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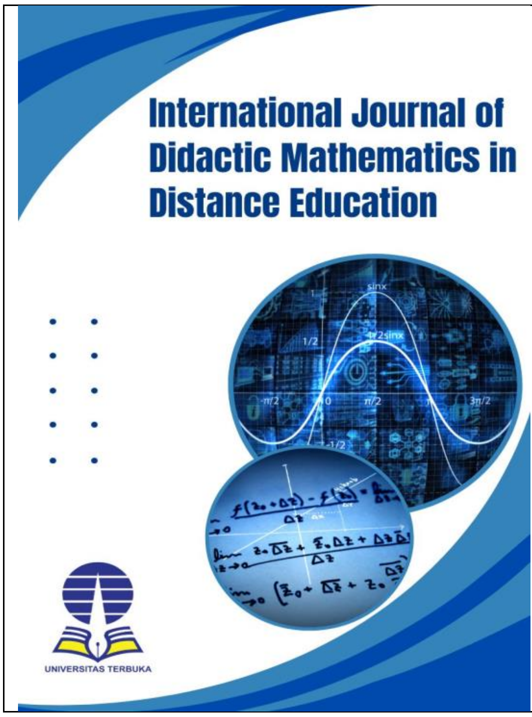

Knowledge mapping of Computational Thinking and Science, Technology, Engineering, and Mathematics (CT+STEM)

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Knowledge mapping of Computational Thinking and Science, Technology, Engineering, and Mathematics (CT+STEM)

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Abstract
There are significant limitations in the current study on CT+STEM addressing the gaps noted in the existing literature. The study is driven by the lack of research on underrepresented students in college STEM courses, the inclusion of CT in STEM education at the entry level, and the insufficiency of teacher training programs that concentrate on integrating computational thinking into STEM classrooms. It aims to fill the knowledge gap about how CTs' professional experience influences their attitudes and practices. The study acknowledges the necessity of empirical research to explore the balance between the widespread use of critical thinking and the distinct characteristics of scientific representations, a significant obstacle in educational planning. The research utilizes bibliometric analysis to cover the period from 1978 to 2023, showing a steady yearly growth rate of 7.22% in the CT+STEM sector. The collection consists of 241 documents from 127 scholarly sources, highlighting collaboration trends and worldwide relationships in CT+STEM research. The study highlights important publications, authors, affiliations, and highly cited papers while also recognizing potential bias and the quantitative character of the investigation. The study has important implications for education, industry, and problem-solving in the digital era. The article suggests further research to investigate qualitative aspects, methodologies, and teaching strategies to enhance the development and influence of CT+STEM in the evolving field of education and technology.

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1. Introduction

There is a noticeable lack of research in CT+STEM studies, particularly on the underrepresentation and achievement disparities for underrepresented students in college STEM courses (Theobald et al., 2020). Furthermore, there is insufficient research on incorporating computational thinking (CT) into STEM education at the matriculation level (Law et al., 2021). Additionally, more research is required on in-service teacher training programs focusing on the incorporation of computational thinking into STEM classrooms (Knie et al., 2022). The existing study does not have a thorough knowledge of how CTs' PE beliefs and practices interact with one other (Moon & Park, 2022). Additionally, additional empirical research is required to address and utilize the trade-off between the broad applicability of critical thinking and the unique nature of scientific representations, which poses a considerable problem in educational design (Basu et al., 2016).

The integration of computational thinking (CT) with science, technology, engineering, and mathematics (STEM), also known as CT+STEM, has received considerable attention in education and research over the past five years (Ching & Hsu, 2023; Knie et al., 2022; Psycharis & Kotzampasaki, 2019; Yang & S. Chittoori, 2022; Gunadi et al., 2023) and (Psycharis & Kotzampasaki, 2019; Yang & S. Chittoori, 2022) agree that CT is an essential competency for problem-solving in a variety of academic disciplines that extend beyond programming (Yang

& Chittoori, 2022) have designed an elementary school curriculum that integrates CT into practical problem-solving activities. The incorporation of CT into STEM courses is viewed as a significant framework for incorporating CT into educational practices (Knie et al., 2022). (Psycharis & Kotzampasaki, 2019) have utilized computational tools and instructional games as a means to augment students' CT abilities and nurture their self-assurance in using computers. The inclusion of these concepts in national curricular standards and frameworks for STEM disciplines (Ching & Hsu, 2023) demonstrates that people recognize the significance of teaching computational literacy and CT. CT+STEM aims to equip students with the skills necessary to address complex problems in a technologically advanced society.

In recent years, there has been a lot of interest in using CT+STEM in school. A scientific study (Guzey et al., 2016; Lee et al., 2019) has shown how important it is for teachers to have good professional development programs to use STEM education well. It is also important to set clear boundaries and methods for STEM education, including where and how technology fits in each STEM field (Yata et al., 2020). Several academic studies have looked at how CT+STEM programs affect students' understanding, attitudes, and performance in different areas. For example, (Jeong & Kim, 2015) looked at how such courses affect the monitoring of climate change, and (Chondrogiannis et al., 2021) looked at how they affect training for jobs in agriculture. Also, (Liu et al., 2023) looked at how CT+STEM courses affect STEM learning in primary schools. In computer science and engineering education, the need to teach computational thought and diagrammatic reasoning has also been pointed out (Osztián et al., 2022).

Research on CT+STEM has explored various aspects of integrating computational thinking into STEM education. One study conducted a systematic review of the application of computational thinking in programming education at higher education institutions (Agbo et al., 2019). The researchers found that while there have been studies on integrating CT in teaching specific disciplines, there is limited research on the application and impact of CT in teaching programming education and problem-solving at the higher education level. Another study investigated the effect of reverse engineering pedagogy on primary school students' computational thinking skills in STEM learning activities (Liu et al., 2023). The researchers used a quasi-experimental study to explore the impact of this pedagogy on CT skills. Additionally, research has explored the use of serious games designed by students to assess CT development in STEM (Troiano et al., 2019). The study used Dr. Scratch to assess CT development in serious games designed by eighth-grade students. Furthermore, research has shown that students who excel academically in STEM have higher levels of CT skills compared to average and low achievers (Law et al., 2021). STEM lessons and activities facilitate the development of CT skills as students explore beyond the disciplinary boundaries of science, technology, engineering, and mathematics.

However, several previous studies have examined CT+STEM research using bibliometric analysis. For example, conducted a study analyzing the scientific performance and mapping of the term STEM in education using the Web of Science database (Lucena et al., 2020). The study found that the scientific community mainly uses English and research papers to present their results. From 2015 onwards, the main lines of research began to be established, which focus on "women" and "science". Another study explored the bibliometric statistical analysis of fuzzy inference system-based classifiers (Chen et al., 2021). This study highlighted the increasing interest among researchers in developing analytical approaches and utilizing them to evaluate the development of research topics. This study aims to demonstrate the application of bibliometric analysis to explore various aspects of CT+STEM research, including research trends, emerging topics, and the assessment of CT+STEM development.

2. Method

This study uses bibliometric analysis to examines citation patterns in the field of CT+STEM scholarly material in the Scopus database by extracting relevant publications on September 23, 2023. It focused on works that included the term "CT and STEM" in their title, abstract, or keywords, representing the integration of computational thinking with science, technology, engineering, and mathematics. After carefully selecting papers, it returned the findings to the Scopus database to improve accessibility and visibility for the scholarly community. The search methodology adopted a targeted query approach, utilizing the precise phrase "CT and STEM" to filter pertinent documents. Data collection primarily relied on the renowned Scopus database, known for its extensive coverage of scholarly literature. During the later stages of the study process, it used *csv and *bib files to effectively manage and analyze the collected data. These file formats enabled a methodical and systematic way of handling information. It also included information from reputable academic sources, particularly referencing studies (Supriyadi, et al., 2023a; Supriyadi, et al., 2023b). The sources offered great insights into the procedures and techniques typically used in the subject of bibliometrics, enhancing the clarity of the overall environment. The study entails a methodical search technique using a trustworthy database and recognized file types. It simultaneously recognizes and incorporates ideas from current literature to ensure that this method is in line with established methods in bibliometric research and data analysis.

3. Results and Discussion

Table 1 provides CT+STEM publications from 1978 to 2023, sourced from 127 scholarly sources, encompassing 241 documents. Notably, it exhibits a robust annual growth rate of 7.22%, signifying the enduring relevance and dynamism of this field. The dataset primarily consists of relatively recent research, with an average document age of 3.37 years and an impressive average of 20.72 citations per document, indicating its impact. Collaboration is evident, with an average of 3.48 co-authors per document, including 14.11% international collaborations. The dataset's rich keyword repository of 613 Keywords Plus (ID) and 687 Author's Keywords (DE) allows for in-depth thematic analysis, and while all documents are categorized as articles, they offer a comprehensive resource for exploring the multifaceted aspects of CT+STEM and Computational Thinking research.

Table 1
Main Information

Description	Results
Timespan	1978:2023
Sources (Journals, Books, etc)	127
Documents	241
Annual Growth Rate %	7.22
Document Average Age	3.37
Average citations per doc	20.72
References	1
Keywords Plus (ID)	613
Author's Keywords (DE)	687
Authors	716
Authors of single-authored docs	27
Single-authored docs	27
Co-Authors per Doc	3.48
International co-authorships %	14.11
Article	241

The annual production table for CT+STEM (Science, Technology, Engineering, and Mathematics) and Computational Thinking publications spanning from 1978 to 2023 reveals a fascinating evolution in the field. Initially, with just two articles in 1978, the field appeared nascent. However, research activity was sporadic until 1987, suggesting that CT+STEM and Computational Thinking were still emerging concepts in academia. A notable resurgence occurred from 2007 to 2013, signifying renewed interest in the intersection of STEM disciplines and computational thinking. Subsequently, from 2014 to 2018, a steady increase in annual publications indicated the field's maturation. The most striking development emerged from 2019 to 2023, with an exponential surge in research output, underscoring the field's growing significance and recognition. This rapid expansion highlights CT+STEM and Computational Thinking as vibrant and influential areas of scholarly inquiry with far-reaching implications for education, industry, and problem-solving in the digital age (Figure 1).

Figure 1

Annual Production

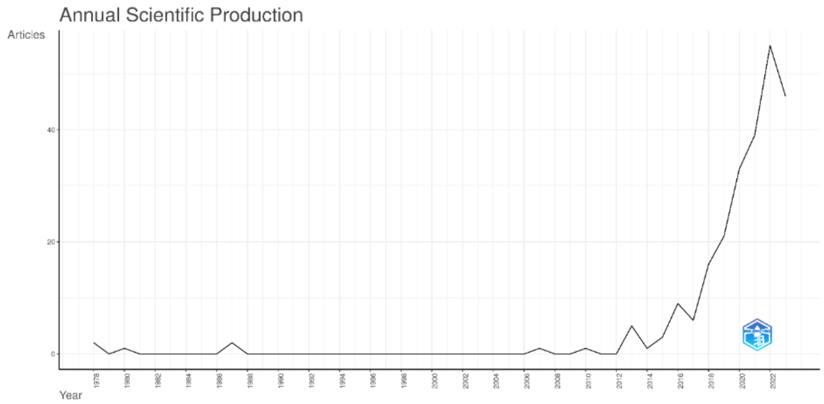

Table 2 featuring the top 10 most relevant sources of publications in CT+STEM (Science, Technology, Engineering, and Mathematics) and Computational Thinking provides valuable insights into the key contributors shaping scholarly discussions within these domains. Leading the list is the "Journal of Science Education and Technology" with a significant 19 articles, underscoring its central role in disseminating research at the intersection of STEM and Computational Thinking. "Education and Information Technologies" follows closely with 13 articles, highlighting its substantial contribution to the field's discourse, particularly in the context of technology-driven education. In third place, "Frontiers in Psychology" with 10 articles suggests a growing exploration of cognitive and psychological aspects within Computational Thinking in STEM education. The remaining sources in the top 10, such as "Education Sciences," "Computer Applications in Engineering Education," and others, represent the multidisciplinary nature of CT+STEM and Computational Thinking research, spanning education, technology, sustainability, and more. These sources collectively serve as essential references for researchers, educators, and policymakers seeking to engage with the dynamic and evolving discussions in these fields.

Table 2

Top 10 Sources

Sources	Articles
Journal of Science Education and Technology	19
Education and Information Technologies	13
Frontiers in Psychology	10
Education Sciences	7
Computer Applications in Engineering Education	6
Journal of Research on Technology in Education	6

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Sources	Articles
Sustainability (Switzerland)	6
Computers and Education	5
Informatics in Education	5
Journal of Educational Computing Research	5

Table 3 highlighting the top 10 most relevant authors in CT+STEM (Science, Technology, Engineering, and Mathematics) and Computational Thinking publications unveils a group of prolific researchers who have significantly shaped the discourse in this interdisciplinary domain. Authors Baek Y, Biswas G, Ching YH, Sengupta P, Yin Y, and Zhang Y have each contributed four articles, indicating their substantial impact and extensive engagement in CT+STEM and Computational Thinking research. Their collective body of work covers a diverse range of topics and approaches within the field. Additionally, authors Arfé B, Basu S, Hadad R, and Kalogiannakis M, with three articles each, further enrich the scholarly landscape, demonstrating their enduring dedication to advancing knowledge in STEM education and Computational Thinking. These top 10 authors collectively represent the forefront of CT+STEM and Computational Thinking research, offering valuable insights and expertise for researchers, educators, and policymakers seeking guidance in this dynamic and influential field.

Table 3
Top 10 Authors

Authors	Articles
Baek Y	4
Biswas G	4
Ching Yh	4
Sengupta P	4
Yin Y	4
Zhang Y	4
Arfé B	3
Basu S	3
Hadad R	3
Kalogiannakis M	3

Table 4 featuring the top 10 most relevant affiliations in the realm of CT+STEM (Science, Technology, Engineering, and Mathematics) and Computational Thinking publications sheds light on the influential role of academic and research institutions in shaping this interdisciplinary field. "Vanderbilt University" leads with 12 articles, highlighting its central position in advancing STEM education and Computational Thinking research. Close behind is "Northwestern University" with 10 articles, underscoring its significant contributions to the field. The "University of Padova" from Italy, with seven articles, exemplifies the international reach of CT+STEM and Computational Thinking, transcending geographical boundaries. "Boise State University," "Education Development Center," and "North Carolina State University," each with six articles, demonstrate a strong commitment to exploring the intersection of STEM and Computational Thinking in education. "Purdue University" and "The Pennsylvania State University" with five articles each further emphasize their importance in shaping the scholarly discourse. Internationally, the "University of Castilla-La Mancha" and the "University of Colorado Boulder" complete the top 10 affiliations with five articles each, reflecting the global nature of research in these fields. Collectively, these affiliations represent key sources of knowledge and expertise in STEM education and Computational Thinking, offering valuable resources for researchers, educators, and policymakers invested in these rapidly evolving domains.

Table 4
Top 10 Affiliations

Affiliation	Articles
Vanderbilt University	12
Northwestern University	10
University of Padova	7
Boise State University	6
Education Development Center	6
North Carolina State University	6
Purdue University	5
The Pennsylvania State University	5
University of Castilla-La Mancha	5
University of Colorado Boulder	5

Table 5 featuring the top 10 most cited documents in CT+STEM (Science, Technology, Engineering, and Mathematics) and Computational Thinking publications provides valuable insights into the seminal contributions that have significantly shaped the field. Leading the list is Weintrop's 2016 document in the Journal of Science Education and Technology, with an astounding 714 total citations and an average of 89.25 citations per year, highlighting its pioneering and enduring impact. Sengupta's 2013 work in Education and Information Technologies follows closely with 344 total citations and an average of 31.27 citations per year, demonstrating its substantial influence. English's 2017 document in the International Journal of Science and Mathematics Education ranks third with 167 total citations and an average of 23.86 citations per year, contributing significantly to CT+STEM discussions. These top 10 documents collectively represent foundational and influential works, serving as essential references for researchers, educators, and policymakers in the ever-evolving fields of STEM education and Computational Thinking.

Table 5
Most Cited Documents

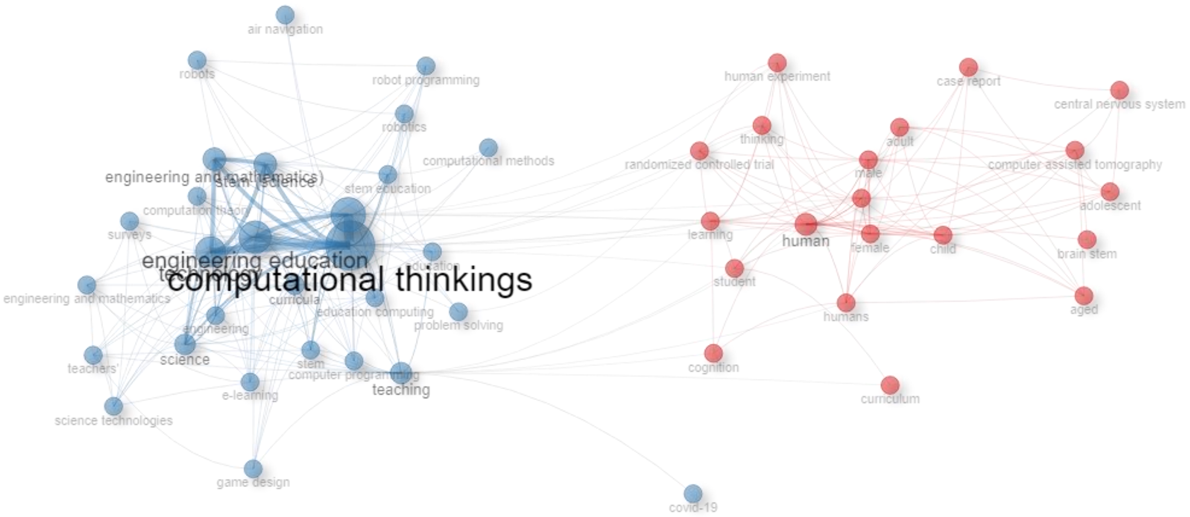
Authors	Total Citations
(Weintrop et al., 2016)	714
(Sengupta et al., 2013)	344
(English, 2017)	167
(Eguchi, 2016)	138
(Leonard et al., 2016)	137
(Jaipal-Jamani & Angeli, 2017)	124
(Repenning et al., 2015)	118
(Ching et al., 2018)	99
(Ioannou & Makridou, 2018)	93
(Manches & Plowman, 2017)	89

The Co-Words network analysis of the CT+STEM (Science, Technology, Engineering, and Mathematics) and Computational Thinking dataset reveals two distinct clusters. Cluster 1 centers on human learning and cognition, with "Human" and "Article" serving as key connectors, emphasizing the significance of human-related research and scholarly articles in CT+STEM discussions. Cluster 2 revolves around computational thinking, technology, education, and students, with "Computational Thinking" playing a central role. "Students" also serves as a crucial connector, underlining its pivotal position in discussions about how computational thinking affects learners. Other terms like "Technology," "Engineering

Education," and "Teaching" contribute to connecting concepts within Cluster 2, highlighting the intricate relationship between technology, education, and computational thinking in STEM fields. This analysis provides valuable insights into the core themes and connections in CT+STEM and Computational Thinking research, shedding light on the foundational concepts driving these fields forward (Figure 2).

Figure 2

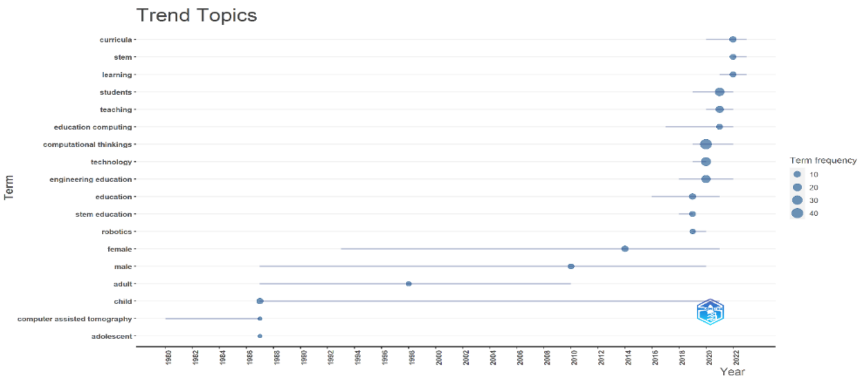
Co-Words Network



The analysis of trend topics in CT+STEM (Science, Technology, Engineering, and Mathematics) and Computational Thinking publications from 1987 to 2023 reveals intriguing patterns. Over this period, research on child development in the context of CT+STEM has consistently been a focal point, with a peak around 2021, highlighting the enduring interest in understanding how children engage with these concepts. Computational Thinking gained significant prominence from 2019 to 2022, reflecting its central role in modern STEM education. Topics related to technology and education have remained consistently relevant since 2019, reaffirming the importance of technological integration in CT+STEM. Gender diversity and inclusivity in CT+STEM research, particularly focusing on females, gained prominence from 2014 to 2021. Additionally, robotics and engineering education experienced surges in relevance from 2019 to 2022, showcasing the intersection of these disciplines. The emphasis on student-centered approaches and effective teaching methods in CT+STEM education has also been on the rise since 2019. This temporal analysis underscores the dynamic and adaptable nature of CT+STEM research, aligning with evolving educational needs and technological advancements (Figure 3).

Figure 3

Trend Topics



This study analyzed a dataset of 241 documents related to CT+STEM (Computational Thinking and Science, Technology, Engineering, and Mathematics) and computational thinking, spanning the years 1978 to 2023. These documents were sourced from 127 academic outlets, indicating a wide range of sources and a diverse body of research. Our analysis revealed a notable predominance of recent research, with an average document age of 3.37 years, highlighting the dynamic nature of the field. This observation aligns with the findings of other studies that have shown the rapid expansion of research in computational thinking. Furthermore, our analysis demonstrated that the field of CT+STEM has been expanding at an impressive annual rate of 7.22 percent, indicating the increasing interest and importance of computational thinking in various disciplines. The significant impact of this research was also evident in our dataset, with an average of 20.72 citations per document, suggesting that research in CT+STEM is influential and widely recognized within the academic community. Additionally, our analysis revealed robust collaboration in the field of CT+STEM, with an average of 3.48 co-authors per document, including international partnerships, highlighting the collaborative nature of research in computational thinking and the importance of interdisciplinary collaboration in advancing the field. Moreover, our dataset's keyword repository provided a robust foundation for in-depth topic analysis, rendering it an invaluable resource for researchers in CT+STEM and computational thinking. The inclusion of keywords related to mathematics, artificial intelligence, coding, and vocational education in our dataset allows for a comprehensive exploration of the intersection between computational thinking and these domains (Bers, 2018; Y.-C. Chen et al., 2021; Richardo et al., 2023).

Analysed in this study were 241 documents on CT+STEM (Computational Thinking and Science, Technology, Engineering, and Mathematics) and computational thinking, covering the period from 1978 to 2023. The dataset was obtained from 127 academic sources, reflecting a broad range of origins and a varied collection of studies. The analysis showed that recent research articles were predominant, with an average document age of 3.37 years, indicating the field's dynamic nature (Soltanian & Dehghani, 2018). This observation is consistent with earlier studies that have demonstrated the swift growth of research in computational thinking (Agbo et al., 2019). The analysis showed that the CT+STEM sector has been growing at an annual rate of 7.22 percent, highlighting the rising significance of computational thinking in many disciplines (Agbo et al., 2019). The research had a notable impact on the dataset, with an average of 20.72 citations per document, indicating that CT+STEM research is important and well-regarded in the academic world (Agbo et al., 2019). The analysis showed strong collaboration in the CT+STEM field, with an average of 3.48 co-authors per document, including international partnerships. This emphasises the collaborative aspect of research in computational thinking and the significance of interdisciplinary collaboration in progressing the field (Agbo et al., 2019).

Furthermore, the dataset's keyword repository served as a strong basis for detailed subject analysis, making it a significant resource for researchers in CT+STEM and computational thinking. The dataset contains keywords pertaining to mathematics, artificial intelligence, coding, and vocational education, facilitating a thorough examination of the relationship between computational thinking and various fields (Agbo et al., 2019). This holistic strategy is in line with the contemporary focus on robotics in education and computational thinking, highlighting the importance of CT skill development in STEM and STEAM (Science, Technology, Engineering, Arts, and Mathematics) settings (García-Peñalvo et al., 2021). Research literature advocates for incorporating computational thinking in K-12 STEM education, highlighting the significance of disciplinary viewpoints and the necessity of introducing CT in primary school education, particularly for students with no prior computer experience (Lee et al., 2019; Psycharis & Kotzampasaki, 2019).

This study presents strong evidence of the swift growth and growing significance of computational thinking across many fields, highlighting the collaborative and interdisciplinary aspects of research in CT+STEM. The dataset includes keywords related to mathematics, artificial intelligence, coding, and vocational education to thoroughly examine the connection between computational thinking and these areas, in line with current trends in robotics in education and computational thinking. This emphasises the active and powerful role of research in CT+STEM and its substantial influence in the academic community.

Furthermore, we identified thought leaders in the field through an analysis of the top ten publications, with prominent journals such as "Journal of Science Education and Technology," "Education and Information Technologies," and "Frontiers in Psychology" playing pivotal roles in disseminating these influential contributions. Additionally, the multidisciplinary nature of CT+STEM and computational thinking research was evident, with top authors and academic institutions exerting substantial influence in shaping the discourse (Y.-C. Chen et al., 2021; Peel et al., 2022). Lastly, co-words network analysis revealed two prominent clusters of research themes, highlighting the field's multidimensionality, focusing on human learning and cognition as well as computational thinking, technology, education, and students. These findings collectively contribute to a comprehensive understanding of CT+STEM and computational thinking research trends and relationships.

The study performed an extensive examination of the CT+STEM (Computational Thinking and Science, Technology, Engineering, and Mathematics) and computational thinking research field from 1978 to 2023. The results showed a significant prevalence of current research, with an average document age of 3.37 years, highlighting the ever-changing character of the subject. This insight is consistent with findings from other studies that have emphasized the swift growth of research in computational thinking. The interdisciplinary aspect of CT+STEM and computational thinking research was apparent, with prominent writers and academic institutions playing a significant role in influencing the discussion. This is consistent with prior research that has highlighted the importance of computational thinking in the abilities needed for the 21st century. The co-words network analysis identified two main clusters of study subjects, emphasizing the multidimensional nature of the area. These clusters focus on human learning and cognition, computational thinking, technology, education, and students. This discovery aligns with the increasing focus on computational thinking, particularly in primary and secondary education environments (Korkmaz & Bai, 2019).

The research also recognized influential figures in the field by examining the top ten publications, including well-known journals like "Journal of Science Education and Technology," "Education and Information Technologies," and "Frontiers in Psychology," which were instrumental in sharing significant contributions (Kallia et al., 2021). This discovery aligns with the rising focus on computational thinking research in higher education, demonstrated by the expanding prospects for further study in this field (Lyon & Magana, 2020). The study in CT+STEM has a notable influence as shown by the dataset, with an average of 20.72 citations per document, indicating that this field of research is prominent and well-regarded in the academic community. This is corroborated by the increasing amount of literature that has presented compelling arguments about the essential importance of mathematical thinking in computational thinking (Rich & Hodges, 2017). The results of this study enhance our understanding of the current trends and connections in research related to CT+STEM and computational thinking. The interdisciplinary aspect, the involvement of key figures and prestigious academic institutions, and the substantial impact of the research highlight the dynamic and influential nature of research in CT+STEM and its acknowledgment in the academic community.

4. Conclusion

This extensive study on CT+STEM (Computational Thinking and Science, Technology, Engineering, and Mathematics) research spanning from 1978 to 2023 has unearthed critical insights into the dynamic evolution of the field. The robust annual growth rate of 7.22% signifies the enduring relevance and vibrancy of CT+STEM, with a dataset of 241 documents from 127 scholarly sources showcasing a diverse body of research. Noteworthy collaboration patterns, an average of 3.48 co-authors per document, and international partnerships at 14.11% underscore the collaborative nature of CT+STEM research. While the study identifies key publications, authors, affiliations, and highly cited documents, it is essential to acknowledge the limitations, such as a potential bias toward recent research and the quantitative nature of the bibliometric analysis. The findings have significant implications for education, industry, and problem-solving in the digital age. Looking forward, future research could delve deeper into qualitative aspects, exploring specific methodologies and pedagogical approaches, and conducting longitudinal studies to capture the sustained impact and evolving trends within the CT+STEM and Computational Thinking domain. Overall, this study provides a robust foundation for continued exploration and advancement, inviting stakeholders to actively engage with the identified trends and contribute to the ongoing discourse, ultimately fostering the growth and impact of CT+STEM in the ever-evolving landscape of education and technology.

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None

Declarations
The authors declare no conflict of interest.

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