggests that assessments should consider these associations to provide a holistic evaluation of students' cognitive levels (Tsarava et al., 2022, 2019). CT also in line with the needs of higher educational context for 4.0 Industrial Revolution in terms of the competency (Masdoki et al., 2021). A holistic approach to CT assessment should incorporate not only technical skill but also reasoning strategies and dispositions, ensuring alignment with educational goals and learner diversity.

Despite the challenges, on-going study steamily exist to cater the needs of different focus group and goals respectively. One of the study reporting the impact of the coding part of the Technovation Girls (TG) program on students' computational thinking skills in vocational high schools in Chile (Simmonds et al., 2023), where the test assess students' computational thinking skills; resulting male students generally performed better than female students in the exit test, suggesting a gender disparity in computational thinking skills. Study by Fang et al. (2022) conducted a computer programming course in a high school to evaluate its influence on students' learning achievement, computational thinking awareness, learning motivation, and self-efficacy, indicating the proposed enhanced the CT skills. By encouraging the learner to become a computer coder and master the art of thought, CT helps them handle complex challenges during their lifetime (Srinivasa et al., 2022). Furthermore, the need for teachers to actively communicate with students and promote the development of students' professional computer talents through computational thinking.

This study focuses on how programming, as a practical application of these principles, has evolved and been shaped by the theoretical underpinnings of computational thinking. Through a comprehensive bibliometric analysis, the exploration interplay between these two domains, examining scholarly articles, that have contributed to the growth and understanding of this synergy. Therefore, this article will review publications on programming and computational thinking for the past decade, from 2014 to 2024. The following research questions will lead the review:

RQ1. What are the research trends in programming and computational thinking according to the year of publication?

RQ2. What are the popular keywords related to programming and computational thinking research?

RQ3. Who and how much has been published in the area with regard to the authors and countries?

RQ4. What is the purpose of the most cited articles?

These RQs collectively support the paper's objective to decode the patterns, trends, and paradigmatic shifts in programming as situated within the broader evolution of computational thinking.

2. Literature Review

Programming, also known as coding, is the process of creating executable instructions for computers to perform specific tasks (Kautsch, 2023). It involves logical structuring, algorithm development, and problem-solving skills to translate human commands into machine-readable code (Gadde et al., 2024). Moreover, instructing computers through a series of commands written in a language that the computer can understand, which is essential for solving problems systematically (Bulan Naysabilla & Yahfizham Yahfizham, 2023). Programming is also described as the art of creating applications or software that enable a wide range of activities, from simple calculations to complex simulations like launching a spaceship (Payne, 2024).

Programming education began with procedural languages such as BASIC, Pascal, and C, which introduced students to structured problem-solving and algorithm design. During 1970s and 1980s, Universities incorporated programming into computer science curricula, focusing on syntax, logic, and data structures (Papert, 2020). The evolution continues in 1990s, where object-oriented programming (OOP), led by languages like Java and C++, became dominant, allowing

for modular, reusable, and scalable software development. Simultaneously, visual programming environments such as Scratch and Alice were introduced to simplify coding for beginners, particularly in K-12 education.

The rise of CT and digital literacy, programming is now an essential skill across multiple disciplines, including engineering, business, healthcare, and TVET programs. These skills are recognized as a key skill for the 21st century, essential for problem-solving and innovation across various fields, including STEM disciplines. CT skills has been highlight by Wing (2014), defining CT as the thought processes enables individuals to formulate problems and solutions in a manner that computers or humans can execute effectively. CT skills, including decomposition, pattern recognition, abstraction, and algorithmic thinking, are indeed core competencies necessary for students to thrive in technology-driven industries, particularly the IT industry. It enhances problem-solving abilities and logical reasoning, crucial for addressing complex real-world challenges (Dehbozorgi & Roopaei, 2024). CT skills enhance problem-solving, critical IT competency, and facilitate career transitions and entrepreneurship by empowering individuals with the skills needed to adapt to the evolving digital economy (Tariq, 2025; Wu et al., 2024). The ability to think computationally supports logical reasoning and technical proficiency, essential for success in IT roles (Das & Mitra, 2024).

The integration of cognitive neuroscience and socio-technical systems offers a multifaceted approach to addressing biases in established CT models. Understanding learning processes, cognitive neuroscience provides insights into how individuals acquire and apply CT skills, emphasizing the importance of cognitive diversity in problem-solving. Thus, behavioral dynamics highlights the role of cognitive biases in decision-making, which can influence how CT is taught and perceived in educational settings (Sezer & Namukasa, 2023). Similarly, socio-technical systems theory emphasizes that programming and CT practices are embedded in broader cultural and institutional contexts. The SCOT (Social Construction of Technology) framework, for instance, suggests that learners' engagement with programming is mediated by tools, norms, and social roles, underscoring the need for context-sensitive pedagogy (Basu, 2023; Pelevin et al., 2023; Renaud, 2023). Furthermore, interconnectedness of technology and society underscores that CT is not merely a technical skill but is deeply embedded in social contexts, affecting and being affected by societal norms and values (Sartori & Theodorou, 2022).

3. Methods

The term bibliometrics was initially introduced in 1969 by Alan Pritchard, with the expectation that it would be universally adopted in studies aimed at quantifying textual communication processes and would rapidly achieve recognition within the field of information science (Pritchard, 1969). Moed, (2006) emphasised the significance of this study type, which demonstrates the substantial potential of quantitative, bibliometric evaluations of academic literature for a more profound comprehension of scholarly activity and performance, while also underscoring their relevance to policy. Bibliometrics also defined as the statistical analysis of articles, books, and other forms of publication. It involves measuring the work of individuals, groups, organizations, and countries to identify networks and map developments in related studies (Retno et al., 2023). The primary purpose of bibliometrics is to create a profile of scientific publications, revealing trends and patterns in research output over time (Tutar et al., 2023). By analyzing co-authorship, citation patterns, and thematic clusters, bibliometric analysis identifies influential authors, institutions, and thematic clusters, enhancing theoretical understanding and practical applications (Alkoud, 2024). This analysis helps direct future studies and enhances understanding of the strategic value of diverse boards (Christiani & Widuri, 2024).

3.1. Data Search Strategy

Study employed a screening sequence to determine the search terms for article retrieval. Study was initiated by querying Scopus database with the search strings TITLE-ABS-KEY (Programming AND (Computational AND Thinking)), thereby assembling 3,141 articles. Afterwards, to ensure the precision and relevance of the dataset, a set of strict inclusion and exclusion criteria was applied. Only journal articles published in English were considered for this study. The use of English as a selection criterion ensures accessibility to a global academic readership and facilitates consistency in content interpretation. Consequently, non-English articles were excluded due to potential translation inconsistencies and limited accessibility. The time frame was deliberately restricted to the period between 2014 and 2024 to reflect contemporary trends and the most recent advancements in computational thinking and programming education. Regarding document types, the analysis was limited to peer-reviewed journal articles to maintain high empirical and methodological standards. Additionally, only articles that had reached their final publication stage were included. Additionally, only articles that had reached their final publication stage were included. Articles that were still in-press were excluded due to the lack of finalized metadata, which is essential for accurate citation and co-authorship analysis.

Applying these criteria, the initial dataset of 3,141 documents retrieved from Scopus was refined to a curated corpus of 949 journal articles. These final selections formed the basis of the subsequent bibliometric mapping. Limiting the analysis to a defined time frame can alleviate biases, such as time-dependent bias, which may arise when the timing of events is inadequately considered (Gaynor et al., 2023). The breakdown of the criteria is summarized in Table 1.

Table 1. The selection criterion in searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Time line	2014 – 2024	< 2014
Literature type	Journal (Article)	Conference, Book, Review
Publication stage	Final	In Press

3.2. Data Analysis

Data sets containing the study publication year, publication title, author name, journal, citation and keyword in PlainText format were acquired from Scopus database covering the period 2014 to 2024 and were analysed in VOSviewer software version 1.6.20. This software was utilized for analysis and map creation using VOS clustering and mapping techniques, where it uses co-occurrence data to position items such as keywords or authors in a low-dimensional space where the distance between nodes reflects their relatedness, and modularity-based clustering algorithms group them into thematic clusters for visual interpretation. VOSviewer is an alternative to Multidimensional Scaling (MDS) approach (Van Eck & Waltman, 2008) and it is similar to MDS approach in terms of its aim which is focussed on placement of items in low-dimensional area in such a manner that the relatedness and similarity of any two items is reflected accurately by the distance between them (Appio et al., 2014). Additionally, employing visualisation techniques via VOSviewer on the dataset revealed patterns based on mathematical correlations, and analyses including keyword co-occurrence, citation analysis, and co-citation analysis were conducted. Citation analysis is useful in identifying key research issues, trends and techniques, along with exploring the historical relevance of a discipline's main area of focus (Allahverdiyev & Yucesoy, 2017).

4. Results and Discussion

4.1. RQ1: What are the research trends in programming and computational thinking according to the year of publication?

Graph present in Figure 1 shows the longitudinal analysis of the number of research documents published from 2014 to 2024, as indexed in Scopus. The trend indicates a steady and accelerating growth in academic contributions over the years, reflecting an increasing focus on the research domain, programming and CT under investigation. The number of documents increased gradually from 19 (2014) to 35 (2017), reflecting the early stages of research activity in the field where the average growth rate in this period was modest, ranging between 5% and 25% per year, indicating a developing area of study with limited contributions. The number of documents grew at a more consistent and noticeable rate, reaching 88 publications in 2020; represents an annual growth of approximately 22% and 14%, respectively. This period shows that research interest in the field began gaining momentum, possibly due to technological advancements, policy shifts, or increased academic funding. The most striking increase in publications occurred from 2021 onwards, where document counts surged from 110 (2021) to 194 (2024). The cumulative growth from 2014 to 2024 represents a tenfold increase in the number of documents published, indicating substantial scholarly engagement and knowledge development in the field.

4.2. RQ2: What are the popular keywords related to programming and computational thinking research?

The density of keywords in the Figure 2 visualization indicates the frequency and strength of connections between different research topics related to computational thinking. CT is widely explored in educational research, cognitive science, and digital skills development, linking it to diverse learning methodologies. The trends identified in this study hold significant implications for curriculum development, instructional design, and policy-making in education systems aiming to integrate CT and programming. The prominence of keywords such as Scratch, STEM and game-based learning reflects the growing emphasis on experiential, project-based learning. These findings suggest that programming curricula should prioritize hands-on, visual programming environments especially in early education to scaffold students' understanding of abstract concepts. Keywords related to self-efficacy, learning strategies, and

4.3. RQ3: Who and how much has been published in the area regarding the authors and countries?

Figure 3 represents, Kong, S.C. emerges as the most prolific author with 11 publications; focuses on curriculum integration, assessment models, and digital learning environment, followed by Sun, L with 10 documents working on educational technology and digital literacy, and Wong, G.K.W. presents 9 documents engages in research on computational thinking in STEM and digital competencies. These authors play a significant role in advancing computational thinking studies, possibly focusing on STEM education, pedagogy, or digital literacy. Furthermore, Bers, Csernoch, Hsu, Lai, Pellas owned 7 to 8 documents respectively, form a strong secondary tier of contributors, reflecting their consistent engagement in the field. They focus on specific computational thinking applications, such as robotics, coding, and pedagogical frameworks. Then, Cho, Hijón-Neira followed with 6 documents where their presence in the top 10 indicates growing impact that represent new research directions and emerging themes in computational thinking.

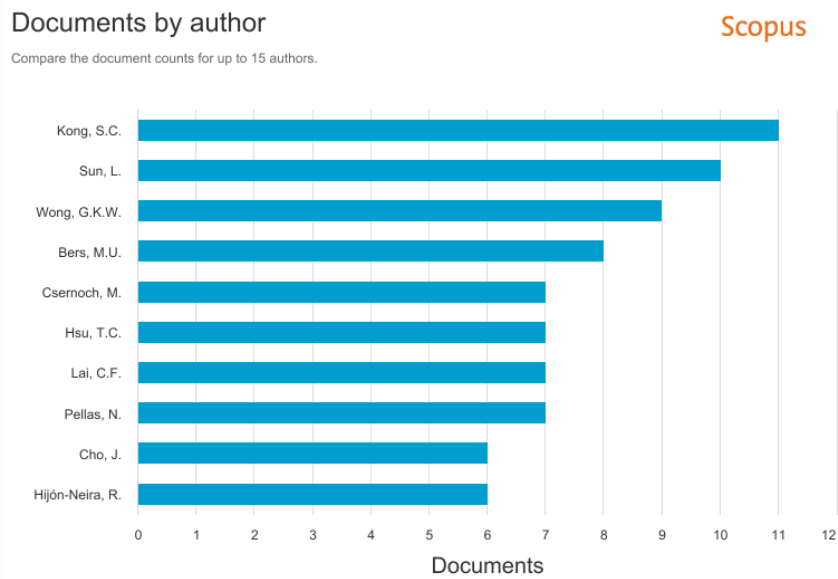


Fig. 3. Authors with articles

Furthermore, in Figure 4, The United States leads in research output with 203 publications, demonstrating its dominant role in the global academic landscape. This can be attributed to strong institutional funding, advanced research facilities, and well-established computational thinking initiatives in STEM and digital education. Following the United States, China ranks second with 115 publications, highlighting its rapid expansion in computational thinking and educational technology research. China’s strong government investments in science, technology, and digital learning have contributed to its increasing research presence. Meanwhile, Taiwan with 83 publications secures its position as the third-highest contributor, surpassing larger economies like Spain and Turkey. Taiwan’s strong education policies, emphasis on digital transformation, and integration of AI in learning curricula have likely fueled its robust research output.

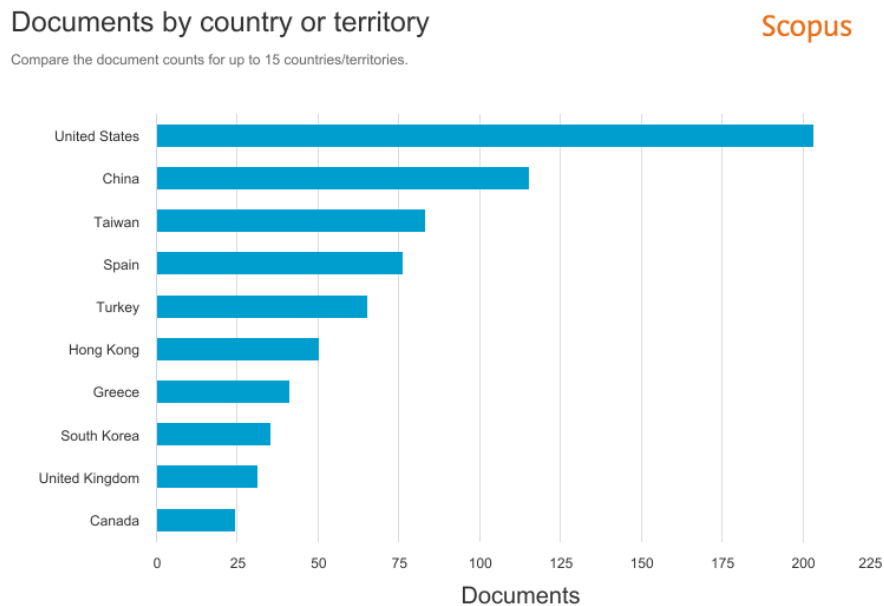


Fig. 4. Top Ten Country based on Documents

Beyond the document count, it is crucial to understand the contextual drivers behind geographical and authorial publication trends. The United States' leadership in publication volume is often attributed to its well-established infrastructure for STEM research, federal and private funding mechanisms, and early policy adoption of CT in K–12 curricula. Likewise, China's strong showing reflects top down educational reforms, state driven technological initiatives and institutional emphasis on publishing in high-impact journals indexed in Scopus. Emerging contributors such as Taiwan, Spain, and Turkey benefit from regional innovation hubs, increasing research funding in digital education, and cross-institutional collaborations. Taiwan's proactive policies in AI and digital transformation have facilitated the integration of CT across disciplines, particularly in compulsory education. Co-authorship and institutional clustering while not the central focus of this study, it can be further explored in follow up analyses to uncover collaboration networks. Patterns suggest growing internationalization in CT research, with frequent collaboration between Asia Pacific and Western institutions.

4.4. RQ4: What is the purpose of the most cited articles?

The findings highlight the growing integration of computational thinking into educational curricula and the diversity of approaches and topics within this realm. The most cited paper by Bers et al. (2014) with 671 citations focuses on early childhood robotics curricula and its role in fostering computational thinking. This indicates the strong research interest in integrating robotics in early education to develop problem-solving and algorithmic thinking skills. The second most cited paper by Hsu et al. (2018) with 505 citations presents a review of literature on teaching and learning computational thinking, providing educators and policymakers with insights into effective teaching strategies. The third most cited study by Tang et al. (2020) with 396 citations is a systematic review on assessing computational thinking, reinforcing the idea that evaluation and measurement frameworks remain a key challenge in this domain.

From the 10 most cited studies, three major research themes emerge such as CT in Early Childhood and K-12 Education, Teacher Education and Curriculum Development and CT Assessment and Pedagogical Frameworks. The most cited papers are predominantly published in high-impact journals, particularly; Computers and Education: top-cited journal, with five papers in the list, Computers in Human Behavior: One highly cited paper and ACM Transactions on Computing Education: A key venue for computational thinking in teacher education. Several studies, including Tang et al. (2020) and Korkmaz et al. (2017) highlight the lack of standardized assessment tools. Future research should focus on developing scalable and adaptive assessment methods to accurately measure computational thinking competencies across different age groups and learning environments. The focus on the rater on the assessment also can help to improve their competencies in assessing CT in future like previous effort (Mohd Noh & Mohd Matore, 2022). The rater can be assessed by the different facet on rating experience, training experience, and teaching experience as well.

Table 2 represent lists the ten most cited articles pertaining to CT and programming. In terms of publication patterns, the most often cited publications generally introduce concepts, methodologies, or results deemed essential foundations within the field of research. The connections between highly cited publications and publishing trends can elucidate how significant studies influence the trajectory and breadth of subsequent research, as well as how contributions from other nations enhance and expand the concept of CT in a global context. For methodology, it will be recommended to develop the instrument by measuring CT and programming for local context (Kamaruddin & Mohd Matore, 2021).

Table 2. Top ten most cited articles

Title	Source	Citations
Computational thinking and tinkering: Exploration of an early childhood robotics curriculum (Bers et al., 2014)	Computers and Education	671
How to learn and how to teach computational thinking: Suggestions based on a review of the literature (Hsu et al., 2018)	Computers and Education	505
Assessing computational thinking: A systematic review of empirical studies (Tang et al., 2020)	Computers and Education	396
Computational thinking in elementary and secondary teacher education (Yadav et al., 2014)	ACM Transactions on Computing Education	396
Computational thinking in compulsory education: Towards an agenda for research and practice (Voogt et al., 2015)	Education and Information Technologies	384
Visual programming languages integrated across the curriculum in elementary school: A two year case study using "scratch" in five schools (Sáez-López et al., 2016)	Computers and Education	383
A validity and reliability study of the computational thinking scales (CTS) (Özgen Korkmaz et al., 2017)	Computers in Human Behavior	376
A systematic review of learning computational thinking through Scratch in K-9 (Zhang & Nouri, 2019)	Computers and Education	300
Assessing elementary students' computational thinking in everyday reasoning and robotics programming (Chen et al., 2017)	Computers and Education	292
Designing for deeper learning in a blended computer science course for middle school students (Grover et al., 2015)	Computer Science Education	272

The study's findings reveal a clear bias toward the reinforcement and empowerment of established CT theories and models, as evidenced by the concentration of highly cited works, dominant keyword patterns, and authorial contributions. This bias is not intrinsically detrimental; rather, it signifies an academic discipline that is solidifying its conceptual parameters. The bibliometric concentration on concepts such as problem-solving, decomposition, algorithmic thinking, and visual programming demonstrates that the academic community is reinforcing the fundamental elements of computational thinking, as delineated in highly cited frameworks, for example, Resnick et al. (2009) CT framework. This trend enhances the validity and utility of these models, especially in educational settings, however it also constrains conceptual diversity. By primarily referencing and expanding upon established CT frameworks, scholars may be neglecting the potential to incorporate new disciplinary perspectives, such as cognitive neuroscience, cultural learning theory, or socio-technical systems thinking. Thus, the results indicate a conservative domain within cognitive psychology, predominantly emphasizing restricted theories and models, while sidelining alternative methods. Further work for the field to evolve meaningfully, forthcoming research must rigorously examine prevailing paradigms, adopt theoretical diversification, and foster epistemic inclusivity by integrating frameworks that embody varied cultural, technological, and educational viewpoints.

5. Conclusion

The emergence of CT and digital literacy has rendered programming an indispensable talent across various fields. This 21st century skills have garnered attention from the academic community, prompting extensive research on

computational thinking, programming, and STEM education. Using the Scopus database, ranging a decade between 2014 until 2024, this paper exposes important themes and trends in programming and CT research using bibliometric analysis. Findings proved CT as dominant keywords towards coding, programming, robotic, STEM, problem solving and game-based learning. The total rise from 2014 to 2024 signifies a tenfold increase in published documents, reflecting significant scholarly involvement and knowledge advancement in CT. The exploration reveals a clear geographical distribution of research productivity in CT, showcasing the United States, China, Taiwan, Spain and Turkey as the top 5 publishing countries. Thus, the predominance of Western centric frameworks and the underrepresentation of localized perspectives suggest a need for research tailored to diverse cultural, linguistic, and educational contexts. There is also a persistent lack of interdisciplinary engagement where future work should incorporate perspectives from cognitive neuroscience, learning sciences, human-computer interaction, and socio-technical systems to enrich the conceptual foundations of CT. Additionally, the absence of standardized, adaptable, and psychometrically validated instruments for CT assessment especially those calibrated for local use is presents an urgent area for development. Such instruments should account for metacognitive dimensions and rater variability, particularly in performance-based settings. This study highlights the significance of computational thinking for practitioners and scholars in education and industry, particularly in directing problem-solving strategies applicable to basic programming instruction. It also uncovers the potential for more comprehensive multidisciplinary research examining how CT might be integrated into several fields beyond coding, programming, and STEM. Finally, expanding bibliometric scope beyond Scopus is suggested, such as WoS database. This can be included with multi-database integrations like KKU-BiblioMerge that would enhance coverage and reduce indexing bias, facilitating more globally representative in understanding of CT and programming research in the future.

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