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Advancements in computational thinking research in science education: a bibliometric analysis of reputable international journals (2014-2024)

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ABSTRACT

This research investigates the development of Computational Thinking (CT) studies in science education by examining selected science journals. It focuses on 1) the distribution of CT research, 2) the proportion of CT-related articles, 3) research methods, 4) authors and citations, 5) education levels, and 6) scientific disciplines and topics. Despite limited systematic literature reviews on CT, its importance in science education is evident as it fosters critical thinking and problem-solving skills. This bibliometric review uses Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) to analyze 13 articles from five reputable international journals: Journal of Science Education (IJSE), International Journal of Science and Mathematics Education (IJMA), Journal of Research in Science Teaching (JRST), Science Education (SE), and Research in Science Education (RISE). Findings show that CT research began to develop in 2019. The mixed method is the most widely used in CT research (40%), with JRST publishing the most CT articles (70%). Citations for CT articles are not yet significant, with the highest being 119. Research at the elementary level needs more attention, as many studies focus on secondary schools. CT STEM is the most focused topic in these journals. Other findings are discussed in detail.

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Introduction

Advances in digital technology in the 21st century have significantly impacted all fields, from social and political to educational. This change is not only in the form of written communication, audio, video, or highly interactive media but also in the opportunity to access and communicate with people in different areas of the country in the same residence or even throughout the world in different contexts (Saykili, 2019). Based on this progress, skills that support it are also needed, currently called 21st-century skills (Caena & Redecker, 2019).

Competency/skills in the 21st century is a construct that refers to international education policy, which seeks to meet the current and future needs of the global workforce through increasing the development of learning that demands cognitive and inter- and intra-personal skills for students (Miller, 2019; Voogt & Roblin, 2012). 21st-century skills encourage learning skills in innovation, information, technology, and media, as well as life and career skills (Caena & Redecker, 2019). The most suitable way to improve 21st-century skills is to use computing skills.

This skill combines problem-solving, logical thinking, coding thinking, and design skills (Tuomi, Multisilta, Saarikoski, & Suominen, 2018). Based on (Denning, 2009) thoughts, Computational Thinking (CT) can interpret the world by converting input into algorithmically controlled output. In other words, this skill involves learning to think about, represent, and solve problems that require a combination of human cognitive power and computational capacity (Lye & Koh, 2014; Sengupta, Dickes, & Farris, 2018). So, there are researchers who claim that computational thinking and Coding skills are also important skills to teach in the 21st century. Coding skills include problem-solving, critical thinking, creativity, collaboration, and communication (Binkley et al., 2012; Niemi & Multisilta, 2016).

Several countries, including England, Finland, Australia, Greece, and France, have made coding/programming skills mandatory in elementary school (Mason & Rich, 2020). This is because the need for jobs in the technology sector has proliferated over this decade, and some jobs humans have carried out have begun to automate (Autor, 2015). In addition, cognitively developing coding skills can improve students' mathematical performance and problem-solving abilities (Schanzer, Fisler, & Krishnamurthi, 2018; Scherer, Siddiq, & Sánchez Viveros, 2018).

Interest in CT within the scientific community has surged in recent years, as evidenced by numerous systematic reviews. For instance, a scoping review highlighted the significant rise in CT research and its integration into educational practices (Melro, Tarling, Fujita, & Kleine Staarman, 2023). The Computational Thinking for Science (CT-S) framework has been proposed to operationalize CT in K-12 science education. This framework emphasizes the importance of CT in authentic science practices and aligns with contemporary science standards (Hurt et al., 2023). Research has shown that integrating CT into STEM education enhances students' problem-solving skills and prepares them for future scientific endeavors. A semi-systematic literature review of 55 empirical studies demonstrated the positive impact of CT on students' learning outcomes in STEM fields (Wang, Shen, & Chao, 2022a).

This research is crucial as it examines the development of Computational Thinking (CT) studies in science education, an increasingly relevant area in the digital age. By focusing on the distribution of CT research, the proportion of CT-related articles, research methods, authors and citations, education levels, and scientific disciplines and topics, this study provides a comprehensive overview of how CT is applied and studied in the context of science education. The urgency of this research is further supported by the limited systematic literature reviews on CT, despite its significant role in science education for enhancing critical thinking and problem-solving skills. Utilizing the PRISMA method to analyze selected articles from five leading international journals, this study not only offers deep insights into the trends and patterns in CT research but also helps identify gaps and opportunities for further investigation. Thus, this research makes a significant contribution to the understanding and development of CT in science education, ultimately supporting the improvement of education quality and preparing students to face future challenges.

Method

This bibliometric review study utilizes the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Cheung & Erduran, 2023; Moher, Liberati, Tetzlaff, Altman, & PRISMA Group, 2009). The primary aim of this study is to investigate research trends focusing on Computational Thinking (CT) in science education. The sample articles in this study include theoretical, empirical, or other types of research. We collected journal articles using the keyword "computational thinking" in the search menu of five internationally reputable journals in science education. The journals targeted in this study include the International Journal of Science Education (IJSE), International Journal of Science and Mathematics Education (IJMA), Journal of Research in Science Teaching (JRST), Science Education (SE), and Research in Science Education (RISE). These journals were selected because they are among the best in the field of science education, not only due to their international reputation but also because they are Scopus Q1 journals. Meanwhile, we excluded book chapters, book reviews, and editorials from the inclusion criteria. We also limited the articles analyzed to the last ten years, from 2014 to 2024, and the search was conducted in May 2024. We are confident that within these ten years, several articles have been published in these leading journals in science education.

Review Procedure

The steps we took in Figure 1 (By the PRISMA) show that through this step, it can be easier for writers to review the chosen theme both in terms of implementation and reporting. This review process is carried out with the following flow. The results of what we have done can be seen in Figure 1.

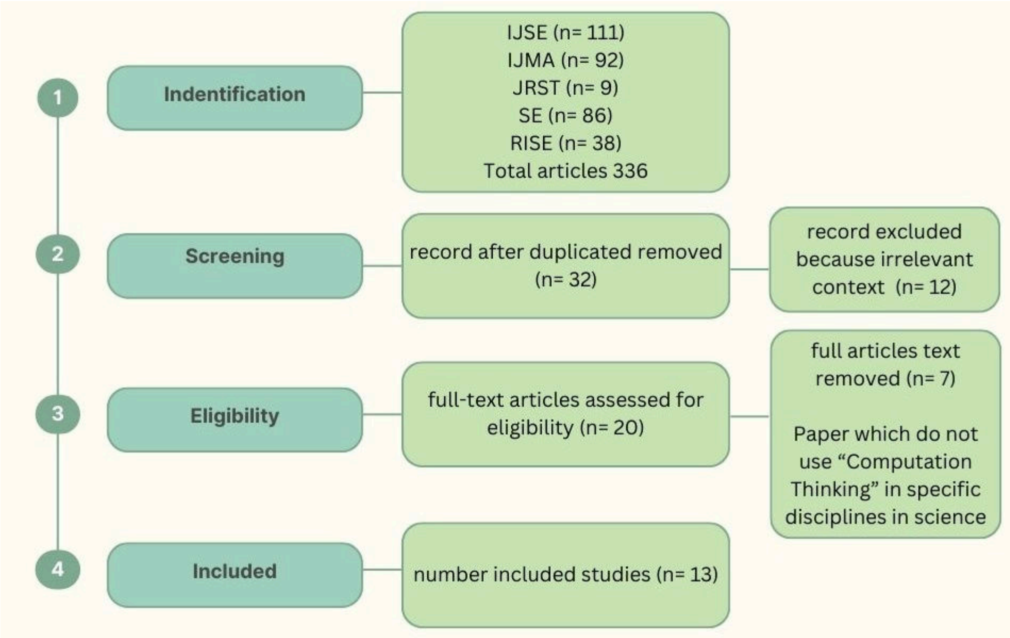

Figure 1 Flow Diagram of the Four Stages of A Bibliometric Review

Identification by searching for relevant research themes. The first step in this research involves searching for relevant research themes related to CT in science education. This includes reviewing selected science journals to find articles that discuss CT. The goal is to identify the distribution of CT research, the proportion of CT-related articles, research methods used, authors and citations, education levels, and scientific disciplines and topics covered.

Screening by adjusting the relevant title. The first step in this research involves searching for relevant research themes related to CT in science education. This includes reviewing selected science journals to find articles that discuss CT. The goal is to identify the distribution of CT research, the proportion of CT-related articles, research methods used, authors and citations, education levels, and scientific disciplines and topics covered.

Eligibility by looking further at the contents of the articles screened. The first step in this research involves searching for relevant research themes related to CT in science education. This includes reviewing selected science journals to find articles that discuss CT. The goal is to identify the distribution of CT research, the proportion of CT-related articles, research methods used, authors and citations, education levels, and scientific disciplines and topics covered.

Included (according to the research theme being sought) by discussing according to the problem formulation. The first step in this research involves searching for relevant research themes related to CT in science education. This includes reviewing selected science journals to find articles that discuss CT. The goal is to identify the distribution of CT research, the proportion of CT-related articles, research methods used, authors and citations, education levels, and scientific disciplines and topics covered.

Coding Analysis

To answer the research questions, we created Table 1 to analyze the articles we selected.

Table 1. Coding Analysis

Abstrack	Categories	Codes
What is the distribution of CT articles based on their published years?	The text is presented in the article title	Computational Thinking
What is the proportion of CT articles in the selected journals?	Writer	First author Corresponding author
What is the standard research method in science education research of CT?	Research methods	Quantitative Qualitative Mix-Method Review articles
Who are the authors, and how are the citations on CT topics?	Type of education	Primary and secondary education Tertiary education Undergraduate Program
How do the publications on CT relate to educational levels?	Amount	Google Scholar Citation
What are the science disciplines and topics in CT studies?	Subject/Topic	Biology Chemistry Physics Other disciplines CT-STEM CT-Inquiry etc

Development of Analysis Schemes

This article was analyzed by a team of three researchers with more than ten years of research experience in the field of education. The tasks of each research team are as follows: 1) Ensure that the titles found are related to the chosen theme, 2) Check the contents of the abstract of each article that has been found, and 3) Look in detail at the research methods contained in the article. Furthermore, the evaluation of this article is adjusted to the agreed open coding system. These articles were coded to obtain categories appropriate to the research questions. Using codes facilitates the conversion of observed criteria into quantitative data, as outlined in Table 1.

After developing the coding scheme, we considered whether the code effectively covered the categories presented in our research questions. Therefore, to ensure the coding scheme's reliability, the articles' authors acted as assessors. Initially, all researchers individually analyzed the article documents to establish a basis for categorization. After the analysis, an agreement was determined according to the rules established by (Caramaschi, Cullinane, Levrini, & Erduran, 2022). We assigned each researcher's agreement a score of one (1), while lack of agreement or disagreement received a zero (0). The accumulated matching codes are calculated and divided by the recorded instances. The Miles and Huberman methodology (as cited in (Caramaschi et al., 2022)) suggests that an agreement exceeding 80% indicates reasonable reliability. Using all codes, 100% agreement was achieved among all authors, indicating unanimous consensus to calculate the same percentage of appropriate categories as specified by the research questions.

Results and Discussions

As is known, computational thinking (CT) is a new focus in education that has developed in recent years in response to developments in the 21st century. This research discusses six big questions about research trends in CT, especially in science education. These problems include research trends from year to year, the distribution of journals that serve as publication platforms, the methods frequently used, the distribution of authors and the number of citations, the level of education as a research subject, as well as the scientific disciplines and topics most used. The following comprehensive Bibliometric analysis answers and explains these questions in detail.

Distribution of Computational Thinking CT Article Based on Years

The first problem formulation discussed in this study is how CT research trends from year to year. In this study, we reviewed the target journal over the last ten years (2014-2024). However, we only found articles published starting from the last few years, namely 2019. The complete author and year distribution can be seen in Table 2.

Table 2. The Proportion of the Article in Each Year

Authors	Published year	Number (%)
Peel, A., Sadler, T. D., & Friedrichsen, P.	2019	1 (7,7)
Wang, C., Shen, J., & Chao, J.	2022	4 (30,8)
Rachmatullah, A., & Wiebe, E. N		
Lilly, S., McAlister, A. M., Fick, S. J., Chiu, J. L., & McElhaney, K. W.		
Gunckel, K. L., Covitt, B. A., Berkowitz, A. R., Caplan, B., & Moore, J. C		
Peters-Burton, E., Rich, P. J., Kitsantas, A., Stehle, S. M., & Laclede, L.	2023	5 (38,5)
Christensen, D., & Lombardi, D.		
Lore, C., Lee, H. S., Pallant, A., Connor, C., & Chao, J.		
Krakowski, A., Greenwald, E., Roman, N., Morales, C., & Loper, S.		
Cabrera, L., Ketelhut, D. J., Mills, K., Killen, H., Coenraad, M., Byrne, V. L., & Plane, J. D.		
Jiang, H., Islam, A. A., Gu, X., & Guan, J.	2024	3 (23,0)
Kite, V., & Park, S.		
Aslan, U., Horn, M., & Wilensky, U.		

The researchers published the most research results (five articles) in 2023. This shows a positive trend in terms of science education research in the field of CT. 2019 (one article) is the first year that articles were published in the five selected journals. Since 2019, published articles have slowly increased from year to year, but in 2021, there are no articles related to CT. Even in early 2024, when this study was conducted, three articles were already published. We are very confident that in other journals that are not in the sample of this study, there are many articles published with the same (positive) trend as this study. An interesting thing to pay attention to is that in the 2014-2018 period, not a single article was found published in the five journals from which this research sample was taken.

The Proportion of the Articles in the Selected Journal

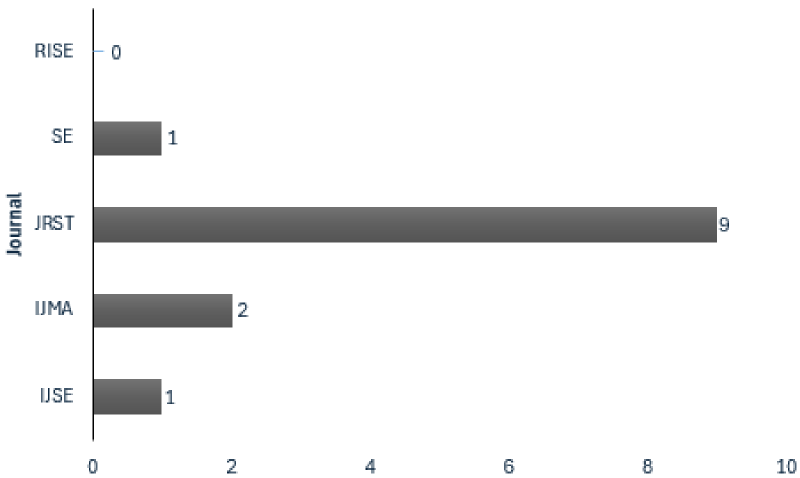

Figure 2 The Proportion of the Articles in Each Journal

Another objective of this study is to determine how articles about CT are distributed in reputable scientific journals. The selected journals are journals that specifically publish articles in the field of science education (Figure 2). In this study, five journals were selected as the primary sources, namely the International Journal of Science Education (IJSE), the International Journal of Science and Mathematics Education (IJMA), the Journal of Research and Science Teaching (JRST), Science Education (SE), and Research in Science Education (RISE).

Currently, the Journal of Research and Science Teaching (JRST) is the journal that publishes the most articles in the field of CT among four other reputable journals in the field of science education. The other three journals (IJSE, IJMA, & SE) have published similar CT articles, with only 1 article difference. Even in the journal Research in Science Education (RISE), articles about CT have yet to be found.

Research Method in the Research of Computational Thinking

Research methods that are generally used in research on CT in the field of science education are also answered in this review study. Figure 3 shows there are four methods used by many authors to research CT.

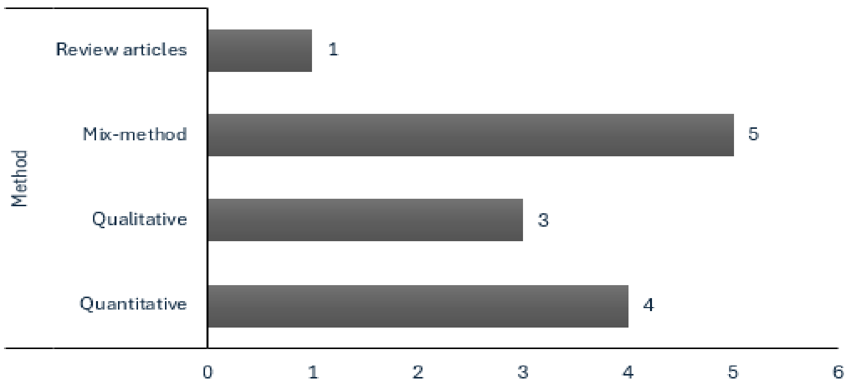

Figure 3 The Research Method of Selected Articles

The mixed method is the most used in research on CT in science learning. Qualitative and quantitative methods are used with almost the same frequency by researchers. However, reviewing articles on CT in science learning still needs to be improved. Specifically, the review article related to CT is a systematic literature review study on the integration of CT learning with STEM education.

Authors and Citation on the Computational Thinking Topic

The second question answered in this study is the author's contribution to the CT topic area. The search and review results show that there is yet to be a single author leading the research focus in CT. All 51 authors (13 articles) only published one article in the field of CT, especially in the five journals taken as samples. Table 3 below describes the contribution of the author and writing team to each published article.

Table 3. The Authors on the Computational Thinking Topic

Authors	Number	Title	Citation
(Peel, Sadler, & Friedrichsen, 2019)	1	Learning natural selection through computational thinking: Unplugged design of algorithmic explanations	79
(Wang et al., 2022)	1	Integrating Computational Thinking in STEM Education: A Literature Review	119
(Rachmatullah & Wiebe, 2022)	1	Building a computational model of food webs: Impacts on middle school students' computational and systems thinking skills	19
(Lilly, McAlister, Fick, Chiu, & McElhaney, 2022)	1	Elementary teachers' verbal supports of science and engineering practices in an NGSS-aligned science, engineering, and computational thinking unit	13

Authors	Number	Title	Citation
(Gunckel, Covitt, Berkowitz, Caplan, B., & Moore, 2022)	1	Computational thinking for using models of water flow in environmental systems: Intertwining three dimensions in a learning progression	5
(Peters-Burton, Rich, Kitsantas, Stehle, S. M., & Laclede, 2023)	1	High school biology teachers′ integration of computational thinking into data practices to support student investigations	3
(Christensen & Lombardi, 2023)	1	Biological evolution learning and computational thinking: Enhancing understanding through integration of disciplinary core knowledge and scientific practice	4
(Lore, Lee, Pallant, Connor, & Chao, 2023)	1	Integrating Computational Thinking into Geoscientific Inquiry About Volcanic Eruption Hazards and Risks	0
(Krakowski, Greenwald, Roman, Morales, & Loper, 2023)	1	Computational Thinking for Science: Positioning coding as a tool for doing science	0
(Cabrera et al., 2023)	1	Designing a framework for teachers' integration of computational thinking into elementary science	6
(Jiang, Islam, Gu, X., & Guan, 2024)	1	How do thinking styles and STEM attitudes have effects on computational thinking? A structural equation modeling analysis	6
(Kite & Park, 2024)	1	Context matters: Secondary science teachers' integration of process-based, unplugged computational thinking into science curriculum	3
(Aslan, Horn, & Wilensky, 2024)	1	Why are some students "not into" computational thinking activities embedded within high school science units? Key takeaways from a micro ethnographic discourse analysis study	0

Table 3 reveals the number of article citations since each article was published. The two most cited articles are the article entitled "Integrating Computational Thinking in STEM Education: A Literature Review," which was published in 2022, and followed by the article entitled "Learning Natural Selection through Computational Thinking: Unplugged Design of Algorithmic Explanations," which was published in 2019. Eleven other articles had different citations, and some articles still needed to be cited at the time this study was conducted.

Publications CT in the Levels of Education

Another issue revealed in this study is the distribution of publications based on levels of education. The distribution of publications at several levels shows important information regarding which areas are still under researched and are of the most significant concern to researchers. Table 4 below illustrates the distribution of articles based on journals and level of education.

Secondary education level is the main subject of study for researchers in CT (38.47%). In more detail, the Journal of Research and Science Teaching (JRST) is the main forum for researchers to publish the results of their research in this relatively new topic area (CT). Meanwhile, the number of publications is even at the high school, undergraduate, teacher, and other levels, although the quantity is small. Another piece of information that can be revealed from this study is that no articles have been published in all selected journals at the primary school level. Of course, these results provide information about further research opportunities that can be carried out at this (primary) education level.

Table 4. The Percentage of Publications on Several Levels of Education Journal

Journal	Percentage in level of education					
	Primary	Secondary	High	Undergraduate	Teacher	Unspecific
IJSE	0	0	1 (7,69)	0	0	0
IJMA	0	1 (7,69)	0	0	0	1 (7,69)
JRST	0	4 (30,76)	0	1 (7,69)	3 (23,08)	1 (7,69)
SE	0	0	1 (7,69)	0	0	0
RISE	0	0	0	0	0	0
Total	0	5 (38.47)	2 (15.38)	1 (7.69)	3 (23,08)	2 (15.38)

Science Discipline and Topics in Computational Thinking

Another exciting thing to know is what fields of science researchers are focused on regarding CT, as shown in Table 5. Table 5 describes in detail the six fields of science that are options for researchers to conduct research in the five target journals. These fields of science include physics, chemistry, biology, environmental science, geology, and unspecific disciplines.

Table 5. The Most Significant Science Discipline in Computation Thinking

Journal	Percentage in science discipline					
	Physics	Chemistry	Biology	Environmental science	Geology	Unspecific
IJSE	0	0	1 (7,69)	0	0	0
IJMA	0	0	0	0	1 (7,69)	1 (7,69)
JRST	0	0	3 (23,08)	3 (23,08)	0	3 (23,08)
SE	1 (7,69)	0	0	0	0	0
RISE	0	0	0	0	0	0
Total	**1 (7,69)**	**0**	**4 (30,77)**	**3 (23,08)**	**1 (7,69)**	**4 (30,77)**

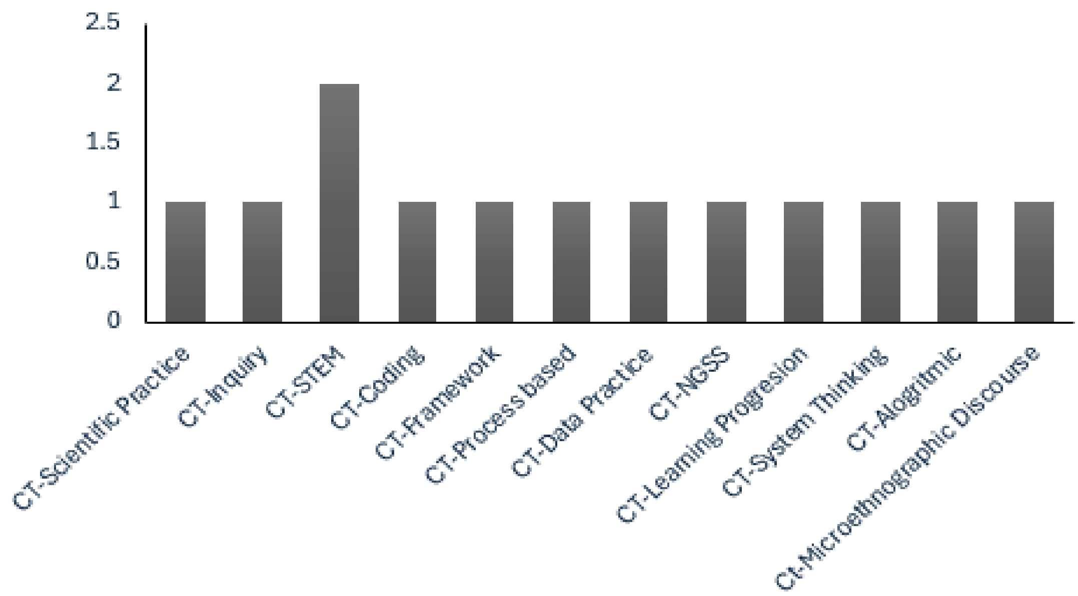

Figure 4 Research Topics in Computational Thinking

Table 5 shows that the field of biology is the subject that researchers focus on the most. This number is the same as the number of articles in the unspecific discipline (4). However, because many authors need to specify what field of science is the focus of their research, the number looks quite large (4 articles). The field of environmental science is in second place, with three articles published. Other scientific disciplines have a relatively even number of articles, namely physics and geology. Another exciting thing is that in the field of chemistry, not a single article has been found that has been published in these five reputable journals we can see at Figure 4.

The selected articles from the five journals also show exciting facts about themes or topics that appear in research challenging CT. Figure 4 shows several variations of research topics in science education in terms of computational thinking. These topics include CT Scientific practice, CT Inquiry, CT STEM, CT Coding, CT Framework, CT Process-based, CT Data practice, CT NGSS, CT Learning progression, CT System thinking, CT algorithm, and CT Microethnographic discourse. Of the 12 topics, two articles have the same topic, namely CT STEM, which was published in different years and journals (2021 IJMA & 2023 JRST).

The discussion of this research will focus on the results of the research we have conducted and obtained. This section will discuss six main points that need attention regarding research in the "Computational Thinking" field. We will discuss the six main points as follows:

Positive Trends in CT Research from Year to Year

The study results revealed that research on CT has shown a positive trend since 2019 and continues to increase in the following year. This shows that CT research is starting to become a part that needs to be researched because students in the future must face life's challenges. In the future, it cannot be denied that computers and similar things are closely related to human life, even today. This CT allows students to solve problems, design systems, and convert them into modes of thinking that humans can understand (Hsu, Chang, & Hung, 2018). (Grover & Pea, 2018) Also added that CT would simultaneously facilitate students to adopt ways of thinking like computer scientists to deal with problems and express them in a form that people, in general, better understand.

(J. Wing, 2008) defines CT as 1) the conceptualization of the programming language development process. Therefore, students are asked to be able to apply layered abstract thinking and CT, not just limited to learning computers; 2) a logical process and not just a mechanical, operational behavior that is carried out repeatedly; 3) can develop ways of thinking to solve problems, not just imitate the way computers think because humans are certainly more imaginative and more innovative than computers (Hsu et al., 2018); 4) the final product of a thought that can help in solving problems in our lives to be able to regulate our daily behavior and communication skills with other people; and 5) basic skills needed in everyday life.

In accordance with the advantages of CT, of course, research on CT will continue to develop to obtain the most optimal learning methods/outcomes to produce comprehensive CT capabilities so that in the future, students can face their lives better by their needs in an increasingly sophisticated era.

There is an Imbalance in CT Articles Published in Selected Journals

This study found that the distribution of articles related to CT was uneven in the selected journals. Of the five journals we analyzed, one journal, namely JRST, published the most research on CT (9 articles). The five journals we used in this research are the best in science education. However, there have not been many publications regarding CT research other than JRST. As with the positive trend in this research field, many authors/researchers will publish research related to CT in other journals, especially in the five journals we have chosen. This likely occurs due to differences in the subjective assessments of journal editors (Soderberg et al., 2021) regarding the potential for developing CT learning in the future.

Mixed-method is the most frequently used

The Mix-Method research method is the most widely used in the articles we analyzed. Through this type of research, researchers will gain a deeper understanding of the phenomenon they are researching. Apart from that, this type of research also fills the void of what is lacking in quantitative and qualitative research; for example, from a quantitative perspective, this research can show an improvement or impact of a treatment given, while from a qualitative perspective, this research can provide analysis to understand students' perceptions of the treatment given. Research on CT is wide open for other types of research because research with this theme is still open for other research methods. The findings of this research support this opinion because research using CT can still be developed in various focuses to produce better research and more optimal descriptions.

There are no authors who focus on CT and citations are still not very optimal

The results of this study also show that no research has produced more than one publication regarding CT. This is because there are no authors in the articles published in the five selected journals that focus on CT research. This is different from other fields of scientific research, such as research related to the nature of science, namely Norman G. Lederman, who has many articles regarding this matter, or scientific research in other fields, for example, a more specific example is regarding diagnostic tests on science learning. We found that David F Treagust had seven articles in five selected journals. CT is an exciting field in science education, making it possible to develop even better and produce experts who have many publications in reputable journals. Apart from that, CT article citations are still not significantly optimal; this can happen because this field is new in science education and is still developing.

Research for elementary school students still needs to be developed

Our research found that CT research still needs to be improved in primary education; no single article in selected journals discusses CT. These results certainly allow researchers to discuss CT at the elementary school level. Research conducted by (Tran, 2019) found that utilizing access to computer science for elementary school students is very important to encourage students' computational thinking abilities. To succeed in the digital world, soft-skill learning, such as collaboration, perseverance, abstraction, and creativity, must be trained early.

In line with the development of programming practices and tools present in this era, it provides opportunities for young students to increase their knowledge of computing (Mohaghegh & Mccauley, 2016; Tran, 2019). CT abilities need to be developed starting from elementary school and applied in various educational fields (Sullivan, R. Kazakoff, & Umashi Bers, 2013), especially in five main skills, namely (1) abstraction, (2) generalization, (3) decomposition, (4) algorithmic thinking, and (5) debugging (Wing, 2006). Therefore, elementary school teachers need to understand and practice effective learning regarding CT to develop these skills so that understanding and application of CT are earlier and better (Atmatzidou & Demetriadis, 2016).

Computational Thinking related to STEM is still dominant

Computational Thinking STEM (CT-STEM) is the most frequently found topic. Up to now, the two are the most appropriate combination. Based on research conducted by (Wang et al., 2022) shows that most researchers adopt a domain-general CT definition and several proposed domain-specific CT definitions in STEM education; the most popular learning model is problem-based learning, and he proposed that future research and practice in this area be discussed in terms of operationalization and assessment of CT in STEM contexts, teaching strategies for integrating CT in STEM, and research for expanding participation in integrated CT and STEM education. (Sengupta et al., 2018) highlighted that CT in representational and epistemic practices is necessary for learning and doing science in STEM education. Of course, this CT-STEM research can still be further developed to be put into practice in learning, so it is also necessary to link it with other topics so that the discussion about CT becomes broader in the learning process because this ability may become an ability that every individual needs to have in the next generation whose development cannot be known how fast and how sophisticated it will be.

The study's results also found that the subject that had not been discussed in the article we analysed was chemistry. This is an opportunity for researchers to conduct CT research in chemistry lessons. We assume that chemistry lessons are still very challenging in applying the five main CT skills: abstracting, generalizing, decomposing, algorithmic thinking, and debugging (Wing, 2006). Therefore, this is a great opportunity for researchers to conduct CT research in chemistry lessons.

Conclusions

Based on the conclusions drawn, several potential avenues for future research in Computational Thinking (CT) can be identified: Expanding Geographical and Institutional Reach: Future research should address the uneven distribution of CT studies by including more diverse geographical regions and institutions. This involves conducting studies in underrepresented areas to understand the unique challenges and opportunities for implementing CT in different educational contexts. Exploring

Alternative Research Methods: While mixed methods are currently dominant, other research methodologies, such as experimental and longitudinal studies, need to be explored. These methods can provide deeper insights into the long-term effects of CT education and its impact on students' problem-solving and critical-thinking skills over time. Focusing on Elementary Education: Given the identified gap in CT research at the elementary level, future studies should investigate the introduction and integration of CT in primary education.

Research could explore the most effective strategies for teaching CT to younger students and the potential long-term benefits of early CT education. Integrating CT into Underrepresented Subjects: Subjects like chemistry and other sciences have been less explored in CT research. Future studies could focus on how CT can be integrated into these subjects to enhance students' understanding and application of scientific concepts. This could involve developing CT-based curricula and instructional materials for these disciplines. Broadening the Scope Beyond CT-STEM: While CT-STEM topics dominate current research, there is a need to broaden the scope to include more disciplines. Future research could explore the application of CT in humanities, social sciences, and arts, examining how CT skills can be beneficial across a wider range of subjects. Investigating the Impact of CT on Diverse Student Populations: Future research could also focus on the impact of CT education on diverse student populations, including those with different learning needs and backgrounds. This could help in developing inclusive CT teaching strategies that cater to a wide range of learners. By addressing these areas, future research can contribute to a more comprehensive and inclusive understanding of CT, ensuring its benefits are widely accessible and applicable across various educational contexts and disciplines.

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