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Bibliometric analysis of computational thinking research trends in science education from 2013 to 2022

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Abstract
Computational thinking (CT) has increasingly been recognised as a fundamental competency in 21st-century education. In response to the growing significance of CT, with this study we aimed to systematically review the development of research on CT in science education by employing bibliometric analysis to examine 337 research papers using VOSviewer and Bibliometrix as analytical tools. The focus was on the topic of CT within the Scopus database from 2013 to 2022. The descriptive data analysis showed a noticeable increase in the significance of CT as a research area within science education in the past 10 years. Co-occurrence knowledge maps revealed 4 principal research themes and their development trajectories. Content analysis indicated that problem-solving and the CT domain were the most examined variables in the articles. We found that technology applications were the most preferred types of learning as academic achievement is highly influenced by CT practices.

Keywords: computational thinking; research; science; secondary data

Introduction
In modern-day education, computational thinking (CT) is gaining more recognition as its importance has become even more relevant among learners in elementary education. CT among school children can start with coding to enhance their thinking skills and prepare them for solving complex problems that are computer-adapted. However, every student or researcher in academia needs CT skills to adapt in today's teaching, learning, or research.

The concept of CT, initially introduced by Papert (1980) known as Papert's CT and further developed by Wing in 2006 and 2008 has gained significant prominence in the field of education (Ogegbo & Ramnarain, 2022; Rich, Yadav & Larimore, 2020; Yadav, Hong & Stephenson, 2016; Yadav, Krist, Good & Caeli, 2018). It is now widely recognised as a foundational idea in computer science, closely linked to programming and coding (Rich et al., 2020; Sun, Hu, Yang, Zhou & Wang, 2021; Sung, Ahn & Black, 2017), and has become a crucial skill in today's information and digitalisation age (Çoban & Korkmaz, 2021; Kert, Erkoç & Yeni, 2020; Tarigan, WPL, Sipahutar & Harahap, 2023). Due to its paramount importance, there is growing consensus that CT should be fostered from primary education onward (Ehsan, Rehmat & Cardella, 2021).

Several studies have sought to provide broadly applicable definitions of computational thinking (CT) as well as effective methods for improving CT education (Sun et al., 2021; Tang, Chou & Tsai, 2020; Wei, Lin, Meng, Tan, Kong & Kinshuk, 2021). Similarly, researchers have also investigated the links between CT and other characteristics such as creativity and innovation (Israel-Fishelson, Hershkovitz, Eguíluz, Garaizar & Guenaga, 2021; Kong, 2019; Manfra, Hammond & Coven, 2022; Sneider, Stephenson, Schafer & Flick, 2014). Furthermore, there have been investigations into methods for evaluating CT (Rich et al., 2020; Tang et al., 2020), and educators' training in CT ability (Li, McNary & Boyd, 2023; Yadav et al., 2016). However, it is not the concern of this article – the importance of integrating CT even in child education is discussed here.

CT has expanded its influence beyond the realm of computer science, making its mark in various disciplines including life sciences, basic science, the intersection of sciences and arts, social sciences and physics by incorporating CT into the science (Sun et al., 2021; Sung et al., 2017). Researchers have placed increasing emphasis on the importance of integrating CT into educational curricula as a fundamental aspect of 21st-century literacy. This emphasis spans from early childhood education to higher education (Barr & Stephenson, 2011; Voogt, Fisser, Good, Mishra & Yadav, 2015) and involves cognitive processes.

These processes encompass defining a problem and articulating its solutions in a manner that enables effective execution by a computer, whether it is operated by a human or functions autonomously (Wing, 2008). The integration of various CT tools into CT activities within the science classroom has become a crucial topic of discussion (Bers, Flannery, Kazakoff & Sullivan, 2014; Hooshyar, Malva, Yang, Pedaste, Wang & Lim, 2021). The development of CT skills is closely linked to the enhancement of scientific process skills, a core element of inquiry-based learning.

Additionally, empirical studies have examined the influence of emotional factors, such as motivation and self-efficacy to identify the intrinsic elements that impact CT education (Tarigan, CU & Tarigan, 2022). The continued growth of CT in the digital age has led to consensus that educators should integrate it into educational curricula starting from primary education onward. Bibliometric studies can provide insight into the growing body of literature on CT, mapping trends, identifying keywords, and emphasising its expanding role in 21st-century literacy and its critical contribution across various academic fields. This research also highlights the importance of monitoring how CT is evolving across disciplines and how it influences educational outcomes globally.

Since 2006, there has been a notable increase in publications related to CT, as observed in the study conducted by Tekdal (2021). Numerous review studies on CT trends have been published in recent years, but none have specifically focused on CT in science education. Therefore, there was a pressing need for a research paper that could identify and dissect the evolving trends and developments in CT in science education research. Such a study would be both timely and critical, as it would offer a comprehensive overview of the current research landscape and serve as a valuable guide for shaping future research efforts in the field of CT.

Furthermore, CT is recognised as a core skill necessary for accessing job opportunities and achieving success. However, comprehensive bibliometric analyses of CT in the context of science education research are still limited. These analyses involve measuring and assessing scientific literature to uncover trends, explore applications, and evaluate achievements within this specific research domain. The majority of existing research in this area has focused on specific aspects of CT, such as programming in education, the use of digital tools to develop CT in elementary schools, methodologies for evaluating CT, and the role of CT in higher education.

In this study we examined 337 documents sourced from primary collections within the Scopus database since 2013. Our goal was to conduct a bibliographic analysis of CT and provide an international viewpoint on the changing scientific production in the field of education. The findings reveal numerous significant discoveries, including the awareness that CT is a critical skill for students to master, enabling them to effectively solve complex problems in and out of the classroom.

With this study we aimed to describe the bibliometric review analysis of CT research in science education published from January 2013 to December 2022. We provide insight into the global landscape of CT research in the field of science education, highlighting growth, geographical distribution, and key research trends. With this review we aimed to uncover novel insight and present the state of the art in CT theory trends within the context of science education. The research questions (RQs) for this study are based on the following framework:

RQ-1. What are the current trends in publications regarding CT in science education research?

RQ-2. Who are the most active authors and countries involved in CT research in science education, and what is the pattern of collaboration among them?

RQ-3. What are the most studied topics and affiliations related to CT in science education?

RQ-4. What are the main publishers, keywords, and terms for CT in science education?

These questions are designed to map the scholarly landscape of CT in science education by identifying influential contributors, dominant themes, and patterns of collaboration across regions and institutions. Using the RQs we aimed to provide a comprehensive overview of CT research in science education, shedding light on trends, authors, publications, and themes that shape the field. This information can be valuable for researchers, educators, and policymakers, guiding future developments and advancements at the intersection of CT and science education.

Methodology

Bibliometric reviews use secondary data from published sources, including journal articles, books, and conference papers. This data are already publicly available and does not involve interaction with individuals. As a result, we did not require ethical approval because we focused on analysing existing literature rather than direct engagement with live subjects. We used various bibliometric techniques in the analysis, including citation analysis, co-citation analysis, and co-occurrence analysis. The procedure for selecting articles and analysing the trends in this study is described in the following section.

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The Process for Selecting Articles for Analysis

Published articles on CT in science education from 2013 to 2022 were retrieved from Scopus indexes. The search was limited to this frame, focusing on articles available in English and classified as "journal articles" to maintain consistent quality. The advanced search function was used, using keywords such as "computational thinking in science education", "science education", "science", and "education." We reviewed each article based on specified inclusion and exclusion criteria. The article selection process for this study is detailed in Figure 1.

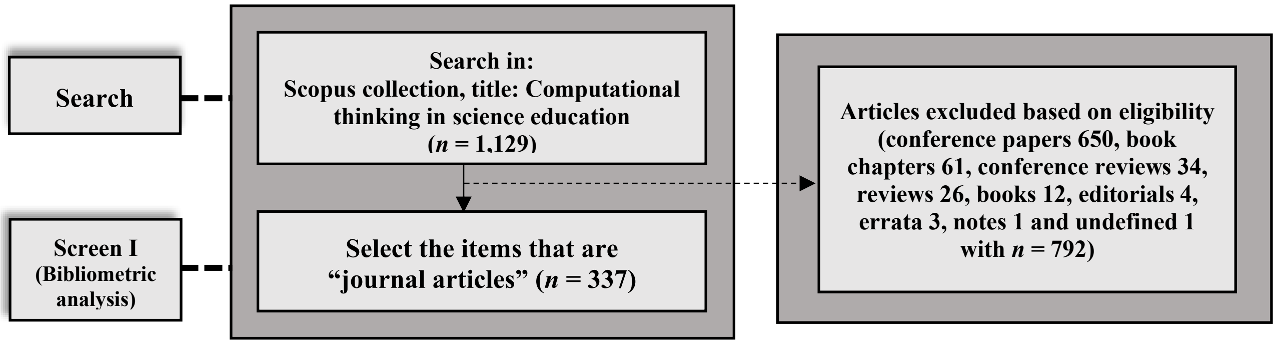

Figure 1 Procedures for selecting Scopus-indexed articles (adapted from Donthu, Kumar, Mukherjee, Pandey & Lim, 2021)

Article Selection Process for Bibliometric Analysis

The data source chosen for this study was the Scopus collection, a reputable database comprising high-quality published research from key international journals. Figure 1 illustrates the article selection process and its methods. In the initial search, we identified a total of 1,129 papers with titles containing keywords related to computational thinking in science education. These papers had been published between 1 January 2013 and 31 December 2022. In the subsequent screening stage, further exclusions were made, particularly for papers in concise formats. Finally, 337 full-length journal articles written in English were included for analysis in the study.

Data Analysis

The data trends and their relevant interrelationships were analysed and visualised using VOSviewer and the Bibliometrics R Studio. These maps serve as graphical representations of the relationships between knowledge fields, documents, or authors. The timeline view function of Bibliometrics R Studio was used to conduct a progression analysis for specific themes. This analysis provides insight into the evolution of CT within the field of science education research over time. We primarily employed citation analysis and clustering mapping to visualise citations of influential research conducted by various researchers, institutions, and countries/regions. By examining citation patterns across different groups, we aimed to identify key contributors and their roles in specific topics or areas of research (Park & Shea, 2020).

Results of the Study

Computational Trends in Literature

Between 1 January 2013 and 31 December 2022, a total of 337 articles addressing CT in science education were published, garnering a combined total of 567 citations. Figure 2 illustrates the distribution of these papers and references over time, showing a steady rise in the number of publications and citations related to CT in science education research from 2019 to 2022.

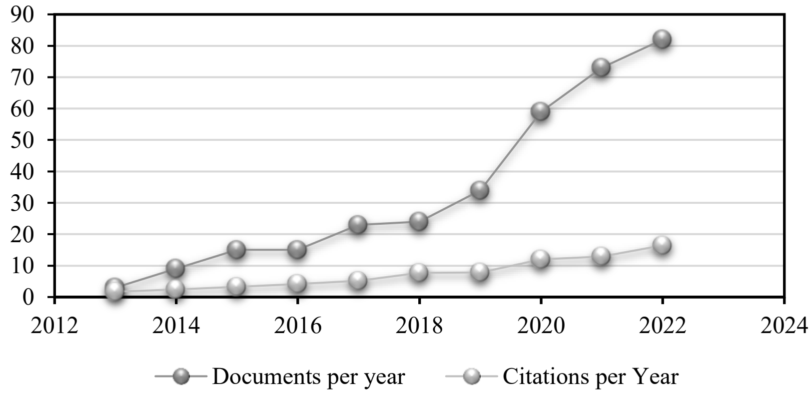

Figure 2 Publications and citations in CT-science education literature (2013 to 2022)

A noticeable upward trajectory has been evident since 2015, with a particularly rapid surge in interest starting from 2019. Since 2019, there has been a constant increasing trend in both publications and citations in the subject of CT in scientific education research.

The Most Prolific Authors and Countries Actively Involved in CT within the Context of Science Education and the Collaboration Patterns

The study encompassed a total of 337 articles authored by 1,076 individuals hailing from 52 different countries worldwide (see Appendix A). Among these authors, 33 individuals produced single-authored articles. On average, each article had two or three co-authors, indicating a prevalent trend of collaborative contributions in this research domain. Table 1 lists the most outstanding writers, ranked by the number of publications to which they have contributed.

Table 1 Top researchers in the field of CT in science education

Number (No.)	Author	Articles	Citations	Country	Affiliation
1)	Yadav, A.	9	655	United States of America (USA)	Michigan State University
2)	Román-González, M.	6	536	Spain	Universidad Nacional de Educación a Distancia (UNED)
3)	Basu, S.	5	200	USA	Stanford Research Institute (SRI) International
4)	Dagiene, V.	5	66	Lithuania	Vilnius University
5)	Kalogiannakis, M.	5	55	Greece	University of Thesally
6)	Sengupta, P	5	344	Canada	University of Calgary
7)	Pérez-González, J.C.	5	59	Spain	National University of Distance Education
8)	Angeli, C.	3	14	Cyprus	University of Cyprus
9)	Dolgopolovas, V.	3	9	Lithuania	Vilnius University
10)	Grover, S.	3	214	USA	Standford University
11)	Weintrop	1	**713**	The Netherlands	Northwestern University

Note. The table is ordered by the number of articles. The highest number of citations is highlighted in bold.

Notably, Weintrop stands out as the top author with numerous citations (one article with 713 citations), followed by Yadav (nine articles with 655 citations), Román-González (six articles with 536 citations), Sengupta (five articles with 344 citations), Basu (five articles with 200 citations), and Dagiene (five articles with 66 citations). Co-authorship analysis was also carried out in order to identify markers of scientific collaboration among authors in CT study. Yadav from the United States of America was the most active author who has written nine articles with 655 citations. Figure 3 presents the top 10 authors who have been at the forefront of research in CT within the context of science education.

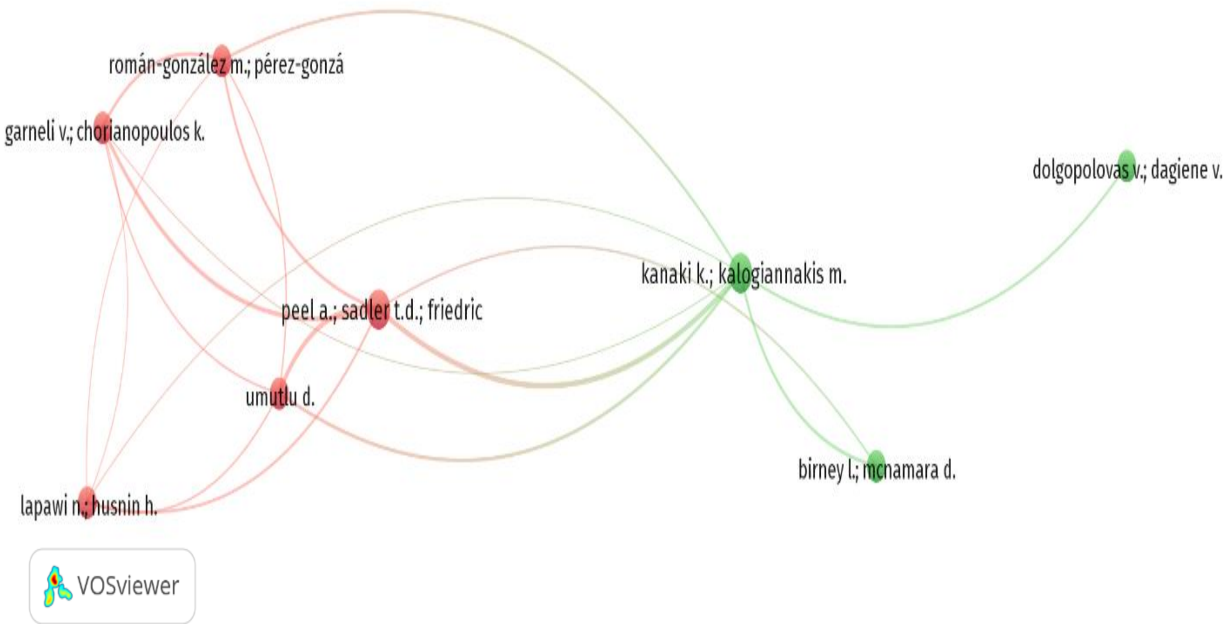

Figure 3 The size of the network's connecting nodes was examined. Larger nodes indicate a greater role in promoting collaboration among peers in the field of CT research in science education

The findings of the investigation show that authors who collaborate on CT research in scientific education can be divided into two separate groups. When the size of the network's connecting nodes was examined, it became clear that each network cluster was led by a notable researcher who enabled connections with other researchers. Sadler and Roman-Gonzalez were associated with the red cluster, while Kalogiannakis and Dolgopolovas were linked to the green cluster.

In other words, these researchers have been the most prolific in terms of co-authored articles and have played a pivotal role in promoting collaboration among their peers in the field of CT research in science education. Researchers from 52 nations around the world have actively contributed to CT research, demonstrating the international involvement in this field of study. Table 2 lists the top 15 countries that have made significant contributions to CT research, each with at least seven publications.

Table 2 Countries contributing with at least seven publications on CT research

No.	Country	Articles	Citations
1)	United States of America	138	**5,007**
2)	Spain	20	1,075
3)	Turkey	18	149
4)	China	16	421
5)	Canada	13	349
6)	Greece	12	534
7)	United Kingdom (UK)	12	503
8)	Italy	11	208
9)	Taiwan	10	479
10)	Germany	9	76
11)	South Korea	9	134
12)	Malaysia	8	29
13)	Brazil	7	46
14)	Hungary	7	21
15)	Israel	7	104

Note. The table is ordered by the number of articles. The highest number of citations is highlighted in bold.

Another co-authorship study was conducted with a focus on countries, to create a network map that illustrates scientific cooperation among different nations. The resulting network map highlights the USA as a central figure in CT research in scientific education. With a total link strength of 22, the USA is also shown to be the most active collaborator with other countries in this field.

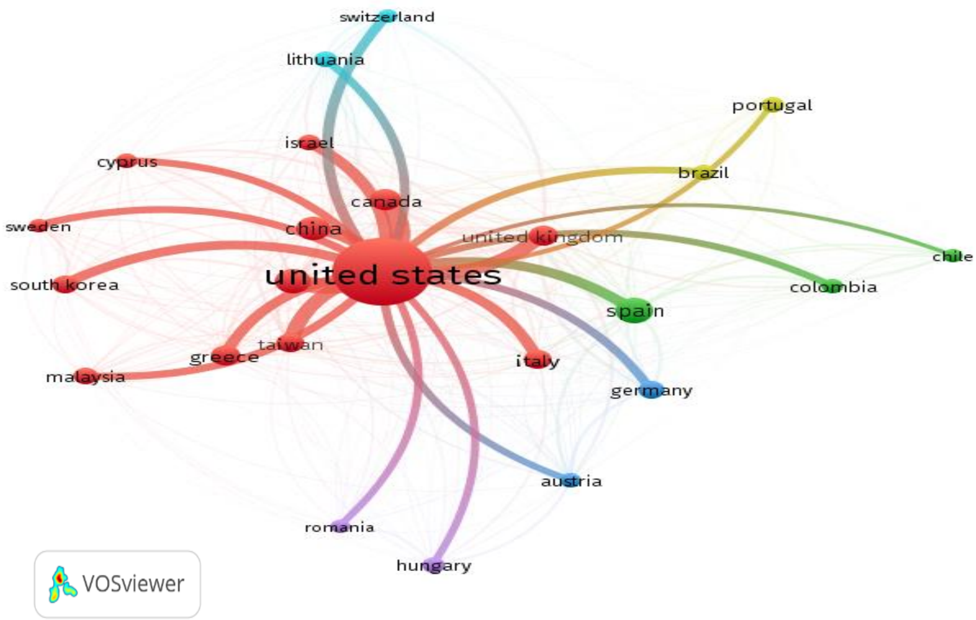

Figure 4 The network visualisation of countries investigating CT. Larger nodes indicate countries with a higher contribution to research in the field of CT research in science education.

However, it is worth noting that the strength of collaboration varied depending on the countries' cluster affiliations as presented in Figure 4. For instance:

- The green cluster includes Spain, Colombia, and Chile.
- The blue cluster comprises Lithuania, Switzerland, Germany, and Austria.
- The purple cluster is dominated by Romania and Hungary.
- The red cluster demonstrates cooperation among European, South American, and Asian countries.
- In contrast, Brazil and Portugal, in the yellow cluster, appear to be separated from the other clusters, showing a lack of collaboration.

Figure 5 shows that China is the country that has conducted extensive research on CT in science education.

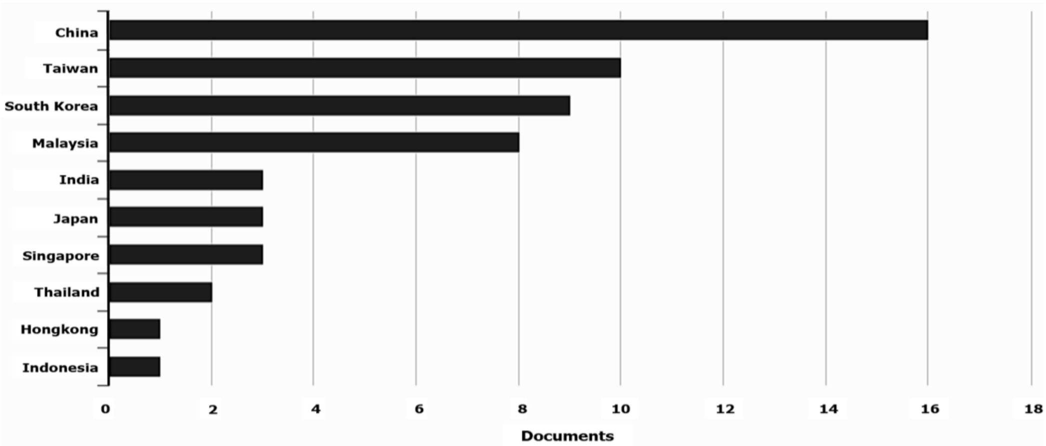

Figure 5 The Asian countries with the most research on CT in science education, as derived from the Scopus database. This visualisation highlights the distribution and contribution of Asian countries to CT-related publications, indicating regional research interest from 2013–2022.

The Most Researched Subject and Affiliation

The distribution of subject/course areas for the papers in the Scopus database related to CT in science education is illustrated in Figure 6. A significant portion of the research falls within the field of social sciences (44.6%), followed by computer science (26.7%) and engineering (11.3%). It is evident that CT research in science education spans a broad spectrum of scientific subjects and attracts researchers from diverse disciplines.

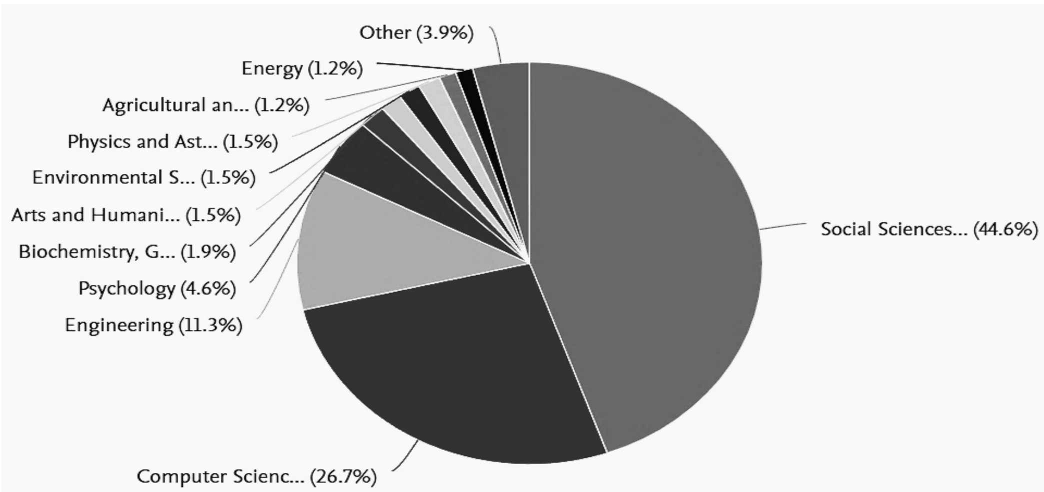

Figure 6 The distribution of subject areas in science education literature related to CT, as derived from the Scopus database

Figure 7 presents a list of institutions that have made significant contributions to the growth of research in CT in scientific education, each with a minimum of nine articles. The number of publications in the field was used to rank these institutions. These institutions have had a notable impact on the research environment in this field, showcasing their dedication and expertise in CT research within scientific education.

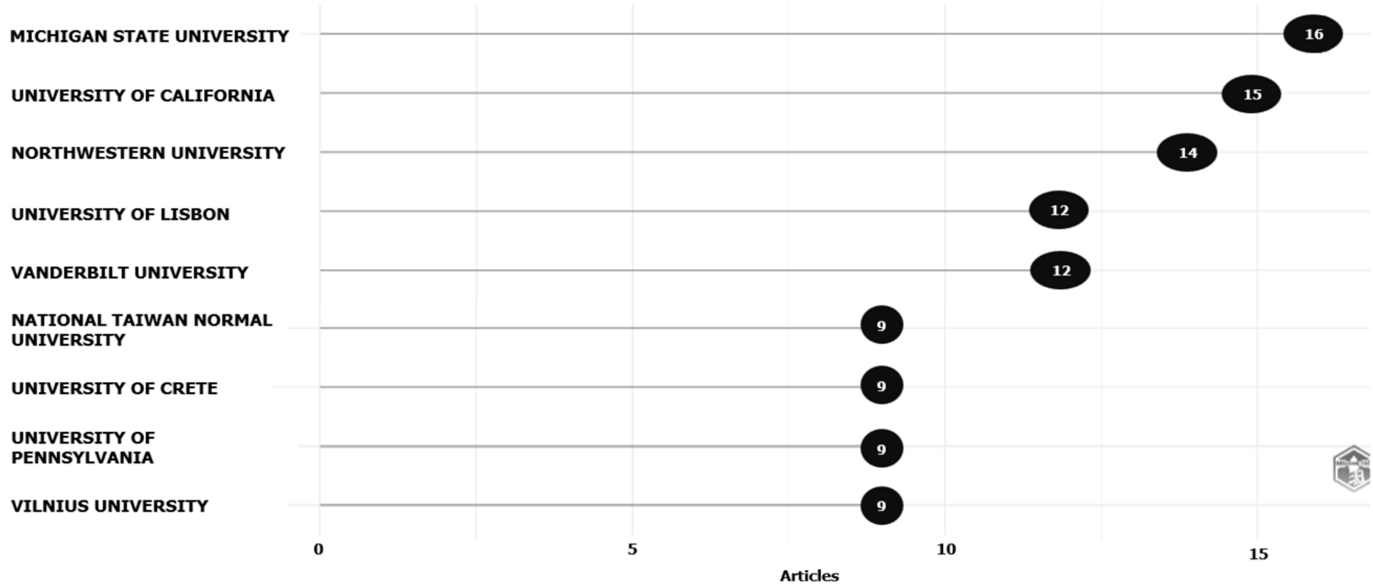

Figure 7 Affiliations actively researching CT, as illustrated using R-Studio. The visualisation presents institutions with significant contributions to CT-related research in science education. Michigan State University stands out as the most active institution.

The Most Significant Publishers, Keywords and Terms

A total of 337 articles on CT in scientific education research were published in 174 journals. Table 3 lists the top 10 journals ranked by the number of articles published. Overall, CT research has been published in a wide range of journals on topics such as science, computer science, mathematics, informatics, educational technology and engineering. This wide range of articles demonstrates that CT in science education is of interest to researchers in a variety of fields.

Table 3 Journals contributing with at least seven publications on CT research

No.	Journal	Articles	Citations
1)	*Education and Information Technologies*	**18**	1,098
2)	*Journal of Science Education and Technology*	14	**1,224**
3)	*Informatics in Education*	11	126
4)	*Computers and Education*	10	1,217
5)	*ACM Transactions on Computing Education*	8	519
6)	*Computer Science Education*	8	259
7)	*Education Sciences*	8	65
8)	*Educational Technology Research and Development*	8	150
9)	*Interactive Learning Environments*	7	102
10)	*Sustainability*	7	22

Note. The table is ordered by the number of articles. The highest number of articles and citations is highlighted in bold.

Figure 8 shows a network map displaying the distribution of 33 frequently used keywords related to CT and 18 frequently used keywords related to science education. The size of the nodes in this map shows the frequency of the occurrence of keywords, while the curved links connecting them indicate the frequency of the occurrence of "keyword."

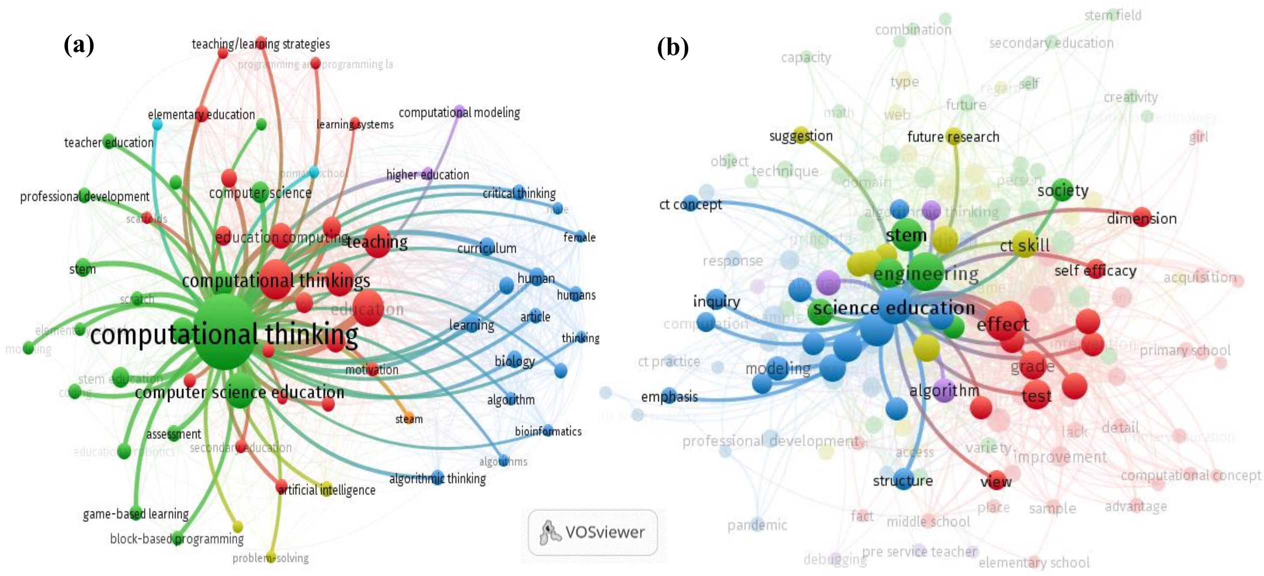

Figure 8 The network visualisation of the most frequently used keywords by authors on CT (a) and keywords by authors on science education (b)

It is noteworthy that "computer science education" and "problem-solving" are closely linked and positioned near each other on the map (Figure 8), highlighting their close relationship and significance within the context of CT research in science education.

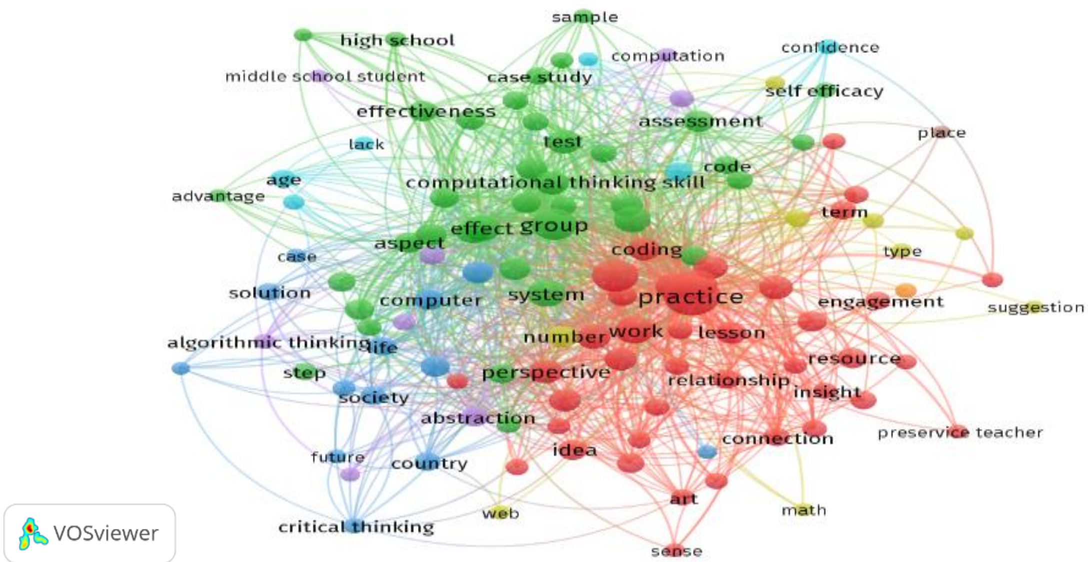

Figure 9 The network visualisation of the most used terms in abstracts

Figure 9 provides insight into the most frequently used author keywords within the CT research field. The keywords with the highest frequency of use include "computational thinking" (276 occurrences), "education" (52 occurrences), "computer science education" (49 occurrences), "students" (44 occurrences), "teaching" (41 occurrences), "curriculum" (31 occurrences), "science education" (27 occurrences), "education computing" (26 occurrences), "learning" (13 occurrences), "computation theory" (13 occurrences), and "biology" (11 occurrences). Additionally, the strength of the links between keywords reveals important associations. For example, the keywords "computer science education" and "problem-solving" exhibit a strong link strength of 141 and 94, respectively.

The abstract section of this study serves as a representation of the overall core of the topic. The terminology used in abstracts of the collected documents might provide valuable insight into primary issues and research purposes in the field of CT. Consequently, an examination of term frequencies in abstracts may assist in identifying the overarching themes that are prominent in CT research. To uncover these overarching themes, an analysis, "generate a textual map" was chosen from the VOSviewer menu. This analysis entailed extracting data from bibliographic database files, with a particular focus on the abstracts and the use of binary counting. Moreover, a minimum occurrence threshold of 10 was established, resulting in the identification of the 117 most significant terms. The resulting map, which illustrates the predominant themes in CT research based on the most frequently employed terms in article abstracts, is displayed in Figure 9.

The size of the nodes in Figure 9 correlates with the occurrence frequency of the terms in the abstracts. Larger nodes imply phrases with higher occurrence rates, whereas closer nodes suggest a stronger level of relatedness. Furthermore, the thickness of the connecting curved lines shows the degree of co-occurrence on the same page. Different colours are used to categorize terms into clusters. This analysis reveals that the terms from the abstracts could be categorised into three distinct clusters. The blue cluster encompasses 30 terms, the red cluster comprises 31 terms, the green cluster includes 30 terms, and the yellow cluster encompasses 26 terms. The frequency with which terms appear in the abstracts were "practice" (87 occurrences), "engineering" (58 occurrences), "group" (57 occurrences), "integration" (47 occurrences), and "work" (42 occurrences), in that order. As represented in abstracts, these terms provide insights into the primary themes and popular issues in CT research.

The findings emphasise that a substantial volume of experimental research has been conducted to evaluate skills related to CT. Many of these studies relied on traditional assessment tools, such as tests and scales, to measure CT-related skills. To deepen our understanding of students' CT proficiency, there is an opportunity for additional research that incorporates qualitative data gathered through methods like interviews, surveys, or focus groups. This qualitative data may offer more profound insight into the development of CT skills. Additionally, the analysis indicates that experimental studies, particularly those examining cause-and-effect relationships, primarily focus on the integration of technology within classroom learning. Although technology undoubtedly plays a significant role in CT education, there may be potential for exploring alternative instructional strategies and pedagogical approaches in future research.

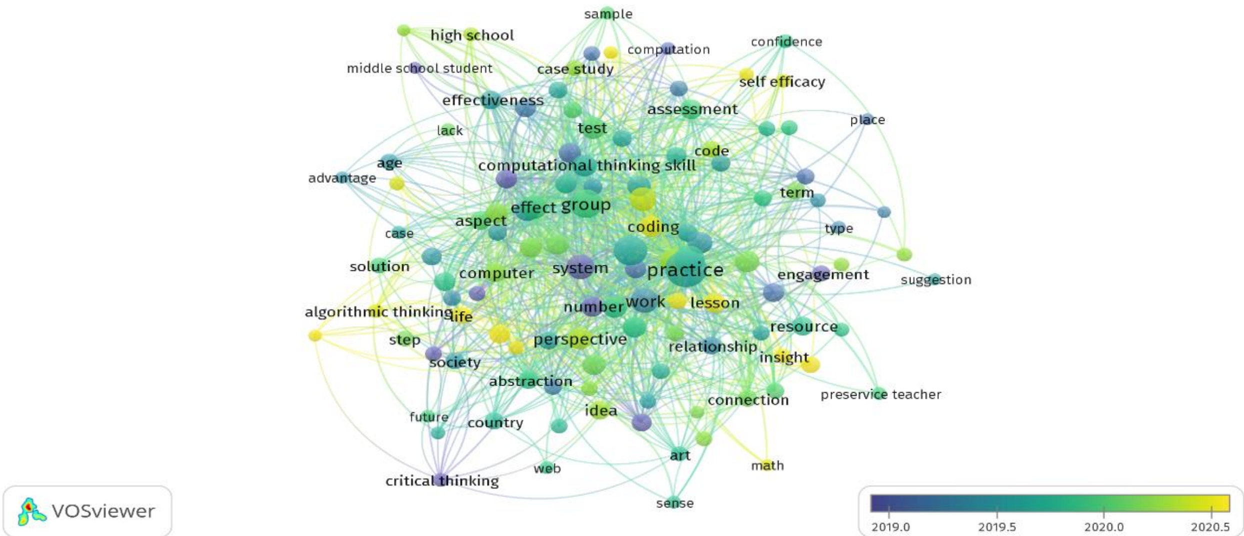

Figure 10 The network visualisation of the most frequently used abstract phrases by year

The resulting map (Figure 10) reveals that several terms, such as "abstraction", "practice", "algorithmic thinking", "computation", "critical thinking", and "perspective", were frequently used in discussions related to the definition of CT and CT skills. These terms hold a central position in defining and understanding the fundamental concepts of CT skills. Research on CT skills encompasses a broad spectrum of topics. This includes investigations into the development of CT skills, as demonstrated in the work of Palts and Pedaste (2020). The analysis of terms associated with CT in abstracts is actively discussed in the field of CT in science education (Kalelioğlu, Gülbahar & Kukul, 2016). Researchers have used various terms like "CT ideas", "CT topics", "CT practices", and

"CT competencies" instead of referring to them as CT skills. An overlay visualisation analysis carried out on the distribution of terms in abstracts over the years indicates that research areas connected to CT have remained consistently active. However, recent studies seem to give more prominence to empirical investigations, as shown by the concentration of terms like "self-efficacy", "life", "coding", and "lesson" in the yellowish portion of the map (Figure 10). This shift towards empirical research signifies the ongoing transformation of research trends in CT in science education.

Discussion

The current trends in publications on CT in science education research show a clear focus on CT as a problem-solving method. The majority of studies emphasise CT as a strategy for scientific problem-solving, aligning with findings from En, Karpudewan and Zaharudin (2021), Kert, Kalelioğlu and Gülbahar (2019), and Yadav et al. (2016). These studies demonstrate that CT is most often linked to integrated education, where knowledge and communication skills are enhanced through computational processes. Peel, Sadler and Friedrichsen (2019) conducted a study in college biology that emphasised integrative activities by comparing the natural selection process using specific computer programs that focused on assessing algorithmic competency. Wang, Shen and Chao (2022) presented another compelling method for integrating informatics concepts across a broad range of science, technology, engineering, and mathematics (STEM) subjects. Furthermore, the research highlights a growing trend towards integrating CT with various scientific disciplines, particularly through the use of tools like physical computing, which have become more prevalent in science education compared to other disciplines like mathematics. Research also suggests that CT's role in science education extends to developing students' scientific problem-solving skills, with various programme development studies exploring new curricula and teaching methods centred around CT.

The most active authors in CT research in science education are those who have contributed significantly to the conceptualisation and development of CT integration in curricula. Research by Lamb, Vallett, Akmal and Baldwin (2014), Pevzner and Shamir (2009) and others has played a pivotal role in advancing CT as a key educational tool. In terms of geographic involvement, countries such as the USA, UK, and various European nations have lead the charge in CT research within science education. Collaboration patterns indicate a strong international network where researchers from different countries often collaborate on developing integrated education programmes and curricula. Notably, the collaboration between educators in computer science and science disciplines is highlighted, as interdisciplinary approaches have proven effective in bridging the gap between the two fields and also advancing CT in educational settings.

The most studied topics in CT research within science education include the integration of CT into various scientific subjects such as biology, chemistry, and physics. Topics such as problem-solving skills, spatial reasoning, and algorithmic thinking are frequently explored, with significant emphasis placed on the use of digital tools to enhance these skills. Institutions focusing on both computer science and science education are often at the forefront of these studies, with universities and research centres being key players in exploring the impact of CT integration. Notably, high schools and colleges are increasingly becoming centres of CT-related empirical studies, particularly those exploring how students' thinking evolves when they apply CT in science learning activities. Educators and science curricula link CT to integrated education, with knowledge and communication skills being enhanced as students participate in this computational process and produce computational products (Sengupta, Kinnebrew, Basu, Biswas & Clark, 2013; Wang et al., 2022). Spatial reasoning in science education is frequently used to help students imagine rotations, such as understanding molecular structures in chemistry or rotational dynamics in physics. Dickes, Kamarainen, Metcalf, Gün-Yildiz, Brennan, Grotzer and Dede (2019) discovered an exploitable link between these abilities and CT, with positive correlations demonstrated in studies with secondary students. Similarly, in a study at a high school using a biology unit it was found that students benefited when CT activities were directly integrated into subject lessons (Garneli & Chorianopoulos, 2018, 2019). The learning analytics tools revealed how students' thinking evolved when they incorporated computer science.

The main publishers of CT research in science education are prominent educational publishers and academic journals that focus on the intersection of technology and education. Key journals in this field include the *Journal of Science Education and Technology*, *Computers & Education*, and *Education and Information Technologies*. The most frequently used keywords in CT research publications were "computational thinking", "problem-solving", "integration", "STEM education", "physical computing", and "algorithmic thinking." Common terms linked to CT in science education were "scientific problem-solving", "digital competencies", "spatial reasoning", and "interdisciplinary education." These keywords reflect the growing recognition of the importance of CT in enhancing students' problem-solving abilities and scientific inquiry skills, particularly in STEM fields.

Conclusion and Limitation

In this study we analysed a dataset of 337 journal articles indexed in the Scopus database. The primary goal was to understand the current state of science research, identify future trends, and assess the growth of CT in science education. We thoroughly examined the development trends, common characteristics, collaborative networks, and current focal points within the realm of CT in science education. The analysis of current trends in CT research within science education reveal a strong emphasis on CT as a core strategy for developing students' problem-solving, algorithmic, and spatial reasoning skills. Integration across science disciplines, especially biology, chemistry, and physics increasingly supported through digital tools and physical computing, reinforces the role of CT in fostering scientific inquiry and interdisciplinary learning.

Michigan State University and researchers such as Yadav have emerged as key contributors, with the USA leading in publication volume. Collaboration across institutions and disciplines, particularly between computer science and science education, underscores the global momentum behind CT integration. Frequently explored themes and keywords such as "STEM education", "physical computing", and "scientific problem-solving", highlight the growing impact of CT on shaping effective, future-oriented science curricula. The primary limitation concerns the dataset, which was restricted to publications indexed in the Scopus database, potentially excluding relevant articles not covered by this source. Additionally, we focused solely on published articles.

Data Availability

Data supporting the findings and conclusions are available upon request from the corresponding author.

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Authors' Contributions

All authors made substantial contributions to the study and agree with the results and conclusions.

Declaration of Interest

No conflict of interest is declared by the authors.

Notes

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References

Barr V & Stephenson C 2011. Bringing computational thinking to K-12: What is involved and what is the role of the computer science education community? *ACM Inroads*, 2(1):48–54. https://doi.org/10.1145/1929887.1929905

Bers MU, Flannery L, Kazakoff ER & Sullivan A 2014. Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. *Computers & Education*, 72:145–157. https://doi.org/10.1016/j.compedu.2013.10.020

Çoban E & Korkmaz Ö 2021. An alternative approach for measuring computational thinking: Performance-based platform. *Thinking Skills and Creativity*, 42:100929. https://doi.org/10.1016/j.tsc.2021.100929

Dickes AC, Kamarainen A, Metcalf SJ, Gün-Yildiz S, Brennan K, Grotzer T & Dede C 2019. Scaffolding ecosystems science practice by blending immersive environments and computational modeling. *British Journal of Educational Technology*, 50(5):2181–2202. https://doi.org/10.1111/bjet.12806

Donthu N, Kumar S, Mukherjee D, Pandey N & Lim WM 2021. How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research*, 133:285–296. https://doi.org/10.1016/j.jbusres.2021.04.070

Ehsan H, Rehmat AP & Cardella ME 2021. Computational thinking embedded in engineering design: Capturing computational thinking of children in an informal engineering design activity. *International Journal of Technology and Design Education*, 31(3):441–464. https://doi.org/10.1007/s10798-020-09562-5

En LK, Karpudewan M & Zaharudin R 2021. Computational thinking in STEM education among matriculation science students. *Asia Pacific Journal of Educators and Education*, 36(1):177–194. https://doi.org/10.21315/apjee2021.36.1.10

Garneli V & Chorianopoulos K 2018. Programming video games and simulations in science education: Exploring computational thinking through code analysis. *Interactive Learning Environments*, 26(3):386–401. https://doi.org/10.1080/10494820.2017.1337036

Garneli V & Chorianopoulos K 2019. The effects of video game making within science content on student computational thinking skills and performance. *Interactive Technology and Smart Education*, 16(4):301–318. https://doi.org/10.1108/ITSE-11-2018-0097

Hooshyar D, Malva L, Yang Y, Pedaste M, Wang M & Lim H 2021. An adaptive educational computer game: Effects on students' knowledge and learning attitude in computational thinking. *Computers in Human Behavior*, 114:106575. https://doi.org/10.1016/j.chb.2020.106575

Israel-Fishelson R, Hershkovitz A, Eguíluz A, Garaizar P & Guenaga M 2021. The associations between computational thinking and creativity: The role of personal characteristics. *Journal of Educational Computing Research*, 58(8):1415–1447. https://doi.org/10.1177/0735633120940954

Kalelioğlu F, Gülbahar Y & Kukul V 2016. A framework for computational thinking based on a systematic research review. *Baltic Journal of Modern Computing*, 4(3):583–596. Available at https://www.bjmc.lu.lv/fileadmin/user_upload/lu_portal/projekti/bjmc/Contents/4_3_15_Kalelioglu.pdf. Accessed 22 November 2023.

Kert SB, Erkoç MF & Yeni S 2020. The effect of robotics on six graders' academic achievement, computational thinking skills and conceptual knowledge levels. *Thinking Skills and Creativity*, 38:100714. https://doi.org/10.1016/j.tsc.2020.100714

Kert SB, Kalelioğlu F & Gülbahar Y 2019. A holistic approach for computer science education in secondary schools. *Informatics in Education*, 18(1):131–150. https://doi.org/10.15388/infedu.2019.06

Kong SC 2019. Components and methods of evaluating Computational Thinking for fostering creative problem-solvers in senior primary school education. In SC Kong & H Abelson (eds). *Computational Thinking Education*. Singapore: Springer. https://doi.org/10.1007/978-981-13-6528-7_8

Lamb RL, Vallett DB, Akmal T & Baldwin K 2014. A computational modeling of student cognitive processes in science education. *Computers & Education*, 79:116–125. https://doi.org/10.1016/j.compedu.2014.07.014

Li Q, McNary SW & Boyd T 2023. Assessment of computational thinking: A study of preservice teachers' knowledge and beliefs. *Athens Journal of Sciences*, 10(2):65–82. https://doi.org/10.30958/ajs.10-2-1

Manfra MM, Hammond TC & Coven RM 2022. Assessing computational thinking in the social studies. *Theory & Research in Social Education*, 50(2):255–296. https://doi.org/10.1080/00933104.2021.2003276

Ogegbo AA & Ramnarain U 2022. A systematic review of computational thinking in science classrooms. *Studies in Science Education*, 58(2):203–230. https://doi.org/10.1080/03057267.2021.1963580

Palts T & Pedaste M 2020. A model for developing computational thinking skills. *Informatics in Education*, 19(1):113–128. https://doi.org/10.15388/infedu.2020.06

Papert S 1980. *Mindstorms: Children, computers, and powerful ideas*. New York, NY: Basic Books.

Park H & Shea P 2020. A review of ten-year research through co-citation analysis: Online learning, distance learning, and blended learning. *Online Learning Journal*, 24(2):225–244. https://doi.org/10.24059/olj.v24i2.2001

Peel A, Sadler TD & Friedrichsen P 2019. Learning natural selection through computational thinking: Unplugged design of algorithmic explanations. *Journal of Research in Science Teaching*, 56(7):983–1007. https://doi.org/10.1002/tea.21545

Pevzner P & Shamir R 2009. Computing has changed biology—biology education must catch up. *Science*, 325(5940):541–542. https://doi.org/10.1126/science.1173876

Rich KM, Yadav A & Larimore RA 2020. Teacher implementation profiles for integrating computational thinking into elementary mathematics and science instruction. *Education and Information Technologies*, 25(4):3161–3188. https://doi.org/10.1007/s10639-020-10115-5

Sengupta P, Kinnebrew JS, Basu S, Biswas G & Clark D 2013. Integrating computational thinking with K-12 science education using agent-based computation: A theoretical framework. *Education and Information Technologies*, 18(2):351–380. https://doi.org/10.1007/s10639-012-9240-x

Sneider C, Stephenson C, Schafer B & Flick L 2014. Teacher's toolkit: Exploring the Science framework and NGSS: Computational thinking in the Science classroom. *Science Scope*, 38(3):10–15. https://doi.org/10.2505/4/ss14_038_03_10

Sun L, Hu L, Yang W, Zhou D & Wang X 2021. STEM learning attitude predicts computational thinking skills among primary school students. *Journal of Computer Assisted Learning*, 37(2):346–358. https://doi.org/10.1111/jcal.12493

Sung W, Ahn J & Black JB 2017. Introducing computational thinking to young learners: Practicing computational perspectives through embodiment in mathematics education. *Technology, Knowledge and Learning*, 22(3):443–463. https://doi.org/10.1007/s10758-017-9328-x

Tang KY, Chou TL & Tsai CC 2020. A content analysis of computational thinking research: An international publication trends and research typology. *The Asia-Pacific Education Researcher*, 29(1):9–19. https://doi.org/10.1007/s40299-019-00442-8

Tarigan CU & Tarigan WPL 2022. The effect of flipped class with project-based learning assisted by Moodle combined with reading, questioning, and answering (RQA) on 4C skills. *Bioedukasi: Jurnal Pendidikan Biologi*, 15(2):82–91. https://doi.org/10.20961/bioedukasi-uns.v15i2.61296

Tarigan WPL, Sipahutar H & Harahap F 2023. The impact of an interactive digital learning module on students' academic performance and memory retention. *Computers and Children*, 2(2):em004. https://doi.org/10.29333/cac/13654

Tekdal M 2021. Trends and development in research on computational thinking. *Education and Information Technologies*, 26(5):6499–6529. https://doi.org/10.1007/s10639-021-10617-w

Voogt J, Fisser P, Good J, Mishra P & Yadav A 2015. Computational thinking in compulsory education: Towards an agenda for research and practice. *Education and Information Technologies*, 20(4):715–728. https://doi.org/10.1007/s10639-015-9412-6

Wang C, Shen J & Chao J 2022. Integrating computational thinking in STEM education: A literature review. *International Journal of Science and Mathematics Education*, 20(8):1949–1972. https://doi.org/10.1007/s10763-021-10227-5

Wei X, Lin L, Meng N, Tan W, Kong SC & Kinshuk 2021. The effectiveness of partial pair programming on elementary school students' Computational Thinking skills and self-efficacy. *Computers & Education*, 160:104023. https://doi.org/10.1016/j. compedu.2020.104023

Wing JM 2006. Computational thinking. *Communications of the ACM*, 49(3):33–35. https://doi.org/10.1145/1118178.1118215

Wing JM 2008. Computational thinking and thinking about computing. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 366(1881):3717–3725. https://doi.org/10.1098/rsta.2008.0118

Yadav A, Hong H & Stephenson C 2016. Computational thinking for all: Pedagogical approaches to embedding 21st century problem solving in K-12 classrooms. *TechTrends*, 60(6):565–568. https://doi.org/10.1007/s11528-016-0087-7

Yadav A, Krist C, Good J & Caeli EN 2018. Computational thinking in elementary classrooms: Measuring teacher understanding of computational ideas for teaching science. *Computer Science Education*, 28(4):371–400. https://doi.org/10.1080/08993408.2018.1560550

Appendix A

Author	Title	Published year	Journal name	Author	Title	Published year	Journal name
Gandolfi E, Ferdig RE & Clements R	Streaming code across audiences and performers: An analysis of computer science communities of inquiry on Twitch. tv	2022	*British Journal of Educational Technology*	Rich KM, Spaepen E, Strickland C & Moran C	Synergies and differences in mathematical and computational thinking: Implications for integrated instruction	2020	*Interactive Learning Environments*
Namli NA & Aybek B	An investigation of the effect of block-based programming and unplugged coding activities on fifth graders' computational thinking skills, self-efficacy and academic performance	2022	*Contemporary Educational Technology*	Ntourou V, Kalogiannakis M & Psycharis S	A study of the impact of Arduino and visual programming in self-efficacy, motivation, computational thinking and 5th Grade students' perceptions on electricity	2021	*Eurasia Journal of Mathematics, Science and Technology Education*
Basson I	Twenty years into the new millennium: How integrated is Mathematics, Physics and Computer Science at secondary school level?	2021	*Perspectives in Education*	Kátai Z & Osztián E	Improving algorythmics teaching-learning environment by asking questions	2021	*International Journal of Instruction*
Araya R, Isoda M & Van der Molen Moris J	Developing computational thinking teaching strategies to model pandemics and containment measures	2021	*International Journal of Environmental Research and Public Health*	Demirkiran MC & Tansu Hocanin F	An investigation on primary school students' dispositions towards programming with game-based learning	2021	*Education and Information Technologies*
Kálózi-Szabó C, Mohai K & Cottini M	Employing robotics in education to enhance cognitive development—A pilot study	2022	*Sustainability*	Manrique-Losada B, Gómez-Álvarez MC & González-Palacio L	Estrategia de transformación para la formación e informática: Hacia el desarrollo de competencias eneducación básica y media para la Industria 4.0 en Medellín – Colombia [Transformation strategy for computer training: Towards the skill development in basic and secondary education for Industry 4.0 I Medellín-Colombia]	2020	*Revista Ibérica de Sistemas e Tecnologias de Informação*
Douglass H & Verma G	Examining STEM teaching at the intersection of informal and formal spaces: Exploring	2022	*Journal of Science Teacher Education*	Montes N, Rosillo N, Mora MC & Hilario L	A novel real-time MATLAB/Simulink/LEGO EV3 platform for	2021	*Sensors*

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	science pre-service elementary teacher preparation				academic use in robotics and computer science		
Li F, Wang X, He X, Cheng L & Wang Y	The effectiveness of unplugged activities and programming exercises in computational thinking education: A Meta-analysis	2022	*Education and Information Technologies*	Alexandre F, Becker J, Comte MH, Lagarrigue A, Liblau R, Romero M & Viéville T	Why, what and how to help each citizen to understand artificial intelligence?	2021	*KI - Künstliche Intelligenz*
Aalbergsjø SG	Learning to make and use computer simulations in science education	2022	*Acta Didactica Norden*	Torres-Torres YD, Román-González M & Pérez-González JC	Unplugged teaching activities to promote computational thinking skills in primary and adults from a gender perspective	2020	*IEEE Revista Iberoamericana de Tecnologias del Aprendizaje*
Eloy A, Achutti CF, Fernandez C & De Deus Lopes R	A data-driven approach to assess computational thinking concepts based on learners' artifacts	2022	*Informatics in Education*	Katai Z	Promoting computational thinking of both sciences- and humanities-oriented students: An instructional and motivational design perspective	2020	*Educational Technology Research and Development*
Bal IA, Alvarado–Albertorio F, Marcelle P & Oaks–Garcia CT	Pre–service teachers computational thinking (CT) and pedagogical growth in a micro–credential: A mixed methods study	2022	*TechTrends*	Drot-Delange B, Parriaux G & Reffay C	Futurs enseignants de l'école primaire: Connaissances des stratégies d'enseignement, curriculaires et disciplinaires pour l'enseignement de la programmation [Preservice primary school teachers: Instructional strategies, curricula and content knowledge for teaching programming]	2021	*RDST. Recherches en Didactique des Sciences et des Technologies*
Bernstein D, Puttick G, Wendell K, Shaw F, Danahy E & Cassidy M	Designing biomimetic robots: Iterative development of an integrated technology design curriculum	2022	*Educational Technology Research and Development*	Solomon C, Harvey B, Kahn K, Lieberman H, Miller ML, Minsky M, Papert A & Silverman B	History of logo	2020	*Proceedings of the ACM on Programming Languages*

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Wang C, Shen J & Chao J	Integrating computational thinking in STEM education: A literature review	2022	*International Journal of Science and Mathematics Education*	Butler D & Leahy M	Developing preservice teachers' understanding of computational thinking: A constructionist approach	2021	*British Journal of Educational Technology*
Kale U, Yuan J & Roy A	Thinking processes in code. org: A relational analysis approach to computational thinking	2022	*Computer Science Education*	Kallia M, Van Borkulo SP, Drijvers P, Barendsen E & Tolboom J	Characterising computational thinking in mathematics education: A literature-informed Delphi study	2021	*Research in Mathematics Education*
Peel A, Sadler TD & Friedrichsen P	Algorithmic explanations: An unplugged instructional approach to integrate science and computational thinking	2022	*Journal of Science Education and Technology*	Gane BD, Israel M, Elagha N, Yan W, Luo F & Pellegrino JW	Design and validation of learning trajectory-based assessments for computational thinking in upper elementary grades	2021	*Computer Science Education*
Tsybulsky D & Sinai E	IoT in project-based biology learning: Students' experiences and skill development	2022	*Journal of Science Education and Technology*	Wu PJ, Hou HY & Huang CC	Applying talent quality-management system (TTQS) to enhance information literacy, learning motivation, and computational thinking competency of nursing undergraduates	2021	*Sustainability*
Bouck EC & Yadav A	Providing access and opportunity for computational thinking and computer science to support mathematics for students with disabilities	2022	*Journal of Special Education Technology*	Waterman KP, Goldsmith L & Pasquale M	Integrating computational thinking into elementary science curriculum: An examination of activities that support students' computational thinking in the service of disciplinary learning	2020	*Journal of Science Education and Technology*
Tengler K, Kastner-Hauler O, Sabitzer B & Lavicza Z	The effect of robotics-based storytelling activities on primary school students' computational thinking	2022	*Education Sciences*	Trilles S & Granell C	Advancing preuniversity students' computational thinking skills through an educational project based on tangible elements and virtual block-based programming	2020	*Computer Applications in Engineering Education*
Payne L, Tawfik A & Olney AM	Computational thinking in education: Past and present	2022	*TechTrends*	Clark DB & Sengupta P	Reconceptualizing games for integrating computational thinking and science as practice:	2020	*Interactive Learning Environments*

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					Collaborative agent-based disciplinarily-integrated games		
Yin Y, Khaleghi S, Hadad R & Zhai X	Developing effective and accessible activities to improve and assess computational thinking and engineering learning	2022	*Educational Technology Research and Development*	Agbo FJ, Oyelere SS, Suhonen J & Laine TH	Co-design of mini games for learning computational thinking in an online environment	2021	*Education and Information Technologies*
Umutlu D	An exploratory study of pre-service teachers' computational thinking and programming skills	2022	*Journal of Research on Technology in Education*	Knake KT, Daly AJ, Frank KA, Rehm M & Greenhow C	Educators meet the fifth estate: Social media in education: Elementary school journal special issue	2021	*The Elementary School Journal*
Çakır NA, Çakır MP & Lee FJ	We game on skyscrapers: The effects of an equity-informed game design workshop on students' computational thinking skills and perceptions of computer science	2021	*Educational Technology Research and Development*	Lachney M, Babbitt W, Bennett A & Eglash R	Generative computing: African-American cosmetology as a link between computing education and community wealth	2021	*Interactive Learning Environments*
Veenman K, Tolboom JLJ & Van Beekum O	The relation between computational thinking and logical thinking in the context of robotics education	2022	*Frontiers in Education*	Fagerlund J, Häkkinen P, Vesisenaho M & Viiri J	Computational thinking in programming with Scratch in primary schools: A systematic review	2021	*Computer Applications in Engineering Education*
Merino-Armero JM, González-Calero JA, Cózar-Gutiérrez R & Del Olmo-Muñoz J	Unplugged activities in cross-curricular teaching: Effect on sixth graders' computational thinking and learning outcomes	2022	*Multimodal Technologies and Interaction*	Weber J & Wilhelm T	The benefit of computational modelling in physics teaching: A historical overview	2020	*European Journal of Physics*
Zapata-Ros M & Palacios YB	El pensamiento bayesiano, un pensamiento computacional omnipresente [The bayesian thinking, a pervasive computational thinking]	2021	*Revista de Educación a Distancia*	So HJ, Kim D & Ryoo D	Trajectories of developing computational thinking competencies: Case portraits of Korean gifted girls	2020	*The Asia-Pacific Education Researcher*
Galoyan T, Barany A, Donaldson JP, Ward N & Hammrich P	Connecting science, design thinking, and computational thinking through sports	2022	*International Journal of Instruction*	Israel M & Lash T	From classroom lessons to exploratory learning progressions: Mathematics + computational thinking	2020	*Interactive Learning Environments*

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Macrides E, Miliou O & Angeli C	Programming in early childhood education: A systematic review	2022	*International Journal of Child-Computer Interaction*	Berikan B & Özdemir S	Investigating "problem-solving with datasets" as an implementation of computational thinking: A literature review	2020	*Journal of Educational Computing Research*
De Melo-Minardi RC, De Melo EC & Bastos LL	OnlineBioinfo: Leveraging the teaching of programming skills to life science students through learning analytics	2022	*Frontiers in Education*	Cano S, Naranjo JS, Henao C, Rusu C & Albiol-Pérez S	Serious game as support for the development of computational thinking for children with hearing impairment	2021	*Applied Sciences*
Sparf M, Löfgren H & Kreitz-Sandberg S	Design for learning programming: Approaches taken by novice learners	2022	*NorDiNa: Nordic Studies in Science Education*	Aminger W, Hough S, Roberts SA, Meier V, Spina AD, Pajela H, McClean M & Bianchini JA	Preservice secondary science teachers' implementation of an NGSS practice: Using mathematics and computational thinking	2021	*Journal of Science Teacher Education*
Kelleher CA, Gannon JP, Jones CN & Aksoy Ş	Best management practices for teaching hydrologic coding in physical, hybrid, and virtual classrooms	2022	*Frontiers in Water*	Rodríguez-Abitia G, Ramírez-Montoya MS, López-Caudana EO & Romero-Rodríguez JM	Factores para el desarrollo del pensamiento computacional en estudiantes de pregrado [Factors for the development of computational thinking in undergraduate students]	2021	*Campus Virtuales*
McGill MM & Reinking A	Early findings on the impacts of developing evidence-based practice briefs on middle school computer science teachers	2022	*ACM Transactions on Computing Education*	Lazarinis F, Karachristos CV, Stavropoulos EC & Verykios VS	A blended learning course for playfully teaching programming concepts to school teachers	2019	*Education and Information Technologies*
Tripon C	Supporting future teachers to promote computational thinking skills in teaching STEM—a case study	2022	*Sustainability*	Rueda-Rueda JS, Rico-Bautista D & Flórez-Solano É	Educación en TIC: Enseñar a usar, enseñar a protegerse y enseñar a crear tecnología [Education in ICT: Teaching to use, teaching to protect oneself and teaching to create]	2019	*Revista Ibérica de Sistemas e Tecnologias de Informação*
Peters-Burton E, Rich PJ, Kitsantas A, Laclede L & Stehle SM	High school science teacher use of planning tools to integrate computational thinking	2022	*Journal of Science Teacher Education*	Adler RF & Kim H	Enhancing future K-8 teachers' computational thinking skills through modeling and simulations	2018	*Education and Information Technologies*

Author	Title	Published year	Journal name	Author	Title	Published year	Journal name
Arrifano Tadeu PJA & Brigas C	El pensamiento computacional en educación infantil: Una análisis a través del Computer Science Unplugged [Computational thinking in early childhood education: An analysis through Computer Science Unplugged]	2022	*Revista Interuniversitaria De Formación Del Profesorado. Continuación De La Antigua Revista De Escuelas Normales*	Miller J	STEM education in the primary years to support mathematical thinking: Using coding to identify mathematical structures and patterns	2019	*ZDM Mathematics Education*
Xu R, Jiang C & Sun L	A novel three-way decision model for improving computational thinking based on grey correlation analysis	2022	*Scientific Programming*	De Souza AA, Barcelos TS, Munoz R, Villarroel R & Silva LA	Data mining framework to analyze the evolution of computational thinking skills in game building workshops	2019	*IEEE Access*
Dolgopolovas V & Dagiene V	On semiotics perspectives of computational thinking: Unravelling the "pamphlet" approach, a case study	2022	*Sustainability*	Mesiti LA, Parkes A, Paneto SC & Cahill C	Building capacity for computational thinking in youth through informal education	2019	*Journal of Museum Education*
Tucker-Raymond E, Cassidy M & Puttick G	Science teachers can teach computational thinking through distributed expertise	2021	*Computers & Education*	Taylor NG, Moore J, Visser M & Drouillard C	Incorporating computational thinking into library graduate course goals and objectives	2018	*School Library Research*
Kanaki K & Kalogiannakis M	Assessing algorithmic thinking skills in relation to gender in early childhood	2022	*Educational Process: International Journal*	Yadav A, Hong H & Stephenson C	Computational thinking for all: Pedagogical approaches to embedding 21st century problem solving in K-12 classrooms	2016	*TechTrends*
Moreno Guerrero AJ, Marín-Marín JA, Parra González ME & López Belmonte J	Computer in education in the 21st century. A scientific mapping of the literature in Web of Science	2022	*Campus Virtuales*	Villalba-Condori KO & Oliva-Córdova LM	Teacher training to develop computational thinking at the primary education level	2019	*Journal of Advanced Research in Dynamical and Control Systems*
Gupta S & Tiwari AA	A design-based pedagogical framework for developing computational thinking skills	2022	*Journal of Decision Systems*	Bati K, Yetişir MI, Çalişkan I, Güneş G & Gül Saçan E	Teaching the concept of time: A steam-based program on computational thinking in science education	2018	*Cogent Education*
De Santo A, Farah JC, Martínez ML, Moro A, Bergram K, Purohit	Promoting computational thinking skills in non-computer-science students:	2022	*IEEE Transactions on Learning Technologies*	Città G, Gentile M, Allegra M, Arrigo M, Conti	The effects of mental rotation on computational thinking	2019	*Computers & Education*

Author	Title	Published year	Journal name	Author	Title	Published year	Journal name
AK, Felber P, Gillet D & Holzer A	Gamifying computational notebooks to increase student engagement			D, Ottaviano S, Reale F & Sciortino M			
Fergusson A & Pfannkuch M	Introducing high school statistics teachers to predictive modelling and APIs using code-driven tools	2022	*Statistics Education Research Journal*	Rose SP, Habgood MPJ & Jay T	An exploration of the role of visual programming tools in the development of young children's computational thinking	2017	*The Electronic Journal of e-Learning*
Kwon K, Ottenbreit-Leftwich AT, Brush TA, Jeon M & Yan G	Integration of problem-based learning in elementary computer science education: Effects on computational thinking and attitudes	2021	*Educational Technology Research and Development*	Ilic U, Haseski Hİ & Tugtekin U	Publication trends over 10 years of computational thinking research	2018	*Contemporary Educational Technology*
Ragonis N, Bukai A & Hazzan O	Selecting examples for CS courses: The case of a computational thinking MOOC	2022	*ACM Inroads*	Vernier M, Cárcamo L & Scheihing E	Critical thinking of young citizens towards news headlines in Chile	2018	*Comunicar: Media Education Research Journal*
Menolli A & Neto JC	Computational thinking in computer science teacher training courses in Brazil: A survey and a research roadmap	2022	*Education and Information Technologies*	Witherspoon EB, Higashi RM, Schunn CD, Baehr EC & Shoop R	Developing computational thinking through a virtual robotics programming curriculum	2017	*ACM Transactions on Computing Education (TOCE)*
Aryan, Hegade P & Shettar A	Effectiveness of computational thinking in problem based learning	2023	*Journal of Engineering Education Transformations*	Yadav A, Stephenson C & Hong H	Computational thinking for teacher education	2017	*Communications of the ACM*
Denervaud S, Christensen AP, Kenett YN & Beaty RE	Education shapes the structure of semantic memory and impacts creative thinking	2021	*npj Science of Learning*	Kanaki K & Kalogiannakis M	Introducing fundamental object-oriented programming concepts in preschool education within the context of physical science courses	2018	*Education and Information Technologies*
Hingston PA & Bracewell DD	Strengthening undergraduate food science programs: Comparing industry relevance of the Institute of Food Technologists' Essential Learning Outcomes with graduate proficiency levels	2021	*Journal of Food Science Education*	Yang S, Mei B & Yue X	Mobile augmented reality assisted chemical education: Insights from Elements 4D	2018	*Journal of Chemical Education*
Lu C, Macdonald R, Odell B, Kokhan V,	A scoping review of computational thinking	2022	*Journal of Computing in Higher Education*	Yu X & Guo X	Case study on "STEM+ computational thinking"	2018	*Journal of Science Education*

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Demmans Epp C & Cutumisu M	assessments in higher education				education model in Chinese K-12 schools		
Huang H & Li Y	Exploring the motivation of livestreamed users in learning computer programming and coding	2021	*The Electronic Journal of e-Learning*	João P, Nuno D, Fábio SF & Ana P	A cross-analysis of block-based and visual programming apps with computer science student-teachers	2019	*Education Sciences*
Osztián PR, Kátai Z & Osztián E	On the computational thinking and diagrammatic reasoning of first-year computer science and engineering students	2022	*Frontiers in Education*	Chen G, Shen J, Barth-Cohen L, Jiang S, Huang X & Eltoukhy M	Assessing elementary students' computational thinking in everyday reasoning and robotics programming	2017	*Computers & Education*
Jacob SR, Montoya J & Warschauer M	Exploring the intersectional development of computer science identities in young Latinas	2022	*Teachers College Record*	Leonard J, Mitchell M, Barnes-Johnson J, Unertl A, Outka-Hill J, Robinson R & Hester-Croff C	Preparing teachers to engage rural students in computational thinking through robotics, game design, and culturally responsive teaching	2018	*Journal of Teacher Education*
Mecca G, Santoro D, Sileno N & Veltri E	Diogene-CT: Tools and methodologies for teaching and learning coding	2021	*International Journal of Educational Technology in Higher Education*	Basu S, Biswas G, Sengupta P, Dickes A, Kinnebrew JS & Clark D	Identifying middle school students' challenges in computational thinking-based science learning	2016	*Research and Practice in Technology Enhanced Learning*
Yıldız Durak H & Atman Uslu N	Investigating the effects of SOLO taxonomy with reflective practice on university students' meta-cognitive strategies, problem-solving, cognitive flexibility, spatial anxiety: An embedded mixed-method study on 3D game development	2023	*Interactive Learning Environments*	Pinto-Llorente AM, Casillas-Martín S, Cabezas-González M & García-Peñalvo FJ	Building, coding and programming 3D models via a visual programming environment	2018	*Quality & Quantity*
Funk M, Cascalho J, Santos AI, Pedro F, Medeiros P, Amaral B, Domingos M, Ramos A & Mendes A	A simple interactive robot to promote computational thinking	2022	*Frontiers in Computer Science*	Kert SB, Kalelioğlu F & Gülbahar Y	A holistic approach for computer science education in secondary schools	2019	*Informatics in Education*
Israel-Fishelson R & Hershkovitz A	Studying interrelations of computational thinking and creativity: A scoping review (2011–2020)	2022	*Computers & Education*	Spieler B, Grandl M, Ebner M & Slany W	Bridging the gap: A Computer Science pre-MOOC for first semester students	2020	*The Electronic Journal of e-Learning*

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Umutlu D	TPACK leveraged: A redesigned online educational technology course for STEM preservice teachers	2022	*Australasian Journal of Educational Technology*	Choi SY & Kim AM	Development of indoor aquaponics control system using a computational thinking-based convergence instructional model	2019	*Universal Journal of Educational Research*
Kravik R, Berg TK & Siddiq F	Teachers' understanding of programming and computational thinking in primary education – A critical need for professional development	2022	*Acta Didactica Norden*	Lee J, Kim JB & Kim JB	Effects of the experience in developing physics teaching materials based on computational thinking for improvement of science teachers' and pre-service teachers' technological pedagogical and content knowledge (TPACK)	2018	*New Physics: Sae Mulli*
Huang X & Qiao C	Enhancing computational thinking skills through artificial intelligence education at a STEAM high school	2024	*Science & Education*	Lachney M	Computational communities: African-American cultural capital in computer science education	2017	*Computer Science Education*
Sun D, Ouyang F, Li Y & Zhu C	Comparing learners' knowledge, behaviors, and attitudes between two instructional modes of computer programming in secondary education	2021	*International Journal of STEM Education*	Pérez-Marín D, Hijón-Neira R & Martín-Lope M	A methodology proposal based on metaphors to teach programming to children	2018	*IEEE Revista Iberoamericana de Tecnologias del Aprendizaje*
Colclasure BC, Durham Brooks T, Helikar T, King SJ & Webb A	The effects of a modeling and computational thinking professional development program on STEM educators' perceptions toward teaching science and engineering practices	2022	*Education Sciences*	Demartini CG, Benussi L, Gatteschi V & Renga F	Education and digital transformation: The "Riconnessioni" project	2020	*IEEE Access*
Jocius R, O'Byrne WI, Albert J, Joshi D, Blanton M, Robinson R, Andrews A, Barnes T & Catete V	Building a virtual community of practice: Teacher learning for computational thinking infusion	2022	*TechTrends*	Snow E, Rutstein D, Basu S, Bienkowski M & Everson HT	Leveraging evidence-centered design to develop assessments of computational thinking practices	2019	*International Journal of Testing*
Contente J & Galvão C	STEM education and problem-solving in space	2022	*Education Sciences*	Manches A & Plowman L	Computing education in children's early years: A call for debate	2017	*British Journal of Educational Technology*

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	science: A case study with CanSat						
Kanaki K & Kalogiannakis M	Assessing algorithmic thinking skills in relation to age in early childhood STEM education	2022	*Education Sciences*	Moschella M & Basso D	Computational thinking, spatial and logical skills. An investigation at primary school	2020	*Ricerche di Pedagogia e Didattica* [Journal of Theories and Research in Education]
Manfra MM, Hammond TC & Coven RM	Assessing computational thinking in the social studies	2022	*Theory & Research in Social Education*	Panskyi T, Rowinska Z & Biedron S	Out-of-school assistance in the teaching of visual creative programming in the game-based environment–Case study: Poland	2019	*Thinking Skills and Creativity*
Ogegbo AA & Ramnarain U	Teachers' perceptions of and concerns about integrating computational thinking into science teaching after a professional development activity	2022	*African Journal of Research in Mathematics, Science and Technology Education*	Kraleva R, Kralev V & Kostadinova D	A methodology for the analysis of block-based programming languages appropriate for children	2019	*Journal of Computing Science and Engineering*
Haldolaarachchige N & Hettiarachchilage K	Comparison of student performance between virtual and in-person modalities of introductory calculus-based physics	2022	*Physics Education*	Sáez-López JM, Sevillano-García ML & Vazquez-Cano E	The effect of programming on primary school students' mathematical and scientific understanding: Educational use of mBot	2019	*Educational Technology Research and Development*
Xu W, Geng F & Wang L	Relations of computational thinking to reasoning ability and creative thinking in young children: Mediating role of arithmetic fluency	2022	*Thinking Skills and Creativity*	Basu S, Biswas G & Kinnebrew JS	Learner modeling for adaptive scaffolding in a Computational Thinking-based science learning environment	2017	*User Modeling and User-Adapted Interaction*
Dolgopolovas V & Dagiene V	On the future of Computational Thinking education: Moving beyond the digital agenda, a discourse analysis perspective	2021	*Sustainability*	Caeli EN & Yadav A	Unplugged approaches to computational thinking: A historical perspective	2020	*TechTrends*
Pewkam W & Chamrat S	Pre-service teacher training program of STEM-based activities in computing science to develop computational thinking	2022	*Informatics in Education*	Biró P & Csernoch M	Computer science students' attitudes	2016	*Turkish Online Journal of Educational Technology*

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Ballard ED & Haroldson R	Analysis of computational thinking in children's literature for K-6 students: Literature as a non-programming unplugged resource	2022	*Journal of Educational Computing Research*	Siegle D	There's an app for that, and I made it	2020	*Gifted Child Today*
Love TS & Asempapa RS	A screen-based or physical computing unit? Examining secondary students' attitudes toward coding	2022	*International Journal of Child-Computer Interaction*	Peel A, Sadler TD & Friedrichsen P	Learning natural selection through computational thinking: Unplugged design of algorithmic explanations	2019	*Journal of Research in Science Teaching*
Musaeus LH, Tatar D & Musaeus P	Computational modelling in high school biology: A teaching intervention	2024	*Journal of Biological Education*	Lakanen AJ & Kärkkäinen T	Identifying pathways to computer science: The long-term impact of short-term game programming outreach interventions	2019	*ACM Transactions on Computing Education (TOCE)*
Stella M, Kapuza A, Cramer C & Uzzo S	Mapping computational thinking mindsets between educational levels with cognitive network science	2021	*Journal of Complex Networks*	Voskoglou MGR	Computers and Artificial Intelligence as tools for education in the forthcoming era of the Internet of Things and Energy	2019	*WSEAS Transactions on Information Science and Applications*
Hsu TC & Chen MS	The engagement of students when learning to use a personal audio classifier to control robot cars in a computational thinking board game	2022	*Research and Practice in Technology Enhanced Learning*	Román-González M, Pérez-González JC & Jiménez-Fernández C	Which cognitive abilities underlie computational thinking? Criterion validity of the Computational Thinking Test	2017	*Computers in Human Behavior*
Kert SB, Yeni S & Fatih Erkoç M	Enhancing computational thinking skills of students with disabilities	2022	*Instructional Science*	Jenson J & Droumeva M	Revisiting the media generation: Youth media use and computational literacy instruction	2017	*E-Learning and Digital Media*
Henze J, Schatz C, Malik S & Bresges A	How might we raise interest in Robotics, Coding, Artificial Intelligence, STEAM and Sustainable Development in university and on-the-job teacher training?	2022	*Frontiers in Education*	López-Belmonte J, Marín-Marín JA, Soler-Costa R & Moreno-Guerrero AJ	Arduino advances in Web of Science. A scientific mapping of literary production	2020	*IEEE Access*
Tekdal M	Trends and development in research on computational thinking	2021	*Education and Information Technologies*	Rinke CR, Gladstone-Brown	Characterizing STEM teacher education: Affordances and	2016	*School Science and Mathematics*

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				W, Kinlaw CR & Cappiello J	constraints of explicit STEM preparation for elementary teachers		
Wang D, Luo L, Luo J, Lin S & Ren G	Developing computational thinking: Design-based learning and interdisciplinary activity design	2022	*Applied Sciences*	Ketenci T, Calandra B, Margulieux L & Cohen J	The relationship between learner characteristics and student outcomes in a middle school computing course: An exploratory analysis using structural equation modeling	2019	*Journal of Research on Technology in Education*
Finke S, Kemény F, Sommer M, Krnjic V, Arendasy M, Slany W & Landerl K	Unravelling the numerical and spatial underpinnings of computational thinking: A pre-registered replication study	2022	*Computer Science Education*	Hsu TC, Chang SC & Hung YT	How to learn and how to teach computational thinking: Suggestions based on a review of the literature	2018	*Computers & Education*
Paucar-Curasma R, Villalba-Condori K, Arias-Chavez D, Le NT, Garcia-Tejada G & Frango Silveira I	Evaluación del pensamiento computacional utilizando cuatro robots educativos con estudiantes de primaria en Perú [Evaluation of computational thinking using four educational robots with primary school students in Peru]	2022	*Education in the Knowledge Society*	Brown JC	A metasynthesis of the complementarity of culturally responsive and inquiry-based science education in K-12 settings: Implications for advancing equitable science teaching and learning	2017	*Journal of Research in Science Teaching*
Cooper RA	Familiarize your students with life at the microscopic scale	2021	*The American Biology Teacher*	Lapawi N & Husnin H	The effect of computational thinking module on achievement in science	2020	*Science Education International*
Tawfik AA, Payne L & Olney AM	Scaffolding computational thinking through block coding: A learner experience design study	2024	*Technology, Knowledge and Learning*	Ayuso ÁM, Povedano NA & López RB	La resolución de problemas basada en el método de Polya usando el pensamiento computacional y Scratch con estudiantes de educación secundaria [Problem solving with Polya’s technique using computational thinking and Scratch with secondary school students]	2020	*Aula Abierta*

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Park W & Kwon H	Research trends and issues including Computational Thinking in science education and mathematics education in the Republic of Korea	2022	*Journal of Baltic Science Education*	Benakli N, Kostadinov B, Satyanarayana A & Singh S	Introducing computational thinking through hands-on projects using R with applications to calculus, probability and data analysis	2017	*International Journal of Mathematical Education in Science and Technology*
Herro D, Quigley C, Plank H, Abimbade O & Owens A	Instructional practices promoting computational thinking in STEAM elementary classrooms	2022	*Journal of Digital Learning in Teacher Education*	Özgür H	Relationships between computational thinking skills, ways of thinking and demographic variables: A structural equation modeling	2020	*International Journal of Research in Education and Science*
Radloff J & Hall JA	Development and testing of the Draw-a-Programmer test (DAPT) to explore elementary preservice teachers' conceptions of computational thinking	2022	*Education and Information Technologies*	Birney L & McNamara D	The Curriculum and Community Enterprise for Restoration Science S.T.E.M.+ C professional learning model: Expansion and enhancement	2019	*Journal of Curriculum and Teaching*
Luo T, Reynolds J & Muljana PS	Elementary students learning computer programming: An investigation of their knowledge retention, motivation, and perceptions	2022	*Educational Technology Research and Development*	Román-González M, Pérez-González JC, Moreno-León J & Robles G	Can computational talent be detected? Predictive validity of the Computational Thinking Test	2018	*International Journal of Child-Computer Interaction*
Kassa EA & Mekonnen EA	Computational thinking in the Ethiopian secondary school ICT curriculum	2022	*Computer Science Education*	Kim C, Yuan J, Vasconcelos L, Shin M & Hill RB	Debugging during block-based programming	2018	*Instructional Science*
Keravnou-Papailiou E	Figuring and drawing: A visual approach to principled programming	2022	*The Art, Science, and Engineering of Programming*	Grover S, Basu S, Bienkowski M, Eagle M, Diana N & Stamper J	A framework for using hypothesis-driven approaches to support data-driven learning analytics in measuring computational thinking in block-based programming environments	2017	*ACM Transactions on Computing Education (TOCE)*
He Z, Wu X, Wang Q & Huang C	Developing eighth-grade students' computational thinking with critical reflection	2021	*Sustainability*	Jaipal-Jamani K & Angeli C	Effect of robotics on elementary preservice teachers' self-efficacy, science learning, and computational thinking	2017	*Journal of Science Education and Technology*

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Kubsch M & Hamerski PC	Dynamic Energy Transfer Models	2022	*The Physics Teacher*	Bergan-Roller HE, Galt NJ, Chizinski CJ, Helikar T & Dauer JT	Simulated computational model lesson improves foundational systems thinking skills and conceptual knowledge in biology students	2018	*BioScience*
Angeli C	The effects of scaffolded programming scripts on pre-service teachers' computational thinking: Developing algorithmic thinking through programming robots	2022	*International Journal of Child-Computer Interaction*	Fronza I, El Ioini N & Corral L	Teaching computational thinking using agile software engineering methods: A framework for middle schools	2017	*ACM Transactions on Computing Education (TOCE)*
Çakiroğlu Ü & Çevik İ	A framework for measuring abstraction as a sub-skill of computational thinking in block-based programming environments	2022	*Education and Information Technologies*	Kwon J & Kim J	A study on the design and effect of Computational Thinking and Software Education	2018	*KSII Transactions on Internet and Information Systems*
Fritz C, Bray D, Lee G, Julien C, Burson S, Castelli D, Ramsey C & Payton J	Project moveSMART: When physical education meets computational thinking in elementary classrooms	2022	*Computer*	Sondakh DE, Osman K & Zainudin S	A proposal for holistic assessment of computational thinking for undergraduate: Content validity	2020	*European Journal of Educational Research*
Chuang HM & Lee CC	Effects of personal construal levels and team role ambiguity on the group investigation of junior high school students' programming ability	2021	*Sustainability*	Sáez-López JM & Cózar-Gutiérrez R	Programación visual por bloques en Educación Primaria: Aprendiendo y creando contenidos en Ciencias Sociales [Visual programming with blocks in Primary Education: Learning and creating content in Social Sciences]	2017	*Revista Complutense de Educación*
Ismail R, Zaman HB & Mohammad UH	A Visual-based Project Production Package for Design & Technology subject, based on Computational Thinking skills across-STEM	2022	*JOIV: International Journal on Informatics Visualization*	Roig-Vila R & Moreno-Isac V	El pensamiento computacional en educación. Análisis bibliométrico y temático [Computational thinking in education. Bibliometric and thematic analysis]	2020	*Revista De Educación a Distancia (RED)*

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Tsarava K, Moeller K, Román-González M, Golle J, Leifheit L, Butz MV & Ninaus M	A cognitive definition of computational thinking in primary education	2022	*Computers & Education*	Dagienė V, Sentance S & Stupurienė G	Developing a two-dimensional categorization system for educational tasks in informatics	2017	*Informatica*
Bati K	Integration of python into science teacher education, developing computational problem solving and using information and communication technologies competencies of pre-service science teachers	2022	*Informatics in Education-An International Journal*	Uysal VŞ & Topaloğlu F	Bridging the gap: A manual primer into design computing in the context of basic design education	2017	*The International Journal of Art & Design Education*
Lee SJ, Francom GM & Nuatomue J	Computer science education and K-12 students' computational thinking: A systematic review	2022	*International Journal of Educational Research*	Kang EJS, Donovan C & McCarthy MJ	Exploring elementary teachers' pedagogical content knowledge and confidence in implementing the NGSS science and engineering practices	2018	*Journal of Science Teacher Education*
Abar CAAP, Dos Santos JMDS & De Almeida MV	Pensamento computacional na escola básica na era da inteligência artificial: Onde está o professor? [Computational thinking in elementary school in the age of artificial intelligence: Where is the teacher?]	2021	*Acta Scientiae*	Peteranetz MS, Flanigan AE, Shell DF & Soh LK	Computational creativity exercises: An avenue for promoting learning in computer science	2017	*IEEE Transactions on Education*
Liao CH, Chiang CT, Chen IC & Parker KR	Exploring the relationship between computational thinking and learning satisfaction for non-STEM college students	2022	*International Journal of Educational Technology in Higher Education*	Chiazzese G, Arrigo M, Chifari A, Lonati V & Tosto C	Educational robotics in primary school: Measuring the development of computational thinking skills with the Bebras tasks	2019	*Informatics*
Jeon AJ, Kellogg D, Khan MA & Tucker-Kellogg G	Developing critical thinking in STEM education through inquiry-based writing in the laboratory classroom	2021	*Biochemistry and Molecular Biology Education*	Damas MC, Ngwira CM, Cheung TD, Marchese P, Kuznetsova M, Zheng Y, Chulaki A & Mohamed A	A model of an integrated research and education program in space weather at a community college	2020	*Space Weather*

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Rottenhofer M, Sabitzer B & Rankin T	Developing computational thinking skills through modeling in language lessons	2021	*Open Education Studies*	Tonbuloğlu B & Tonbuloğlu İ	The effect of unplugged coding activities on computational thinking skills of middle school students	2019	*Informatics in Education*
Yang K, Liu X & Chen G	Global research trends in robot education in 2009-2019: A bibliometric analysis	2020	*International Journal of Information and Education Technology*	Song IY & Zhu Y	Big data and data science: Opportunities and challenges of iSchools	2017	*Journal of Data and Information Science*
Fidai A, Capraro MM & Capraro RM	"Scratch"-ing computational thinking with Arduino: A meta-analysis	2020	*Thinking Skills and Creativity*	Garneli V & Chorianopoulos K	Programming video games and simulations in science education: Exploring computational thinking through code analysis	2018	*Interactive Learning Environments*
Sivaraj R, Ellis JA, Wieselmann JR & Roehrig GH	Computational participation and the learner-technology pairing in K-12 STEM education	2020	*Human Behavior and Emerging Technologies*	Pittarello F & Pellegrini T	HCI and education: A blended design experience	2017	*Multimedia Tools and Applications*
Dorotea N, Piedade J & Pedro A	Mapping K-12 computer science teacher's interest, self-confidence, and knowledge about the use of educational robotics to teach	2021	*Education Sciences*	Pellas N & Peroutseas E	Leveraging Scratch4SL and Second Life to motivate high school students' participation in introductory programming courses: Findings from a case study	2017	*New Review of Hypermedia and Multimedia*
Rose SP, Habgood MPJ & Jay T	Designing a programming game to improve children's procedural abstraction skills in Scratch	2020	*Journal of Educational Computing Research*	Papadakis S & Kalogiannakis M	Evaluating a course for teaching introductory programming with Scratch to pre-service kindergarten teachers	2019	*International Journal of Technology Enhanced Learning*
Otterborn A, Schönborn KJ & Hultén M	Investigating preschool educators' implementation of computer programming in their teaching practice	2020	*Early Childhood Education Journal*	Pérez A	A framework for computational thinking dispositions in mathematics education	2018	*Journal for Research in Mathematics Education*
Columba L	Computational thinking using the First in Math® online program	2020	*Mathematics Teaching-Research Journal*	Juškevičienė A & Dagienė V	Computational thinking relationship with digital competence	2018	*Informatics in Education*

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Rehmat AP, Ehsan H & Cardella ME	Instructional strategies to promote computational thinking for young learners	2020	*Journal of Digital Learning in Teacher Education*	Shook E, Bowlick FJ, Kemp KK, Ahlqvist O, Carbajeles-Dale P, DiBiase D, Kim EK, Lathrop S, Ricker B, Rickles P, Rush J, Swift JN & Wang S	Cyber literacy for GIScience: Toward formalizing geospatial computing education	2019	*The Professional Geographer*
Bryce S, Heath KN, Issi L, Ryder EF & Rao RP	Using COVID-19 as a teaching tool in a time of remote learning: A workflow for bioinformatic approaches to identifying candidates for therapeutic and vaccine development	2020	*Biochemistry and Molecular Biology Education*	Breslyn W & McGinnis JR	Investigating preservice elementary science teachers' understanding of climate change from a computational thinking systems perspective	2019	*Eurasia Journal of Mathematics, Science and Technology Education*
Jocius R, O'Byrne WI, Albert J, Joshi D, Robinson R & Andrews A	Infusing computational thinking into STEM teaching: From professional development to classroom practice	2021	*Educational Technology & Society*	Chookaew S, Howimanporn S & Hutamarn S	Investigating students' computational thinking through STEM robot-based learning activities	2020	*Advances in Science, Technology and Engineering Systems*
Gazzano A	Japan's *programming education*: A critical focus on music in elementary schools	2024	*Arts Education Policy Review*	Negrini L & Giang C	How do pupils perceive educational robotics as a tool to improve their 21st century skills?	2019	*Journal of e-Learning and Knowledge Society*
Luo F, Antonenko PD & Davis EC	Exploring the evolution of two girls' conceptions and practices in computational thinking in science	2020	*Computers & Education*	Proctor C & Blikstein P	Unfold studio: Supporting critical literacies of text and code	2019	*Information and Learning Sciences*
Lodi M & Martini S	Computational thinking, between Papert and Wing	2021	*Science & Education*	Sentance S & Csizmadia A	Computing in the curriculum: Challenges and strategies from a teacher's perspective	2017	*Education and Information Technologies*
Csapó G, Csernoch M & Abari K	Sprego: Case study on the effectiveness of teaching spreadsheet management with schema construction	2020	*Education and Information Technologies*	Román-González M, Pérez-González JC, Moreno-León J & Robles G	Extending the nomological network of computational thinking with non-cognitive factors	2018	*Computers in Human Behavior*
Gallardo-Alba C, Grüning B & Serrano-Solano B	A constructivist-based proposal for bioinformatics teaching practices during lockdown	2021	*PLoS Computational Biology*	Zhong B, Wang Q & Chen J	The impact of social factors on pair programming in a primary school	2016	*Computers in Human Behavior*

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Dagienė V, Hromkovič J & Lacher R	Designing informatics curriculum for K-12 education: From Concepts to Implementations	2021	*Informatics in Education*	Garneli V & Chorianopoulos K	The effects of video game making within science content on student computational thinking skills and performance	2019	*Interactive Technology and Smart Education*
Goldenberg EP & Carter CJ	Programming as a language for young children to express and explore mathematics in school	2021	*British Journal of Educational Technology*	Ioannou A & Makridou E	Exploring the potentials of educational robotics in the development of computational thinking: A summary of current research and practical proposal for future work	2018	*Education and Information Technologies*
Fields D, Lui D, Kafai Y, Jayathirtha G, Walker J & Shaw M	Communicating about computational thinking: Understanding affordances of portfolios for assessing high school students' computational thinking and participation practices	2021	*Computer Science Education*	Smirnov EI, Zykova TV & Tikhomirov SA	The management of school mathematical education with synergistic effect	2019	*Perspektivy Nauki i Obrazovania*
Monjelat N & Lantz-Andersson A	Teachers' narrative of learning to program in a professional development effort and the relation to the rhetoric of computational thinking	2020	*Education and Information Technologies*	Csizmadia A, Standl B & Waite J	Integrating the constructionist learning theory with computational thinking classroom activities	2019	*Informatics in Education*
Arastoopour Irgens G, Dabholkar S, Bain C, Woods P, Hall K, Swanson H, Horn M & Wilensky U	Modeling and measuring high school students' computational thinking practices in science	2020	*Journal of Science Education and Technology*	Vieira C, Magana AJ, Roy A & Falk ML	Student explanations in the context of computational science and engineering education	2019	*Cognition and Instruction*
Cheng GM & Chen CP	Processing analysis of Swift Playgrounds in a children's computational thinking course to learn programming	2021	*Computers*	Gero A & Levin I	Computational thinking and constructionism: Creating difference equations in spreadsheets	2019	*International Journal of Mathematical Education in Science and Technology*
Bezuidenhout HS	An early grade science, technology, engineering and mathematics dialogue reading programme: The development of a conceptual framework	2021	*South African Journal of Childhood Education*	Lapawi N & Husnin H	Investigating students' computational thinking skills on matter module	2020	*(IJACSA) International Journal of Advanced Computer*

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Dickes AC, Farris AV & Sengupta P	Sociomathematical norms for integrating coding and modeling with elementary science: A dialogical approach	2020	*Journal of Science Education and Technology*	Duggan SB	Examining 'digital disruption' as problem and purpose in Australian education policy	2019	*Science and Applications International Education Journal: Comparative Perspectives*
Horton NJ & Hardin JS	Integrating computing in the statistics and data science curriculum: Creative structures, novel skills and habits, and ways to teach computational thinking	2021	*Journal of Statistics and Data Science Education*	Law M, Veinot P, Campbell J, Craig M & Mylopoulos M	Computing for medicine: Can we prepare medical students for the future?	2019	*Academic Medicine*
Metcalf SJ, Reilly JM, Jeon S, Wang A, Pyers A, Brennan K & Dede C	Assessing computational thinking through the lenses of functionality and computational fluency	2021	*Computer Science Education*	Fessakis G & Prantsoudi S	Computer Science teachers' perceptions, beliefs and attitudes on Computational Thinking in Greece	2019	*Informatics in Education*
Lamb R, Hand B & Kavner A	Computational modeling of the effects of the Science Writing Heuristic on student critical thinking in science using machine learning	2021	*Journal of Science Education and Technology*	Ragonis N & Shilo G	Analogies between Logic Programming and linguistics for developing students' understanding of argumentation texts	2018	*Journal of Information Technology Education: Research*
Tsakeni M	Preservice teachers' use of computational thinking to facilitate inquiry-based practical work in multiple-deprived classrooms	2021	*Eurasia Journal of Mathematics, Science and Technology Education*	Buitrago Flórez F, Casallas R, Hernández M, Reyes A, Restrepo S & Danies G	Changing a generation's way of thinking: Teaching computational thinking through programming	2017	*Review of Educational Research*
Saidin ND, Khalid F, Martin R, Kuppusamy Y & Munusamy NA	Benefits and challenges of applying computational thinking in education	2021	*International Journal of Information and Education Technology*	Fisher WP, Jr. & Stenner AJ	Theory-based metrological traceability in education: A reading measurement network	2016	*Measurement*
Gilchrist PO, Alexander AB, Green AJ, Sanders FE, Hooker AQ & Reif DM	Development of a pandemic awareness STEM outreach curriculum: Utilizing a Computational Thinking Taxonomy framework	2021	*Education Sciences*	Jiemin Z & Fangda L	Problems and solutions for cultivating innovation talents who have computational thinking quality	2014	*BioTechnology: An Indian Journal*
McGill MM, DeLyser LA, Brennan K, Franke B, Kaylor E, Mayhew E, Mills K & Yadav A	Evaluation and assessment for improving CS teacher effectiveness	2020	*ACM Inroads*	Kules B	Computational thinking is critical thinking: Connecting to university	2016	*Proceedings of the Association for Information*

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					discourse, goals, and learning outcomes		*Science and Technology*
Clayson JE	Broadening constructionism through visual modelling: My self as subject and object	2021	*British Journal of Educational Technology*	Kafai YB	From computational thinking to computational participation in K–12 education	2016	*Communications of the ACM*
Peteranetz MS & Albano AD	Development and evaluation of the Nebraska Assessment of Computing Knowledge	2020	*Frontiers in Computer Science*	Buxton CA, Allexsaht-Snider M, Kayumova S, Aghasaleh R, Choi YJ & Cohen A	Teacher agency and professional learning: Rethinking fidelity of implementation as multiplicities of enactment	2015	*Journal of Research in Science Teaching*
Burgiel H, Sadler PM & Sonnert G	The association of high school computer science content and pedagogy with students’ success in college computer science	2020	*ACM Transactions on Computing Education (TOCE)*	Sáez-López JM, Román-González M & Vázquez-Cano E	Visual programming languages integrated across the curriculum in elementary school: A two year case study using “Scratch” in five schools	2016	*Computers & Education*
Bortz WW, Gautam A, Tatar D & Lipscomb K	Missing in measurement: Why identifying learning in integrated domains is so hard	2020	*Journal of Science Education and Technology*	Rubinstein A & Chor B	Computational thinking in life science education	2014	*PLoS Computational Biology*
Rich KM, Yadav A & Larimore RA	Teacher implementation profiles for integrating computational thinking into elementary mathematics and science instruction	2020	*Education and Information Technologies*	Ngan SC & Law KMY	Exploratory network analysis of learning motivation factors in e-learning facilitated computer programming courses	2015	*The Asia-Pacific Education Researcher*
Noh J & Lee J	Effects of robotics programming on the computational thinking and creativity of elementary school students	2020	*Educational Technology Research and Development*	Lamb RL, Vallett DB, Akmal T & Baldwin K	A computational modeling of student cognitive processes in science education	2014	*Computers & Education*
Bouck EC, Sands P, Long H & Yadav A	Preparing special education preservice teachers to teach computational thinking and computer science in mathematics	2021	*Teacher Education and Special Education*	Israel M, Pearson JN, Tapia T, Wherfel QM & Reese G	Supporting all learners in school-wide computational thinking: A cross-case qualitative analysis	2015	*Computers & Education*
Maraza-Quispe B, Sotelo-Jump AM, Alejandro-Oviedo OM, Quispe-Flores LM, Cari-Mogrovejo LH,	Towards the development of computational thinking and mathematical logic through Scratch	2021	*International Journal of Advanced Computer Science and Applications*	Voogt J, Fisser P, Good J, Mishra P & Yadav A	Computational thinking in compulsory education: Towards an agenda for research and practice	2015	*Education and Information Technologies*

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Fernandez-Gambarini WC & Cuadros-Paz LE							
Lui D, Walker JT, Hanna S, Kafai YB, Fields D & Jayathirtha G	Communicating computational concepts and practices within high school students’ portfolios of making electronic textiles	2020	*Interactive Learning Environments*	Atmatzidou S & Demetriadis S	Advancing students’ computational thinking skills through educational robotics: A study on age and gender relevant differences	2016	*Robotics and Autonomous Systems*
Finch L, Moreno C & Shapiro RB	Teacher and student enactments of a transdisciplinary art-science-computing unit	2020	*Instructional Science*	Sengupta P, Kinnebrew JS, Basu S, Biswas G & Clark D	Integrating computational thinking with K-12 science education using agent-based computation: A theoretical framework	2013	*Education and Information Technologies*
Le Y, Li Q & Guo R	融合式研究趋势下的地理信息教学体系探索 [Exploration of geographic information teaching system under the trend of integrated research]	2020	*Acta Geographica Sinica*	Yuen TT & Robbins KA	A qualitative study of students’ computational thinking skills in a data-driven computing class	2014	*ACM Transactions on Computing Education (TOCE)*
Burr W, Chevalier F, Collins C, Gibbs AL, Ng R & Wild CJ	Computational skills by stealth in introductory data science teaching	2021	*Teaching Statistics*	Basawapatna A	Alexander meets Michotte: A simulation tool based on pattern programming and phenomenology	2016	*Educational Technology & Society*
Park H, Kim HS & Park HW	A scientometric study of digital literacy, ICT literacy, information literacy, and media literacy	2021	*Journal of Data and Information Science*	Dolgopolovas V, Dagienė V, Minkevičius S & Sakalauskas L	Teaching scientific computing: A model-centered approach to pipeline and parallel programming with C	2015	*Scientific Programming*
Lee I, Grover S, Martin F, Pillai S & Malyn-Smith J	Computational thinking from a disciplinary perspective: Integrating computational thinking in K-12 science, technology, engineering, and mathematics education	2020	*Journal of Science Education and Technology*	Grover S, Pea R & Cooper S	Designing for deeper learning in a blended computer science course for middle school students	2015	*Computer Science Education*
Tsai MJ, Liang JC & Hsu CY	The Computational Thinking Scale for computer literacy education	2021	*Journal of Educational Computing Research*	Goodman AL & Dekhtyar A	Teaching bioinformatics in concert	2014	*PLoS Computational Biology*
Csapó G, Sebestyén K, Csernoch M & Abari K	Case study: Developing long-term knowledge with Sprego	2021	*Education and Information Technologies*	Weintrop D, Beheshti E, Horn M, Orton K, Jona	Defining computational thinking for mathematics and science classrooms	2016	*Journal of Science*

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				K, Trouille L & Wilensky U			*Education and Technology*
Testov VA & Perminov EA	РОЛЬ МАТЕМАТИКИ В ТРАНСДИСЦИПЛИНАРНОСТИ СОДЕРЖАНИЯ СОВРЕМЕННОГО ОБРАЗОВАНИЯ [The role of mathematics in transdisciplinarity content of modern education]	2021	*Obrazovanie i Nauka*	Dagiene V & Stupuriene G	Informatics concepts and computational thinking in K-12 education: A Lithuanian perspective	2016	*Journal of Information Processing*
Pierson AE & Brady CE	Expanding opportunities for systems thinking, conceptual learning, and participation through embodied and computational modeling	2020	*Systems*	Stefan MI, Gutlerner JL, Born RT & Springer M	The quantitative methods boot camp: Teaching quantitative thinking and computing skills to graduate students in the life sciences	2015	*PLoS Computational Biology*
Shin S, Cheon J & Shin S	Teachers' perceptions of first-year implementation of computer science curriculum in middle school: How we can support CS initiatives	2021	*Computers in the Schools*	Swaid SI	Bringing computational thinking to STEM education	2015	*Procedia Manufacturing*
En LK, Karpudewan M & Zaharudin R	Computational thinking in STEM education among matriculation science students	2021	*Asia Pacific Journal of Educators and Education*	Katai Z, Toth L & Adorjani AK	Multi-Sensory Informatics Education	2014	*Informatics in Education*
Abesadze S & Nozadze D	Make 21st century education: The importance of teaching programming in schools	2020	*International Journal of Learning and Teaching Mathematics*	Fenton JD	Hydraulics: Science, knowledge, and culture	2016	*Journal of Hydraulic Research*
Valovičová Ľ, Ondruška J, Zelenický Ľ, Chytrý V & Medová J	Enhancing computational thinking through interdisciplinary STEAM activities using tablets	2020		Yadav A, Mayfield C, Zhou N, Hambrusch S & Korb JT	Computational thinking in elementary and secondary teacher education	2014	*ACM Transactions on Computing Education (TOCE)*
Tang KY, Chou TL & Tsai CC	A content analysis of computational thinking research: An international publication trends and research typology	2020	*The Asia-Pacific Education Researcher*	Lamb R & Premo J	Computational modeling of teaching and learning through application of evolutionary algorithms	2015	*Computation*
Mirolo C, Izu C, Lonati V & Scapin E	Abstraction in computer science education: An overview	2021	*Informatics in Education*	Hagiya M	Defining Informatics across bun-kei and ri-kei	2015	*Journal of Information Processing*

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Pierson AE, Brady CE & Clark DB	Balancing the environment: Computational models as interactive participants in a STEM classroom	2020	*Journal of Science Education and Technology*	Shell DF & Soh LK	Profiles of motivated self-regulation in college computer science courses: Differences in major versus required non-major courses	2013	*Journal of Science Education and Technology*
Birney L & McNamara D	The curriculum and community enterprise for restoration science: Engaging marginalized students in STEM fields through data acquisition and computational thinking	2021	*Journal of Curriculum and Teaching*	Farris AV & Sengupta P	Democratizing children's computation: Learning computational science as aesthetic experience	2016	*Educational Theory*
Peel A, Sadler TD & Friedrichsen P	Using unplugged computational thinking to scaffold natural selection learning	2021	*The American Biology Teacher*	Blades NJ, Schaalje GB & Christensen WF	The second course in statistics: Design and analysis of experiments?	2015	*The American Statistician*
Fridberg M & Redfors A	Teachers' and children's use of words during early childhood STEM teaching supported by robotics	2024	*International Journal of Early Years Education*	Williamson B	Governing methods: Policy innovation labs, design and data science in the digital governance of education	2015	*Journal of Educational Administration and History*
Gopinath B & Santhi R	Development and evaluation of Fishbone-based advanced computational thinking (FACT) pedagogy: A teacher-student collaborative learning environment in engineering and science education	2021	*Higher Education for the Future*	Czerkawski BC & Lyman EW, III	Exploring issues about computational thinking in higher education	2015	*TechTrends*
Piedade J, Dorotea N, Pedro A & Matos JF	On teaching programming fundamentals and computational thinking with educational robotics: A didactic experience with pre-service teachers	2020	*Education Sciences*	Belcaid M & Toonen RJ	Demystifying computer science for molecular ecologists	2015	*Molecular Ecology*
Zha S, Morrow DAL, Curtis J & Mitchell S	Learning culture and computational thinking in a Spanish course: A development model	2021	*Journal of Educational Computing Research*	Chang CK	Effects of using Alice and Scratch in an introductory programming course for corrective instruction	2014	*Journal of Educational Computing Research*
Christensen D & Lombardi D	Understanding biological evolution through	2020	*Science & Education*	Korcsmaros T, Dunai ZA, Vellai T & Csermely P	Teaching the bioinformatics of signaling networks: An	2013	*Briefings in Bioinformatics*

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	computational thinking: A K-12 learning progression				integrated approach to facilitate multi-disciplinary learning		
Polanco Padrón N, Ferrer Planchart S & Fernández Reina M	Aproximación a una definición de pensamiento computacional [Approach to a definition of computational thinking]	2021	*RIED. Revista Iberoamericana de Educación a Distancia*	Makarevitch I, Frechette C & Wiatros N	Authentic research experience and "big data" analysis in the classroom: Maize response to abiotic stress	2015	*CBE—Life Sciences Education*
Kandemir CM, Kalelioğlu F & Gülbahar Y	Pedagogy of teaching introductory text-based programming in terms of computational thinking concepts and practices	2021	*Computer Applications in Engineering Education*	Fazarinc Z	Lagrange, Hamilton, Schrödinger, and computers	2014	*Computer Applications in Engineering Education*
Ketelhut DJ, Mills K, Hestness E, Cabrera L, Plane J & McGinnis JR	Teacher change following a professional development experience in integrating computational thinking into elementary science	2020	*Journal of Science Education and Technology*	Lin YT, Yeh MKC & Hsieh HL	Teaching computer programming to science majors by modelling	2021	*Computer Applications in Engineering Education*
Stone J & Cruz L	The wicked and the logical: Facilitating integrative learning among introductory computing students	2021	*Teaching and Learning Inquiry*	Lee I & Malyn-Smith J	Computational thinking integration patterns along the framework defining computational thinking from a disciplinary perspective	2020	*Journal of Science Education and Technology*
Mensan T, Osman K & Majid NAA	Development and validation of unplugged activity of computational thinking in science module to integrate computational thinking in primary science education	2020	*Science Education International*				