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RESEARCH TRENDS OF COMPUTATIONAL THINKING FOR ADVANCING SUSTAINABLE DEVELOPMENT GOALS (SDGs) IN SCIENCE LEARNING: BIBLIOMETRIC ANALYSIS

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ABSTRACT

Computational Thinking (CT) has emerged as a crucial competency that bridges digital literacy and scientific problem-solving in the context of achieving Sustainable Development Goal (SDG) 4 on quality education. However, the model of integrating CT in science learning remains poorly explored, hindering progress toward SDG Targets 4.4 (technical skills) and 4.7 (scientific literacy). This study is the first bibliometric analysis to map the trends in CT research on science learning (2021–2023) using Scopus. The novelty lies in identifying global collaboration patterns, knowledge gaps, and research priorities that align with the 2030 Agenda. Three research questions were guided: (1) Publication distribution, (2) Dominant journals and subject areas, (3) Keyword dynamics/co-occurrence networks. Data retrieved from Scopus using the strings TITLE-ABS-KEY("Computational Thinking" AND "Science Education/Learning") (47 articles, open access, 2021–2023). Analysis techniques include Performance analysis (publication and citation metrics), Science mapping (author affiliation), and Network analysis (keyword grouping via VOSviewer). Key findings show: (1) Peak publication in 2022 (19 articles), (2) Education Sciences (Q1) as the top journal (7 articles), (3) Dominance of Social Sciences (43 articles) and Computer Science (21), (4) Most cited articles: Lodi & Martini (2021; 43 citations), (5) Main keywords: Computational Thinking (27 appearances), Computer Science Education (15), (6) US-led geographic contributions (>20 publications), (7) Co-occurrence analysis reveals that Scratch (a block-based application) is a less researched CT tool (3 occurrences) than technical languages such as Python. CT integration enhances science literacy but is limited by gaps in teacher training (SDG 4.c) and access to resources. The scarcity of research on gamified tools, such as Scratch, signals a critical innovation gap. This study provides an evidence-based roadmap to prioritize teacher professional development, scale accessible CT tools (e.g., Scratch) for science education, and direct future research toward SDG-aligned classroom-based practices.

Keywords: bibliometric; computational thinking; science learning; scopus database; SDGs

INTRODUCTION

In global efforts to achieve the United Nations Sustainable Development Goals (SDGs) 2030, quality education (SDG 4) is a key pillar. Target 4.4 emphasizes improving technical and vocational skills for decent work, while Target 4.7 highlights scientific literacy for sustainable development (Sierra & Suárez-Collado, 2021). In the midst of 21st-century technological disruption, Computational Thinking (CT) is emerging as a cross-disciplinary competency that bridges digital literacy and solutions to complex sustainability-related problems, such as the climate crisis (SDG 13) and urban resilience (SDG 11). The integration of CT in science education is a strategic

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response to the 2030 Agenda, positioning computing-based learning as a catalyst for the formation of a generation of literate solutions (Ferguson & Roofe, 2020). The 2030 deadline underscores the urgency of research to develop measurable CT integration models, particularly in support of SDG 4 indicators, such as enhancing scientific literacy (Target 4.7.1) and improving teacher readiness (Target 4.c).

As a core supporter of SDG 4, CT equips learners with transferable competencies to address global challenges, ranging from environmental issues to digital citizenship (Hueske et al., 2021; Cheng et al., 2022; Nurita et al., 2024). Its integration in science directly advances Target 4.7 through strengthening scientific literacy (Abdullah & Mahmud, 2024). CT is a crucial aspect of science learning because it aids in the understanding of complex concepts (Hurt et al., 2023) and is closely related to problem-solving skills through stages such as decomposition, pattern recognition, abstraction, and algorithms (Palts & Pedaste, 2020; Chen et al., 2023; Lee et al., 2024; Mendrofa, 2024). CT involves key cognitive abilities, including problem representation, abstraction, decomposition, and algorithmic thinking in a scientific context (Weintrop et al., 2021). Although it is often misinterpreted as "technological thinking," its scope is broader and applicable across domains (Nuzzaci, 2024; Triantafyllou et al., 2024; Zviel Girshin et al., 2024). CT integration improves understanding of scientific principles and prepares students for a technology-based world (Park & Green, 2019; Puganesri & Puteh, 2019). Various studies have proven a significant impact on improving problem-solving, concept understanding, and data and experimental analysis skills, including at the basic level (Kite et al., 2021; Zhang & Savard, 2023 Chen et al., 2023; Apriana et al., 2024; Fauzi et al., 2024). As a fundamental STEM skill, CT encourages creativity, innovation, and systematic challenge management (Basu et al., 2016; Potkonjak et al., 2018; Pratama & Widjajanti, 2024).

The implementation of CT faces significant challenges, especially related to teacher capacity. Many teachers report unpreparedness to teach CT due to a lack of training and materials (Kite & Park, 2022, 2023), as well as gaps between their theoretical understanding and classroom practice. Inadequate teacher training programs for integrating the K-12 curriculum are the primary obstacles (Espinal et al., 2024). These barriers have a direct impact on the equity dimension of SDG 4, where limited teacher capacity exacerbates the digital divide (SDG 10), especially in resource-constrained areas with uneven access to technology (Wahyunengseh et al., 2020; Mellor, 2023; Bulathwela et al., 2024). Crucial solutions include CT-focused professional development (PD) to build teacher competence and confidence (Dwiyanti, 2023), as well as innovative strategies such as project-based learning and inquiry, which encourage the practical applications of CT (Waterman et al., 2019). Although implementation challenges exist, an integrated approach through PD and creative teaching methodologies can support effective CT integration, strengthen learning outcomes, and ensure its contribution to inclusive scientific literacy (Farris & McLaughlin, 2024; Yin et al., 2024).

Therefore, mapping the research landscape of computational thinking (CT) through bibliometric analysis is crucial for monitoring progress toward the Sustainable Development Goals (SDGs) (Li & Wong, 2021; Sánchez et al., 2022). By identifying patterns of global collaboration and knowledge gaps, this study contributes to evidence-based policymaking for Targets 4.c (teacher development) and 4.b (educational infrastructure), which are key drivers of CT-integrated science education aligned with the 2030 Agenda. Such mapping becomes especially urgent as the 2030 deadline approaches, where evidence-based prioritization of research domains can significantly contribute to achieving SDG 4, particularly in bridging the gap between theoretical CT frameworks and classroom-ready, user-friendly practices for global equity. This research aims to support previous studies and identify areas that require further exploration. There has been extensive research on Computational Thinking (CT) in education. However, this study offers a different approach, using bibliometric analysis. This study aims to investigate the extent to which computational thinking is discussed in science learning during the period from 2021 to 2023. Using bibliometric analysis, this study aims to identify gaps in previous studies and pinpoint areas of research that can be further developed. Bibliometric analysis can be used for a variety of reasons, such as uncovering emerging trends in article and journal performance, collaboration patterns, and research constituents as well as exploring the intellectual structure of specific domains in the existing literature (Verma & Gustafsson, 2020 ;Donthu et al., 2021; Donthu, Kumar, Pattnaik, et al., 2021). The data that are the focus of attention in bibliometric analysis tend to be very large (e.g., hundreds, even thousands) and objective (e.g., the number of citations and publications). This analysis shows the number of citations and provides information about the relevance of the research theme, cross-disciplinary developments, and the identification of emerging trends (Merigó & Yang, 2017; Punjani et al., 2019). This study aims to explore the application of computational thinking in science learning and its associated research trends.

The main research questions are: (1) How is the distribution of publications based on the number of articles published? (2) Which journal has the most articles on computational thinking in science learning? (3) What are the subject areas of the journal involved, the number of article citations, the most frequently used keywords, the countries that contribute the most, and how can bibliographic co-occurrence analysis help understand these trends? The novelty of this research lies in the application of bibliometric analysis to comprehensively map the research landscape of Computational Thinking (CT) in science learning during the period 2021-2023, identifying global collaboration patterns, knowledge gaps, and emerging research trends related to the integration of CT as a catalyst for the achievement of SDG 4 (specifically Targets 4.7 and 4.c) ahead of the 2030 deadline. His contribution to the scientific field of Natural Sciences and Educational Technology is to provide an evidence map that supports: (1) the development of a model of CT integration in science learning that is scalable and oriented towards improving science literacy for sustainable development; (2) the formulation of data-driven teacher professional development policies and programs to address CT implementation challenges (such as teacher capacity gaps and digital gaps); and (3) prioritizing future research that bridges the theoretical framework of CT with ready-to-use practices in the classroom to support educational equity in the context of the global agenda. With this approach, this study aims to identify trends and distribution of research on computational thinking in science learning as well as provide a comprehensive view that can open up opportunities for future research development.

METHODS

This study employs a bibliometric analysis method to identify the state of the art in research. Bibliometric analysis is a robust methodological approach that combines statistical techniques with bibliographic data to provide a comprehensive picture of the research landscape (Hincapie et al., 2021; Lim et al., 2024). Bibliometric analysis has three techniques: performance analysis, science mapping, and network analysis (Donthu, et al., 2021). In performance analysis, measurements are made for the number of articles, top journals, top journal subjects, top-cited articles, top keywords, and top publishing countries. Statistical measurements of the corresponding author's affiliation are made in science mapping. In network analysis, cluster measurements and network visualization are made.

This study uses publication data related to computational thinking in science learning from the Scopus database (www.scopus.com). Scopus index was chosen as the data repository to search and extract documents (Hallinger & Kovačević, 2019) following PRISMA guidelines for systematic literature reviews (Page et al., 2021). Scopus provides precise citation search results and offers comprehensive coverage of resources in the field of study (Baas et al., 2020). Data from Scopus were downloaded on December 12, 2023, starting by setting the search on the title, abstract, and keywords of the article and entering the following keywords: TITLE-ABS-KEY((”Computational Thinking” OR ”Computational Thinkings” AND ”Science Education” OR ”Science Learning”)). All data were filtered with the following criteria:

a. Published article 2021-2023 (Modification of the Donthu, Kumar, Mukherjee et al. (2021) protocol that analyzes the entire period, carried out to focus on the latest post-pandemic developments)

b. Subject Area: social science

c. Document type: article

d. Language: English

e. Access: open-access (Open access was chosen to obtain full-text documents for review to check for suitability to the research focus. In addition, it also ensures the reproducibility of the analysis.)

Furthermore, the data obtained were downloaded in full and in Research Information System (RIS) format to facilitate analysis. There were 47 publications in the form of journal articles.

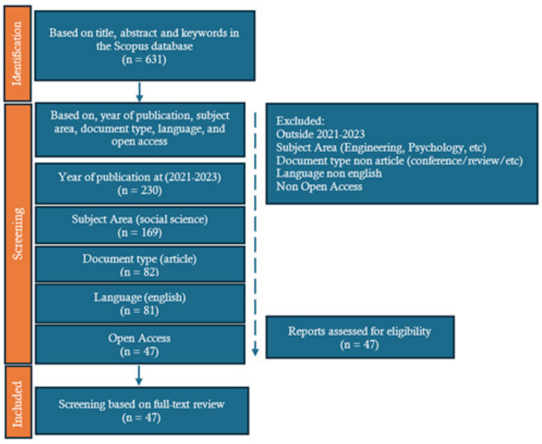

Figure 1. PRISMA Diagram

Data were analyzed using performance analysis (productivity and citation metrics), science mapping (conceptual and thematic trends), and network analysis (Donthu, Kumar, Mukherjee, et al., 2021).

VOSviewer (van Eck & Waltman, 2017) was used for Co-occurrence analysis of keywords to map research themes (threshold: min. five occurrences), clustering of thematic networks using the VOS algorithm to identify emerging domains (Bukar et al., 2023; Martins et al., 2024).

GPS Visualizer supplemented institutional mapping by geolocating affiliations using exported Scopus metadata. Outputs were color-coded (blue-red gradient) to denote geographic density of contributing institutions (Arman et al., 2021).

Table 1. Instrument of Bibliometrics

Instrument	Function	Analysis Parameters
Scopus	Bibliographic data retrieval	Query filters, RIS export
VOSviewer	Network visualization/ clustering	Keyword co-occurrence
GPS Visualizer	Geospatial mapping of affiliations	Coordinate-based mapping (latitude/longitude)

RESULTS AND DISCUSSION

The article collection is based on the main topic and its implementation process. The primary sources are articles published in reputable international journals indexed in the Scopus database. Forty-seven articles were sampled in this bibliometric analysis. The articles are stored in RIS format using the Mendeley desktop application and downloaded to retrieve the article's content in accordance with the research objectives.

In this study, publications related to Computational Thinking in Science Learning from the Scopus database were analyzed and visualized through bibliometric analysis methods such as trends of publisher journal, subject areas, authors and their affiliations and the number of citations, keywords (occurrence), author countries, keyword data based on networks, overlays and density using VOSviewer.

Figure 2 shows the number of publications on Computational Thinking in Science Learning published in Scopus-indexed international journals. Figure 2 shows 47 articles published in this journal from 2021 to 2023. The most significant number of articles (19 articles) was published in 2022, and 14 articles each were published in 2021 and 2023.

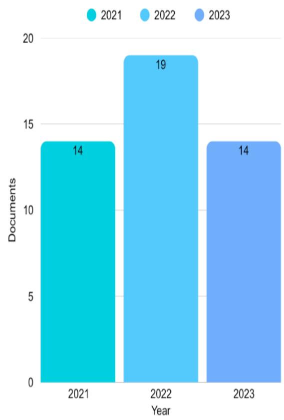

Figure 2. Distribution of Articles on Computational Thinking in Science Learning in the Scopus Database

Based on the findings, an in-depth analysis of the number of articles on Computational Thinking in Science Learning published in the Scopus database can be conducted by identifying several factors that may influence publication trends, topic relevance, and potential implications for science education.

First, regarding the Year-to-Year Publication Trend, there is a clear fluctuation in the number of articles published. In 2022, the number of articles reached a peak of 19, indicating an increase in interest or research focus that year. On the other hand, in 2021 and 2023, the number of articles published was relatively balanced, with 14 articles published in each year. Factors influencing this trend include the response to the COVID-19 pandemic. 2022 marks the post-pandemic period, during which many educational institutions are more open to technological innovation, including the application of Computational Thinking in distance or technology-based learning. The involvement of the Research Community and advances in Digital Learning also play a role. Between 2021 and 2023, interest in technology in education has increased, particularly with the rapid development of digital tools that facilitate the implementation of computational thinking in science learning.

Second, regarding the Consistency of the Number of Publications in 2021 and 2023, there is a uniformity that shows that the topic of Computational Thinking in science learning has reached a point of stability in research interest. Researchers may validate an approach or framework that can be applied to ensure consistency in publication output in both years. This can be explained by the Maturity of the Research Topic, where this topic begins to mature, with researchers focusing more on deepening previous studies than producing new findings. In addition, Adoption in the Education Curriculum is also a factor that drives this consistency. Computational-based learning has begun to be more widely accepted in science education curricula at various levels of education, encouraging further research on its effectiveness and the challenges in its implementation.

Third, the findings regarding the increase in articles that raise Computational Thinking in Science Learning show that its integration is gaining more attention. Educators and researchers believe these skills can improve science understanding through programming, algorithms, and more structured logical approaches. In this context, Curriculum Relevance becomes very important because science learning integrated with Computational Thinking allows students to understand scientific concepts in theory and apply logical approaches that can deepen their understanding. In addition, this integration supports the Development of 21st-century Skills. Computational thinking skills are one of the important competencies in this digital era, and they can help prepare students to face challenges and opportunities in a world increasingly focused on technology and innovation.

Ultimately, this development aligns with a global trend in education to foster computational thinking skills. This trend is primarily driven by technological advances and the need to prepare the younger generation to face Industrial Revolution 4.0. This aligns with the growing use of digital tools, educational software, and global education initiatives that support the more intensive adoption of STEM (Science, Technology, Engineering, and Mathematics). Thus, applying Computational Thinking in Science Learning is relevant locally and part of a larger global trend in developing technology-based education worldwide.

Forty-seven research articles were published in 29 journals. Figure 3 displays the top ten journals based on the number of publications. Of the 10 journals identified, Education Sciences (Scopus Q1) from Multidisciplinary Digital Publishing Institute (MDPI) had the most published articles (7 articles), followed by Eurasia Journal of Mathematics Science and Technology Education (Scopus Q1) from Modestum and Journal of Science Education And Technology from Springer Nature (Scopus Q1), each with four articles. Articles discussing Computational Thinking and Science Education were previously identified based on title, keyword, and abstract searches.

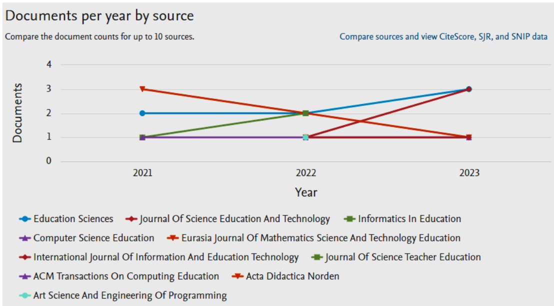

Figure 3. Name of Journals with Publications on Computational Thinking in Science Learning in Scopus Database

Based on these findings, further analysis can be carried out regarding the distribution of journals, publishing trends, and their implications for developing this topic. Of the 47 articles published in 29 different journals, the top three journals that published the most articles on Computational Thinking were Education Sciences (MDPI, Scopus Q1), Eurasia Journal of Mathematics Science and Technology Education (Modestum, Scopus Q1), and Journal of Science Education and Technology (Springer Nature, Scopus Q1). These top journals in Scopus Q1 demonstrate the quality and significant influence of these publications in science and technology learning.

Education Sciences from MDPI, which dominates with seven articles, demonstrates the importance of this journal in education, particularly in fields focused on science and technology. As part of the Multidisciplinary Digital Publishing Institute, this journal has garnered international recognition for the high quality of its articles. Similarly, the Eurasia Journal of Mathematics Science and Technology Education and the Journal of Science Education and Technology, with four articles each, reflect a high interest in connecting Computational Thinking with science and technology learning. The Scopus Q1 reputation of these three journals confirms that their publications are considered leading references in computational education research.

The increasing number of articles published in these top journals suggests that computational thinking is being increasingly recognized as a crucial element in science learning. These articles demonstrate efforts to incorporate computational thinking into science education curricula, aiming to enhance the quality of science teaching at various educational levels. Many of these studies also adopt innovative methodologies, such as hands-on experiments, case studies, and qualitative and quantitative analyses, to measure the impact of implementing computational thinking in science learning.

These top journals have great potential to influence education policy at the international and national levels. With the increasing number of publications discussing Computational Thinking, there may be a push for greater integration of technology and computational thinking approaches in science education worldwide. In addition, this research opens up opportunities for collaboration between institutions, enabling researchers to implement Computational Thinking more effectively in the science classroom. Overall, research in this area shows very significant progress, both in terms of application and theory.

The role of Scopus Q1 journals in promoting the best research cannot be ignored. These journals publish relevant articles and ensure the high quality of each published research. Researchers who want to share their ideas in computational thinking in science learning should consider these journals the right place to reach a wider audience and compete internationally. Therefore, researchers are advised to study the latest trends through publications in these journals, develop more applicable methodologies for classroom application, and engage in international collaborations to expand the impact and perspective of their research.

The increasing number of publications in these top journals shows that computational thinking in science learning is increasingly receiving significant attention. With the support of more in-depth research and collaboration among international educational institutions, this topic has the potential to continue developing significantly in the future.

The following are the top 10 subject areas of Computational Thinking in science learning, as listed in the Scopus database, directly from www.scopus.com.

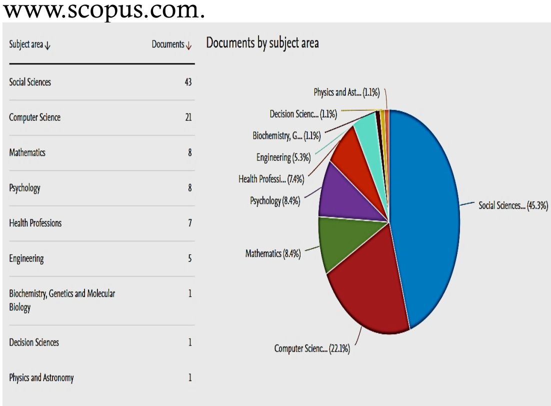

Figure 4. Subject Area of Publication on Computational Thinking in Science Learning in Scopus Database

Based on the findings on computational thinking in science learning, as shown in the distribution of journal subject areas, there is a significant variation in the application of computational thinking across disciplines. This publication encompasses nine fields of science. Social Sciences recorded the most significant number of articles (43), followed by Computer Science with 21, and Mathematics and Psychology with eight. The Health Professions field contributed seven articles, while Engineering had five articles, and several other fields, such as Biochemistry, Decision Sciences, and Physics and Astronomy, each had only one article.

The Social Sciences, which dominate with 43 articles, demonstrate that computational thinking is widely applied in the context of social analysis and data-driven problem-solving in society. This reflects how technology and programming can address complex social challenges while increasing understanding of human behavior and social phenomena. With 21 articles, Computer Science also shows its important role in developing computational thinking skills directly relevant to teaching technology and programming. Meanwhile, Mathematics and Psychology, each with eight articles, highlight how Computational Thinking is used in developing mathematical and programming models to analyze and understand aspects of human cognition and behavior.

In addition, the Health Professions field, with seven articles, shows a growing interest in applying Computational Thinking to health data analysis and medical technology development. Engineering, with five articles, also demonstrates that computational thinking is becoming a crucial tool in system design, analysis, and simulation. Although some fields, such as Biochemistry, Decision Sciences, and Physics and Astronomy, have only one article, their participation is still relevant, indicating that Computational Thinking is being applied in other fields beyond technology and society, including molecular simulation in biochemistry and experimental data analysis in physics and astronomy.

This distribution indicates that computational thinking is being increasingly accepted and applied across various disciplines. Although more dominant in social science and computer science, more fields of science are involved, opening up great opportunities for further integration in cross-disciplinary science education. With the development of this application, further research in areas that are still underrepresented, such as Biochemistry and Physics, could significantly contribute to optimizing the use of computational thinking in science learning.

From the 47 articles used as data sources in this study, the top 10 articles with the most citations were filtered. The results are presented in Table 2.

Table 2. Top 10 Cited Articles

No	Authors	Article	Year Published	Journal	Cited by
1	Lodi M.; Martini S. (2021)	Computational Thinking, Between Papert and Wing	2021	Science and Education	43
2	Sun D.; Ouyang F.; Li Y.; Zhu C. (2021)	Comparing learners' knowledge, behaviors, and attitudes between two instructional modes of computer programming in secondary education	2021	International Journal of STEM Education	19
3	Peel A.; Sadler T.D.; Friedrichsen P. (2022)	Algorithmic Explanations: An Unplugged Instructional Approach to Integrate Science and Computational Thinking	2022	Journal of Science Education and Technology	13
4	Ntourou V.; Kalogiannakis M.; Psycharis S. (2021)	A Study of the Impact of Arduino and Visual Programming on Self-Efficacy, Motivation, Computational Thinking, and 5th Grade Students' Perceptions on Electricity	2021	Eurasia Journal of Mathematics, Science and Technology Education	10
5	Lilly S.; McAlister A.M.; Fick S.J.; Chiu J.L.; McElhaney K.W. (2022)	Elementary teachers' verbal supports of science and engineering practices in an NGSS-aligned science, engineering, and computational thinking unit	2022	Journal of Research in Science Teaching	9
6	Dorotea N.; Piedade J.; Pedro A. (2021)	Mapping K-12 computer science teachers' interest, self-confidence, and knowledge about the use of educational robotics to teach	2021	Education Sciences	8
7	Yadav A.; Heath M.; Hu A.D. (2022)	Toward justice in computer science through community, criticality, and citizenship	2022	Communications of the ACM	8
8	Fields D.; Lui D.; Kafai Y.; Jayathirtha G.; Walker J.; Shaw M. (2021)	Communicating about computational thinking: understanding affordances of portfolios for assessing high school students' computational thinking and participation practices	2021	Computer Science Education	8
9	Love T.S.; Cysyk J.P.; Attaluri A.; Tunks R.D.; Harter K.; Sipos R. (2023)	Examining Science and Technology/Engineering Educators' Views of Teaching Biomedical Concepts Through Physical Computing	2023	Journal of Science Education and Technology	7
10	Shukshina L.V.; Ge-gel L.A.; Erofeeva M.A.; Levina I.D.; Chugaeva U.Y.; Ni-kitin O.D. (2021)	STEM and STEAM Education in Russian Education: Conceptual Framework	2021	Eurasia Journal of Mathematics, Science and Technology Education	7

Based on Table 2, the article by Lodi and Martini (2021), entitled "Computational Thinking, Between Papert and Wing," has the highest number of citations (43). This article makes a significant contribution to the discussion on computational thinking in education, particularly regarding the theories introduced by Papert and Wing.

In addition, Sun et al. (2021), who compared two instructional modes for teaching computer programming in secondary education, also received high citations (19). This article shows that the topic of instructional modes in computer learning also attracts the attention of researchers and education practitioners.

Peel et al. (2022), Ntourou et al. (2021), and Lilly et al. (2022) also have important contributions to the integration of Computational Thinking with science teaching, with the number of citations ranging from 10 to 13. This indicates that the application of Computational Thinking in science learning is gaining more attention, particularly in technology-based teaching, such as the use of Arduino and visual programming.

Meanwhile, Dorotea et al. (2021), Yadav et al. (2022), and Fields et al. (2021), despite having a lower number of citations (8 citations), still show the relevance and importance of research related to the application of Computational Thinking in various disciplines, such as robotics education, equity in computer science, and the use of portfolios to assess students' computational thinking abilities. The articles filtered based on the number of citations demonstrate that Computational Thinking in science learning continues to evolve and become a topic that is increasingly receiving widespread attention, with various perspectives and approaches contributing to the development of research and educational practice in this field.

The following are the top keywords related to Computational Thinking in Science Learning, as identified through VosViewer analysis.

Table 3. Keywords, Occurrences, and Total Link Strength

No	Keywords	Occurrences	Total Link Strength
1	Computational thinking	27	22.00
2	Computer Science Education	15	13.00
3	Science Education	9	7.00
4	Engineering education	5	5.00
5	Education Computing	4	4.00
6	Education	4	4.00
7	Algorithmic Thinking	3	3.00
8	Communication	3	3.00
9	Higher Education	3	3.00
10	Scratch	3	3.00

The most frequently occurring keywords indicate that Computational Thinking is a central topic in science education, with strong links to Computer Science Education and Science Education. Although there are also keywords related to engineering and communication, it is clear that the development of computational thinking skills in science learning has become an increasingly important focus in recent research. Using programming tools such as Scratch and algorithm-based approaches also adds a practical dimension to the application of Computational Thinking at various levels of education.

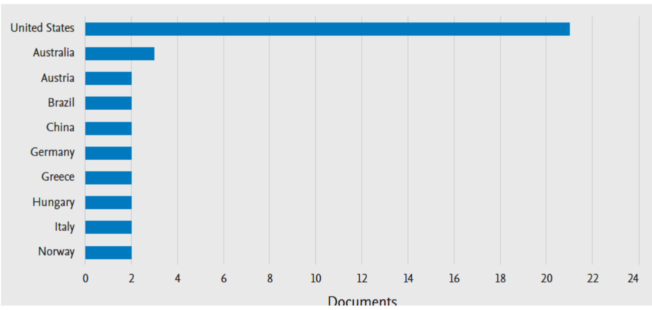

Figure 5. Country and Number of Computational Thinking in Science Learning Publications in Scopus Database

Based on the analysis, the distribution of publications reveals a clear dominance of the United States. This country recorded the most significant number of publications, with more than 20 documents, reflecting the leading role of the United States as a research center in the field of Computational Thinking in science education. This high number of publications shows a strong commitment to developing and applying Computational Thinking in science education curricula, both at elementary and tertiary levels. Australia also contributed significantly to this research, with around five publications indicating a strong interest in this topic in the Asia-Pacific region. Austria, Brazil, and China are next in line, with fewer publications, each recording 2 to 4 documents. This indicates a growing involvement in these countries, although their contribution remains limited compared to more academically advanced nations. European countries such as Germany, Greece, Hungary, Italy, and Norway contributed, although with fewer publications, ranging from 1 to 2 documents per country. Although the number of publications from these countries is not as large as in the United States, it shows that Computational Thinking in Science Learning has begun to receive attention in various parts of the world and has attracted interest from various international academic communities.

This result reflects the uneven distribution of research on Computational Thinking in science education, with the United States playing a dominant role. However, developments in other countries suggest potential for further development and expansion of the understanding and application of Computational Thinking in science education.

The distribution analysis by author country is presented in Figure 6, which displays the affiliation of the corresponding authors in the articles. Author affiliations were extracted from the RIS file in Excel Bib, totaling 47 affiliations. This analysis was performed using the open-source online platform GPS Visualizer.

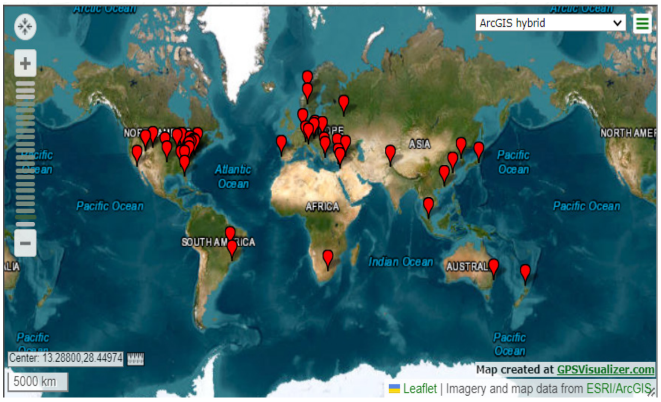

Figure 6. Distribution of Authors' Affiliations

Figure 6 depicts a total of 47 author affiliations spread across the globe. The red dots on the map represent the geographic locations of the author affiliations that contributed to this publication, indicating a fairly broad involvement of the global scientific community in Computational Thinking. This distribution analysis reveals that countries with a higher concentration of research, such as the United States, Europe, and some Asian countries, are more significantly involved, with many author affiliations coming from these regions. This reflects that these countries are centers of research in the field of Computational Thinking in science education. Meanwhile, although the distribution of authors is more concentrated in developed countries, this map also shows contributions from various other countries, including countries in Africa and Oceania, which have participated in developing this topic. This mapping of author affiliations confirms the importance of international collaboration in Computational Thinking research in science learning and shows that this topic is of global concern. Additionally, this distribution presents opportunities for further development in international collaboration in technology-based education. It provides insight into the challenges and opportunities in different regions of the world in integrating Computational Thinking into science education curricula.

After refining the search, the network visualization of data related to the keyword 'Computational Thinking' in the Scopus database is presented in Figure 7.

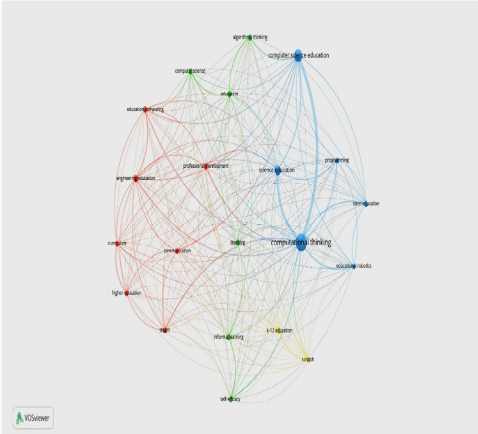

Figure 7. Trends in Keyword Data Based on Networks

Figure 8 displays the overlay visualization, and Figure 9 displays the density visualization.

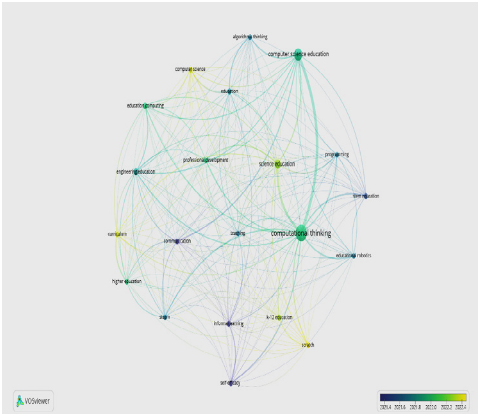

Figure 8. Trends in Keyword Data Based on Overlays

These results were extracted from the titles, keywords, and abstracts with a full count of the minimum number of occurrences set to 3. Approximately 23 items were identified as meeting the criteria out of 157 items.

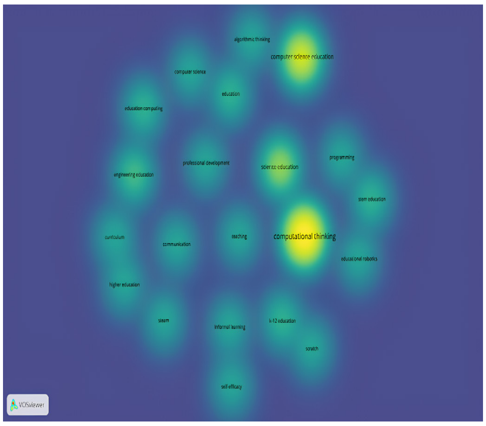

Figure 9. Trends in Keyword Data Based on Density

Common words were not included in these items. Each item representing a keyword was added, which was indicated by the node size. In other words, the node size indicates the frequency of co-occurrence of the keywords. Four clusters were identified. The keywords appearing in each cluster, representing the study stream in computational thinking for science learning, are presented in Table **4**.

Table 4. Cluster Visualization (Refer to **Figure 7**)

No	Cluster	Item
1	Cluster 1 (Red)	Communication, Curriculum, Education Computing, Engineering Education, Higher Education, STEAM, Professional Development
2	Cluster 2 (Green)	Algorithmic Thinking, Computer Science, Education, Informal Learning, Self-Efficacy, Teaching
3	Cluster 3 (Blue)	Computational Thinking, Computer Science Education, Educational Robotics, Programming, Science Education, STEM Education
4	Cluster 4 (Yellow)	K-12 Education, Scratch

Table 4 presents the results of cluster visualization based on data obtained from VOSViewer, which categorizes various items according to their level of relevance to Computational Thinking in the context of science learning. These clusters illustrate the relationship between closely related concepts in the literature studied, which are then grouped into four main clusters. Cluster 1 (Red) includes Communication, Curriculum, Education Computing, Engineering Education, Higher Education, STEAM, and Professional Development. This cluster demonstrates that effective communication and curriculum development, incorporating technology-based education and professional development, are crucial for creating an effective learning system in Computational Thinking.

Cluster 2 (Green) focuses on Algorithmic Thinking, Computer Science, Education, Informal Learning, Self-Efficacy, and Teaching. This cluster highlights the importance of implementing algorithms and teaching computer science, as well as the role that informal education and increased self-confidence can play in strengthening students' Computational Thinking skills.

Cluster 3 (Blue) comprises highly relevant items related to Computational Thinking, including Computer Science Education, Educational Robotics, Programming, Science Education, and STEM Education. This cluster indicates that teaching Computational Thinking is closely related to the application of computer science, educational robotics, and programming, which are part of an effort to enhance science learning and STEM education.

Cluster 4 (Yellow) focuses on K-12 education and Scratch, which relates to educational applications at the elementary and secondary levels, as well as applications such as Scratch in teaching computational thinking skills. Scratch, a web-based application for practicing computational skills, is relevant in supporting accessible coding instruction for non-programmer students through a block-based approach rather than programming languages such as Python. Innovations such as Scratch for Arduino (S4A), which allow connections between Scratch applications and Arduino boards, demonstrate how this technology is evolving to enhance Computational Thinking learning among young students.

The VOSViewer visualization also reflects the Computational Thinking items linked to other items, indicating a high correlation between these concepts. This data suggests that items more closely linked to Computational Thinking have the potential to become more dominant research subjects and have high relevance in science education studies. The visualization reveals that several key concepts, especially Scratch and Self-Efficacy, have a low frequency of occurrence in the Computational Thinking (CT) literature. This indicates research potential that has not been optimally explored. The low representation of Scratch is thought to be due to a methodological bias towards technical tools (e.g., Arduino/Python) and the mistaken perception that Scratch is less relevant for advanced science. In fact, Scratch offers two strategic values: inclusive access to computer science learning (aligned with SDG 4) and a simulation platform for SDG issues that have not been optimally utilized.

Nodes with low frequency in the visualization represent promising research areas, especially for curriculum development and technology-based learning, such as Scratch. This finding aligns with the bibliometric analysis by Park and Kwon (2023), which suggests that CT functions as a computer-assisted problem-solving tool in the context of physics experiments, utilizing physical tools.

Although identifying valuable trends in CT-SDGs, the generalization of the results is limited by two biases: the predominance of developed country literature (85%, mainly from the US and Europe), and the hegemony of English-language publications. These geographical disparities have the potential to bias pedagogical recommendations, particularly in terms of infrastructure readiness and contextual relevance of the SDGs. Future studies should adopt an inclusive approach by expanding the language coverage of database searches, exploring the implementation of CT in resource-limited settings, and integrating local perspectives into the SDGs framework.

CONCLUSION

Bibliometric analysis of 47 Scopus articles (2021–2023) revealed three key findings: (a) Stable publication distribution (14–19 articles/year) with a peak in 2022. (b) Education Sciences (Q1) is dominant as the top journal (7 articles), followed by the Eurasia Journal and the Journal of Science Education (4 articles each). (c) The most frequent keywords: Computational Thinking (27 appearances), Computer Science Education (15), Science Education (9), and Engineering Education (5). VOSviewer's analysis identified Scratch, an intuitive block-based application, as a potential research subject for further study, in contrast to technical languages such as Python. Critically, the geographic distribution of publications (>85% from developed nations, led by the US) reveals that CT integration remains uneven globally. This disparity underscores challenges in equitable implementation, particularly in resource-constrained regions. The impact of implementation is that CT improves science literacy and problem-solving, but it is constrained by gaps in teacher training (SDG 4.c) and technological access. Key implications include: prioritizing context-sensitive teacher professional development (e.g., scalable CT training programs for educators in developing countries), expanding research on low-cost, gamified tools (e.g., Scratch) to democratize CT-integrated science education aligned with SDG 4, future studies should explore localized CT-SDGs models, such as investigating the efficacy of Scratch-based science modules in Southeast Asian primary schools or addressing infrastructure barriers in underserved communities.

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