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Trends on Computational Thinking (CT) in Science Education Research (SER) (2015-2024): Bibliometrics and Content Analysis

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ABSTRACT This study examines research methods, target groups, technologies, pedagogies, and institutions and countries involved in CT research in the SER literature—using a bibliometric analysis of 137 articles identified in the SCIE and SSCI Web of Science (WoS) databases. A total of 120 articles were also subjected to content analysis. 17 articles were excluded from the content analysis because the full texts were not accessible. The results indicate that the studies focused on CT itself from 2015 to 2018. In contrast, from 2019 to 2020, CT was linked to computer science education, science education, teaching and learning strategies, and teacher education. However, CT has become the dominant topic, accompanied by the concept of assessment. From 2021 to 2022, the SARS-CoV-2 pandemic led to studies focusing on programming, assessment, computer science education, robotics, science education, and teacher education.

Keywords Bibliometrics analysis, Computational thinking, Content analysis, Science education

1. Introduction

In recent years, the use of technology in everyday life has increased, contributing to growing interest in computer science. The appropriate application of computer science and technology can facilitate the effective and efficient retrieval of information (Liu et al., 2007). To achieve effective access to information, it is not sufficient to be literate in information, media, computers, and technology (Kite & Park, 2022). Consequently, in the 21st century, the objective is to foster not only individuals who can solve problems but also individuals who can do so with the assistance of technology (Gülbahar et al., 2020). In accordance with this objective, the utilization of computers and technology in educational and training processes has increased considerably in recent years (Bocconi et al., 2022; Seckel et al., 2023). Given the pivotal role of computer science in contemporary educational systems, individuals must acquire fundamental computer skills at an early age, as these form the foundation of computer science (Barr et al., 2011; Barr & Stephenson, 2011). In recent years, the concept of computational thinking has come to the fore, enabling more effective use of these skills and the utilisation of different components to solve complex problems.

Complex problems can be effectively addressed through CT, which involves decomposing them into more manageable components, elucidating the interrelationships among these components, and formulating algorithms to address these interrelationships (Ketelhut et al., 2020). CT skills encompass problem-solving, productivity, collaboration, algorithmic thinking, and critical thinking (Barr & Stephenson, 2011). These skills have begun to be employed in several fields, including computer science, engineering, mathematics, and science. Computational thinking (CT) is a method of solving complex problems via principles from computer science and information technology. It involves the formulation of problems, their solution, and the reformulation of solutions via an information processing tool (Wing, 2006). The Computer Science Teachers Association (CSTA) and the International Society for Technology in Education (ISTE) define CT as a problem-solving process. Based on this definition, problems can be solved using computers, technology, and other similar tools. In addition, it enables the organisation, analysis, and presentation of data through models or simulations. Furthermore, it develops skills such

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as using algorithmic thinking more effectively to solve problems, identifying the best solutions, analysing and applying them, and adapting solutions (ISTE & CSTA, 2011).

In addition to these skills, another important element of CT is the ability to identify overlooked details when solving complex problems (Denning & Martell, 2015). This feature helps individuals and organisations solve problems effectively and efficiently (Resnick & Robinson, 2017). Furthermore, in the contemporary era, where technology is advancing rapidly, it is proving to be an effective tool across a multitude of domains, with increasing prevalence in education. The benefits of CT extend beyond the development of analytical abilities; it also enhances reading, writing, and arithmetic skills in education (Bundy, 2007; Gretter & Yadav, 2016; Sands et al., 2018).

Given that computational skills are aligned with 21st-century competencies such as creativity, critical thinking, and problem solving, and are reflected in the US Next-Generation Science Standards, there is a consensus that they should be integrated into educational processes (Barr et al., 2011; Barr & Stephenson, 2011; Kite & Park, 2022). A review of the literature reveals that the CT skills of students are associated with a range of abilities, including problem solving and ideation (Román-González, Pérez-González, & Jiménez-Fernández, 2017), algorithmic thinking (Choi, Lee, & Lee, 2016), critical thinking, creative thinking, collaborative learning, and communication skills (ISTE, 2016). Moreover, studies have indicated that the development of CT skills is related to the teaching of mathematics and science courses (Calder, 2010; Lai & Lai, 2012).

In conclusion, CT skills are essential not only for computer science courses but also for all scientific disciplines. These skills encompass fundamental processes such as reasoning, abstraction, data processing, problem solving, and algorithm design. It is a cognitive ability that facilitates project-based pedagogical approaches, particularly in mathematics and science disciplines where interdisciplinary strategies are employed (Jaipal-Jamani & Angeli, 2017). The science course covers the life sciences, earth and space sciences, engineering, technology, and science applications. In this context, CT skills, including problem-solving and enquiry skills, are important for effective science teaching. Weinberg (2013) states that CT skills can be acquired through alternative means, such as block-based teaching applications, educational games, or physical programming approaches, without the use of computers. In this process, the acquisition of concepts is typically structured around a scenario, with a clear objective in mind. Accordingly, a problem to be solved may be either a relatively simple one or a project comprising several discrete problems. In addressing the aforementioned problems, students are expected to utilize the processes, concepts, and information pertinent to the field of informatics.

CT in SER is important for helping students think through problems they encounter, design technology-based solutions, arrive at innovative ones, and think critically and creatively. In addition, the study highlights trends over the last 10 years in the topics studied, countries, journals, and organizations for researchers studying CT in SER. Unlike bibliometric analyses based on metadata from databases, this study was enhanced by content analysis of published papers. The content analysis provides further information about the papers' content. Moreover, the keyword analyses are performed under three different categories in the context of target groups, pedagogies, and technologies, whereas other studies are performed as a whole. Finally, these three categories are also divided into three subcategories: common, emerging, and missing keywords.

Bibliometric analyses are based on metadata gathered from Web of Science (WoS), SCOPUS, etc., and report on research trends according to country, prolific authors, publication year, topic, language, etc. Therefore, bibliometric analyses are limited to the metadata provided by the databases. In this study, however, we have included a content analysis component based on the full papers identified. Consequently, the trend analysis results we provide are in-depth. In this context, identifying missing topics is expected to guide researchers in future bibliometric analysis studies.

Given its growing significance in recent years, CT has also begun to be employed in SER. A literature review has revealed that bibliometric analyses in the field of science education research over the past decade have focused on specific topics. This study aims to examine the research methods employed, the target groups studied, the technologies and pedagogies utilized, the institutions involved, and the countries in which research on CT in the SER literature was published. In this context, the following questions were posed in the study:

RQ1. How is the distribution of articles on CT published in the SER by year?

RQ2. What are the frequently used keywords on CT papers published in the SER?

RQ3. Who are the most prolific researchers on CT papers published in the SER?

RQ4. Which countries, journals, and institutions are most prolific in publishing CT papers in the SER?

RQ5. What are the most frequently cited publications on CT published in the SER?

RQ6. Which technologies and pedagogies, target groups, research designs, data collection tools, and analysis methods are most commonly utilized in CT papers published in the SER?

2. METHOD

This study employs bibliometric analysis. The term "bibliometric" refers to the application of statistical methods to analyse bibliometric data on publications such as peer-reviewed journal articles, books, conference proceedings, reports, and related documents (Aria & Cuccurullo, 2017; Donthu et al., 2021). A bibliometric analysis is a quantitative analysis of scientific literature based on metrics such as evolution over time, citation counts, keywords, and the most prolific authors. Moreover, this analysis is a quantitative method for examining the structure of knowledge and the development of research fields by analyzing relevant publications (Aria & Cuccurullo, 2017; Donthu et al., 2021).

2.1 Data for the Bibliometric Analysis

During data collection, the terms "computational thinking," "teaching," and "science education" were identified as key terms. An online search was conducted on September 18, 2024, using the Web of Science (WoS) database. Web of Science was used because it indexes high-impact, peer-reviewed journals that adhere to strict quality criteria, providing reliable citation tracking and strengthening the academic rigour of the study. The search query was entered into the "topic" field. The search was limited to the Social Science Citation Index (SSCI) and the Science Citation Index Expanded (SCIE), as defined by the WoS Categories. The search yielded 137 articles and review articles on the topic of "education and educational research" published between January 1, 2015, and September 18, 2024. The analytical tools employed in this study include RStudio, the Biblioshiny© web application (version 4.3.1), and VOSviewer© software (version 1.6.20).

A bibliometric analysis was conducted on 137 articles retrieved from the WoS database, and a content analysis was performed on 120 of these articles for which the full text was accessible. 17 articles were excluded from the content analysis because their full texts were not accessible. However, they were all included in the bibliometric analysis, as the metadata were accessible via WoS.

Data for the Content Analysis

The content analysis of the 120 articles was conducted using a review form in Google Docs. The articles were then reviewed and analyzed using this form. Figure 1 shows the steps relating to the bibliometric and content analyses.

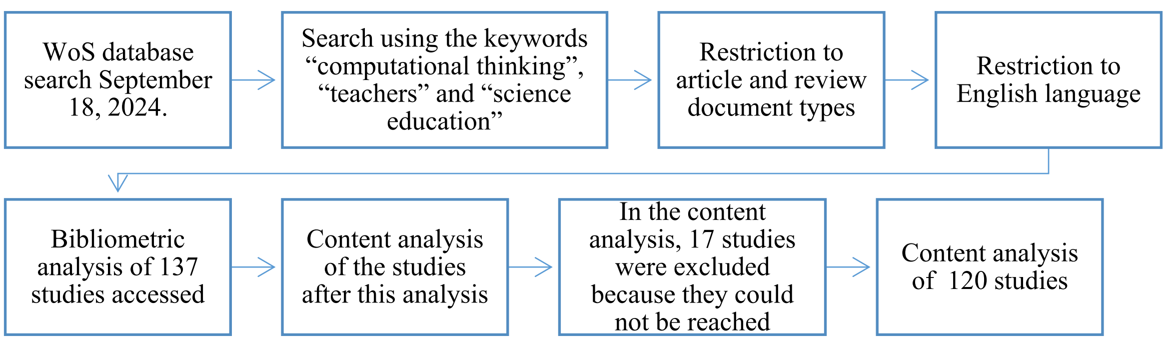


Figure 1 Data retrieval and analysis process

A total of 137 articles related to CT in SER were retrieved from WoS between 2015 and 2024. Figure 2 illustrates the demographic characteristics of the retrieved articles.

Figure 2 Demographic characteristics of the CT articles on SER

3. RESULT AND DISCUSSION

This section presents the results of the bibliometric and content analyses. The bibliometric analysis of CT articles in SER studies revealed trends in author keywords, countries, journals, universities, and authors. The content analysis identified technology, target groups, pedagogies, research methods, data collection tools, and analyses related to CT articles in SER.

3.1 Bibliometric Analysis

This study presents a comprehensive analysis of the publication and citation trends of CT articles in SER studies from 2015 to 2024. Figure 3 illustrates the number of published CT articles in SER studies over the study period. In general, the number of CT articles included in SER studies has gradually increased over time. However, a minor decline in the number of articles has been observed since 2022.

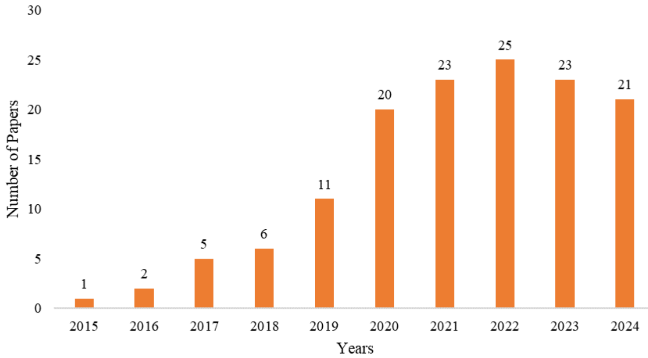


Figure 3 Number of CT articles on SER by year (2015-2024)

As illustrated in Figure 4, the most frequently utilized author keywords were computer science education, computer science, teacher education, programming, and robotics. The author keywords were classified into three principal categories: technology, pedagogy, and target groups. The network maps of these groups are also presented in Figures 3 and 4 and Table 1. The table illustrates the prevalence of common, emerging, and absent topics across the three groups. This three-way grouping of topics was done based on the color scale that emerged in the bibliometric analysis by year. The blue and purple colors represent common topics, while the yellow color represents emerging topics in recent years. Missing topics are those that have not been studied and will become more important in the future. This color scale is shown in Figure 4. The absence of certain topics is determined in accordance with the extant literature on technology education (UNESCO, 2023).

The most frequently discussed topics are programming, simulation, block-based coding, and game design. In recent years, there has been a notable increase in the number of studies focusing on Arduino and robotics. Conversely, subjects such as artificial intelligence, m-learning, augmented reality, virtual reality, smart technologies, and e-learning were identified as absent from the CT studies in SER, despite their prevalence in general technology education studies (see Table 1 and Figure 4).

Table 1 List of author keywords grouped as common, emerging, and missing topics

Aspects	Common Topics	Emerging Topics	Missing Topics
Technology	Programming, simulation, block-based coding, game design	Robots, Arduino	Artificial intelligence, m-learning, augmented reality, virtual reality, smart technologies, e-learning
Pedagogy	Project-based learning, computational modelling, problem solving	TPACK, design thinking, system thinking, integrated STEM	Flipped classroom, learning cycle, design-based learning
Target Group	Preservice teachers, elementary school	Teachers, middle school	Preschool, high school and graduate school

Common topics in pedagogy include project-based learning, computational modelling, and problem-solving. In recent years, however, there has been a shift in focus towards emerging topics, including TPACK, design thinking, system thinking, and integrated STEM. Conversely, subjects such as the flipped classroom, learning cycle, and design-based learning were identified as absent from the discourse on CT studies in SER, despite their prevalence in general pedagogy studies (see Table 1 and Figure 4).

The common topics are preservice teachers and elementary schools, whereas the emerging topics studied in recent years are teachers and middle schools. On the other hand, topics such as preschool, high school, and graduate school were considered missing, as they are common among the target group but not observed in CT studies in SER (see Table 1 and Figure 4).

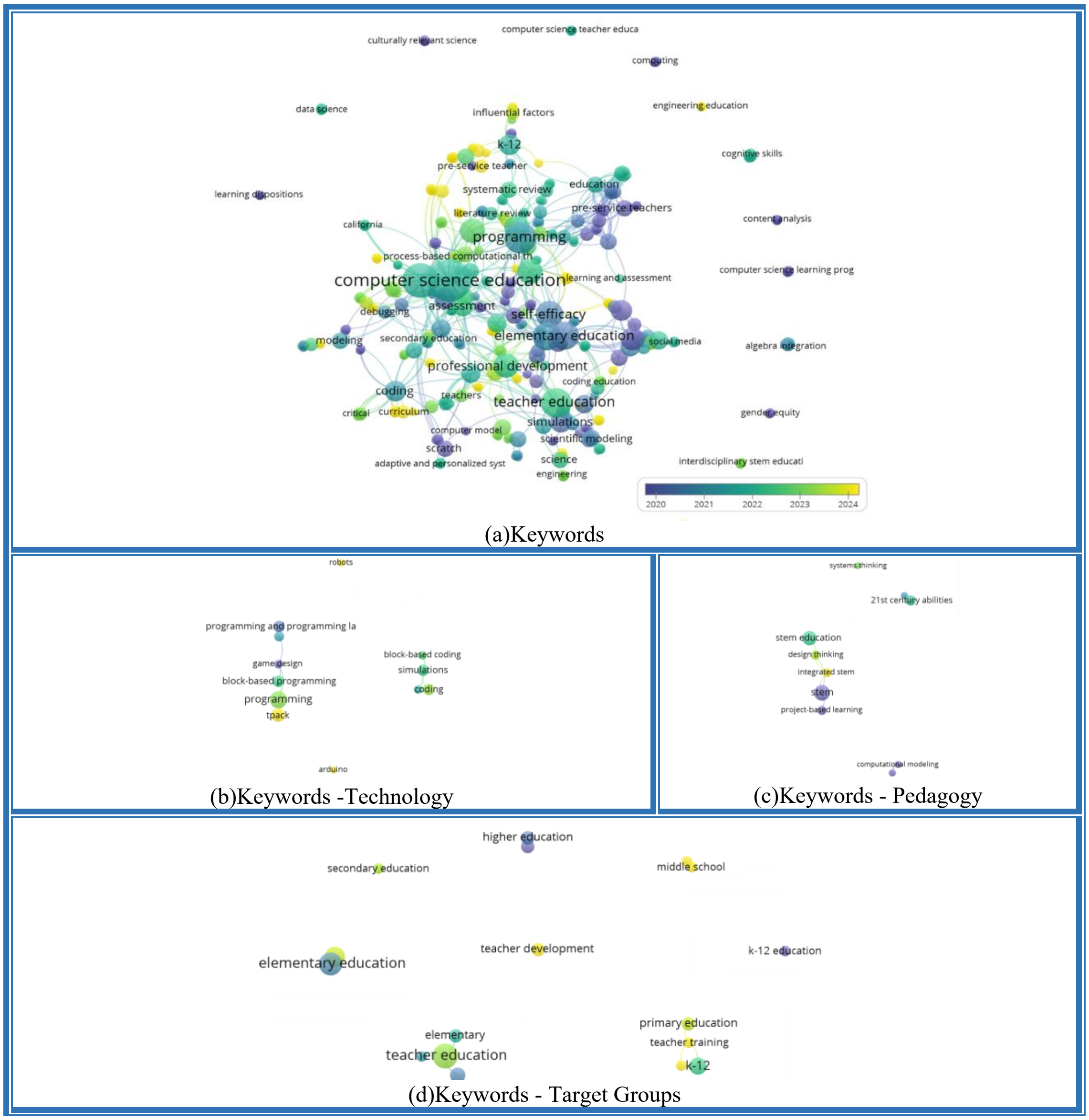


Figure 4 Keywords most frequently used to CT in the SER by authors (2015-2024)

Figure 5 shows that, between 2019 and 2020, the concept of CT was used alongside the concepts of 'computer science education', 'science education', 'teaching/learning strategies' and 'teacher education'. Between 2021 and 2022, it was used alongside the concept of 'assessment', and between 2023 and 2024, it was used alongside the concepts of 'programming, assessment, computer science education, robots, and teacher education'.

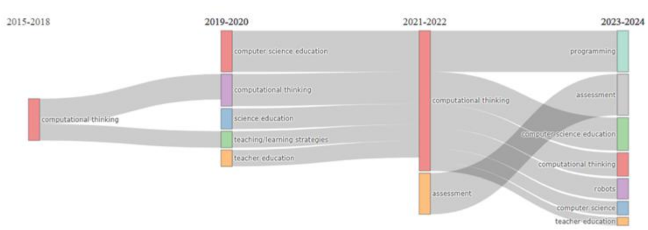
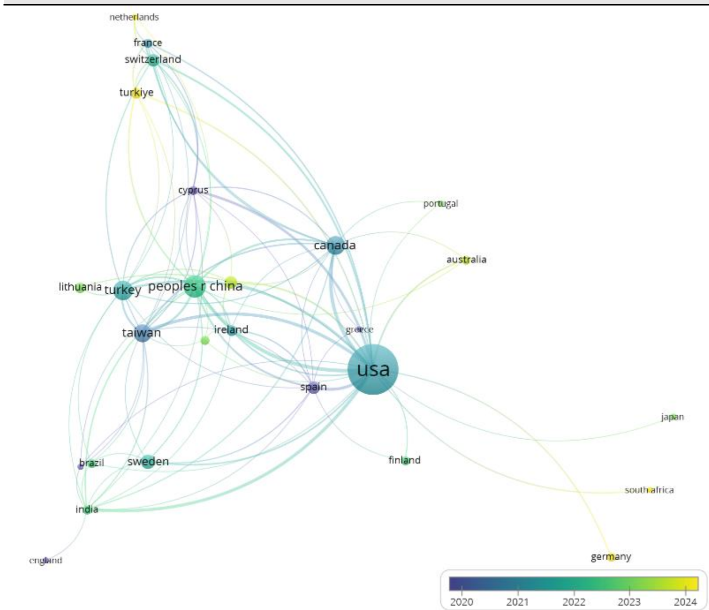


Figure 5 Thematic evolution of CT in the SER by year

A total of 32 countries have contributed to CT articles in the SER literature over the last five years. The top 20 most productive countries are shown in Table 2. With a total of 64 publications, the USA has the highest number of papers published. Türkiye and China are the second most prolific countries, with 13 publications. Canada is the third with nine publications, followed by Taiwan with eight publications. However, the country with the highest number of average citations per paper is Spain with 118 average citations per paper Cyprus is second with 69 average citations per paper followed by Taiwan, with 61 average citations per paper.

Table 2 The top 20 most productive countries and the CT articles of the mapping network in the SER

Mapping Network	Country	Documents	Citations	Citations per Paper
	USA	64	1800	28
	China	13	472	36
	Türkiye	13	126	10
	Canada	9	202	22
	Taiwan	8	491	61
	Sweden	5	56	11
	Spain	4	473	118
	Switzerland	4	42	11
	Norway	4	23	6
	Ireland	3	55	18
	Lithuania	3	11	4
	India	2	4	2
	Cyprus	2	137	69
	France	2	38	19
	Australia	2	3	2
	Brazil	2	3	2
	Israel	2	11	6
	Finland	2	24	12
	Germany	2	5	3
	Mexico	1	36	36

The analysis revealed that these papers were published in 42 different journals. Table 3 and Figure 6 show the top 20 journals in which the CT articles in the SER papers were published. While the journal Education and Information Technologies have the highest number of papers published (19 documents), the most cited journal is Computers & Education, with an average of 114 citations per paper.

Table 3 Citations of journal publishing CT articles in SER (2015-2024)

Journals	Documents	Citations	Citations per paper
Education and Information Technologies	19	244	13
Computers & Education	14	1601	114
Journal of Science Education and Technology	13	342	26
ACM Transactions on Computing Education	9	184	20
ETR&D-Educational Technology Research and Development	7	91	13
Interactive Learning Environments	7	67	10
Journal of Research in Science Teaching	5	102	20
British Journal of Educational Technology	4	66	17
International Journal of Technology A..	4	28	7
Journal of Research on Technology in Education	4	23	6
Journal of Educational Computing Research	4	80	20
Computer Applications in Engineering Education	3	53	18
Journal of Computer Assisted Learning	3	5	2
IEEE Transactions on Education	3	25	8
Asia-Pacific Education Researcher	3	69	23
Instructional Science	2	52	26
International Journal of STEM Education	2	22	11
Teaching and Teacher Education	2	2	1
Thinking Skills and Creativity	2	13	7
Early Childhood Education Journal	2	24	12

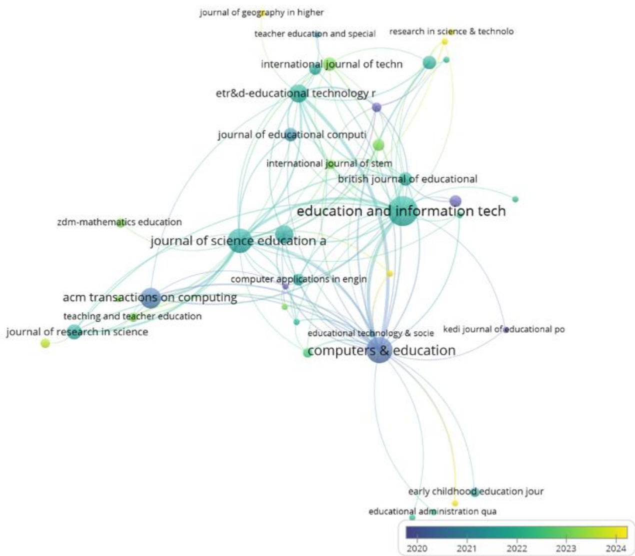


Figure 6 Journal network visualization on CT articles in SER (2015-2024)

The total number of organizations/ universities on CT Articles in SER was 190. Figure 7 and Table 4 show that the university with the most citations to CT is the University of Illinois, whereas the university with the most average citations per paper is Northeastern Illinois University.

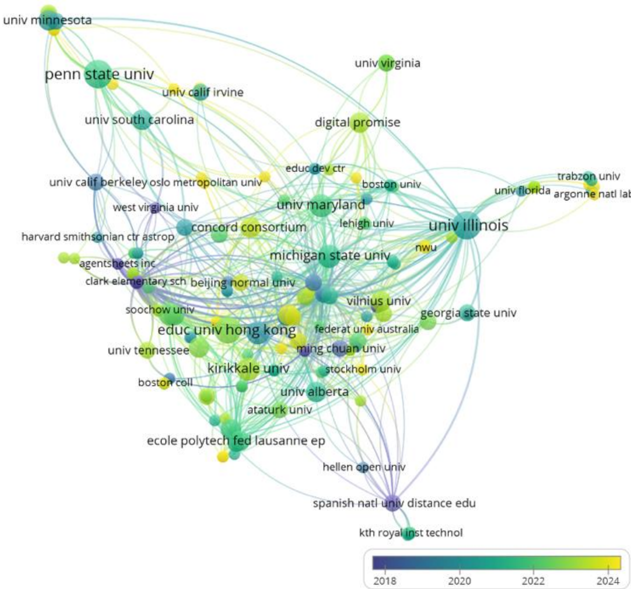


Figure 7 Citations of university network visualization on CT articles in SER (2015-2024)

Table 4 Citations of Universities on CT articles in SER (2015-2024)

University	Documents	Citations	Citations per year
University Illinois	6	488	81
Penn State University	6	49	8
Education University Hong Kong	5	142	28
Michigan State University	4	342	86
National Taiwan Normal University	4	413	103
National Taiwan University Science & Tech	4	110	28
University Maryland	4	85	21
Kırıkkale University	4	33	8
University Teacher Education	3	41	14
Ecole Polytech Fed Lausanne EPFL	3	39	13
Fu Jen Catholic University	3	91	30
Concord Consortium	3	56	19
University Alberta	3	44	15
Digital Promise	3	9	3
Minzu University China	3	10	3
University South Carolina	3	21	7
North Carolina State University	3	13	4
Vilnius University	3	11	4
University Minnesota	3	73	24
NE Illinois University	2	338	169

Based on an analysis of 137 articles, the total number of authors was 405. Table 5 shows the most prolific authors by the number of CT articles in SER. Table 5 shows the top 20 authors with the highest number of average citations per document. Among them, Hsu (2018), Tang (2020a), and Saez-Lopez (2016) are the first to be cited per paper, followed by Chen (2017), Israel (2015), and Bers (2019).

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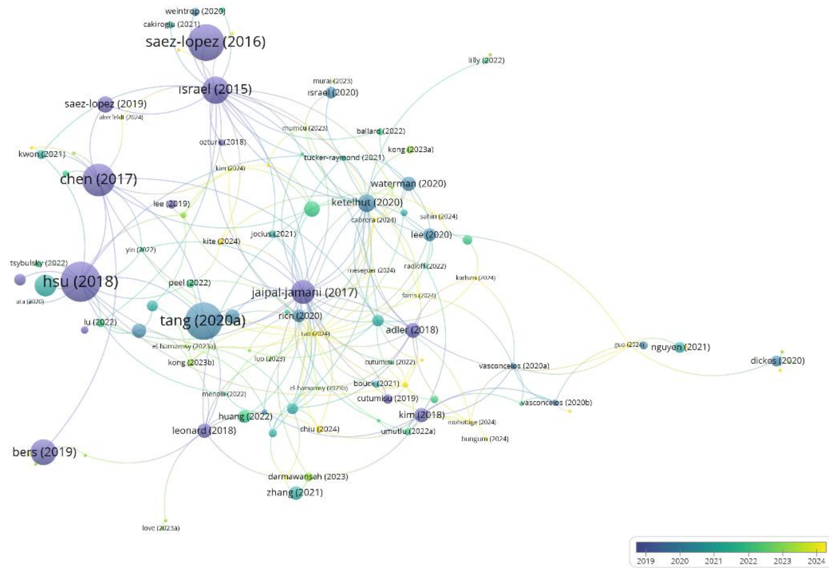
Table 5 Highly Productive network visualization of the top 20 authors and authors (2015-2024)

Author	Citation	Network Visualization
Hsu (2018)	331	
Tang (2020a)	287	
Saez-Lopez (2016)	276	
Chen (2017)	224	
Israel (2015)	154	
Bers (2019)	140	
Jaipal-Jamani (2017)	115	
Repenning (2015)	102	
Wei (2021)	97	
Ketelhut (2020)	67	
Brown (2017)	62	
Saez-Lopez (2019)	56	
Wang (2022)	52	
Adler (2018)	46	
Leonard (2018)	45	
Waterman (2020)	44	
Tang (2020b)	44	
Kim (2018)	43	
Lyon (2020)	42	
Zhang (2021)	40	

3.2 Content Analysis

This section presents the findings related to the content analysis. These are the findings related to technology, pedagogy, the target group, research methods, data collection tools, and data analysis.

As illustrated in Figure 8, the technologies associated with CT articles in SER are indicative of the current state of the field. It is evident that the technologies employed in 64 CT articles in SER remain "Not defined". Figure 8 shows that the most commonly used topics grouped under technologies are coding or programming (f=28 articles).

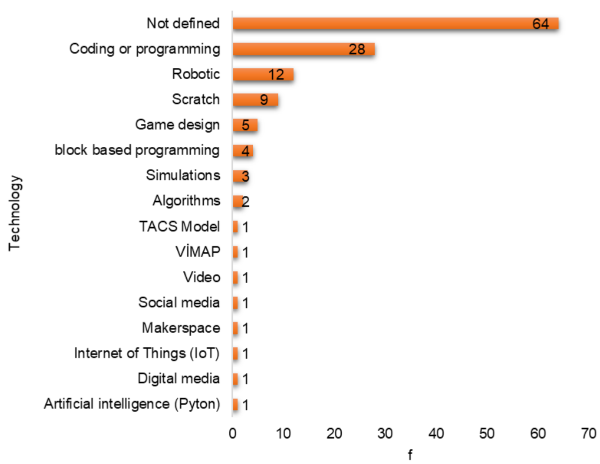


Figure 8 Technologies used on CT papers in SER

Figure 9 shows the pedagogies used for the CT articles in SER. The STEM approach was the most commonly observed pedagogy in 41 CT articles in SER.

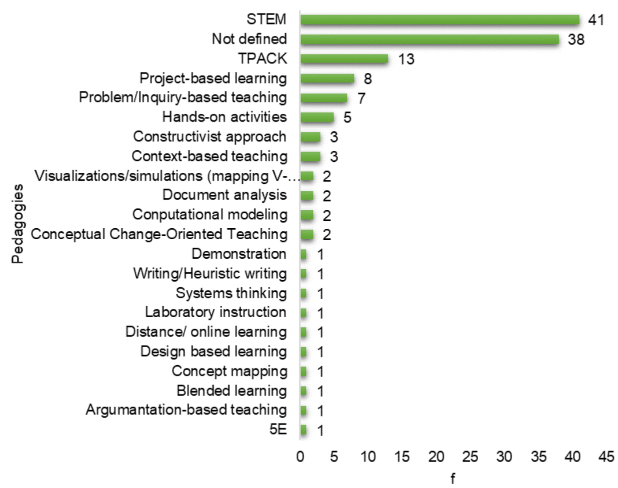


Figure 9 Pedagogies used on CT papers in SER

Figure 10 shows the target groups of CT articles in SER, and Figure 11 shows the sample sizes. Although educators are the most frequently studied target group, 49 articles focus on educators, and the most frequently studied sample size is between 11 and 50, with 38 articles.

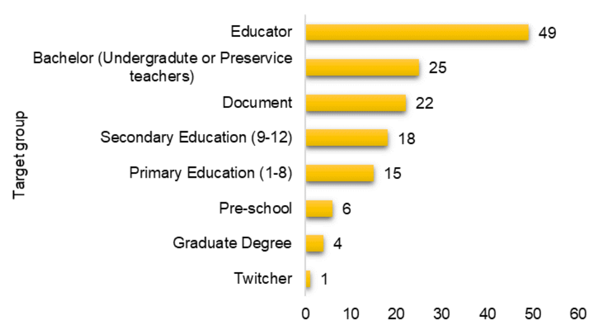


Figure 10 Target group of CT articles in SER

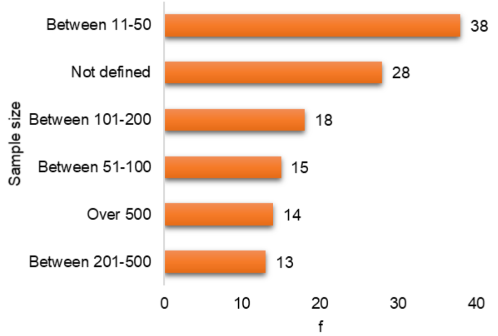


Figure 11 Sample size of CT articles in SER

Figure 12 shows the research design of the CT articles in SER. The most commonly used research design is case studies (25 articles), followed by document analysis (18 articles).

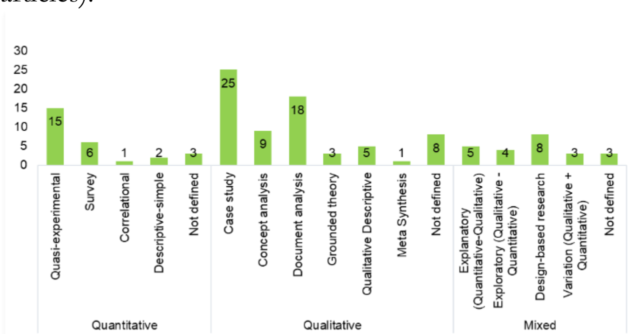


Figure 12 Research designs of CT articles in SER

Figure 13 shows the data collection tools, and Figure 14 shows the data analysis of the CT articles in SER. While the most studied data collection tool is interviews (39 articles), the most studied data analysis method is content analysis (84 articles).

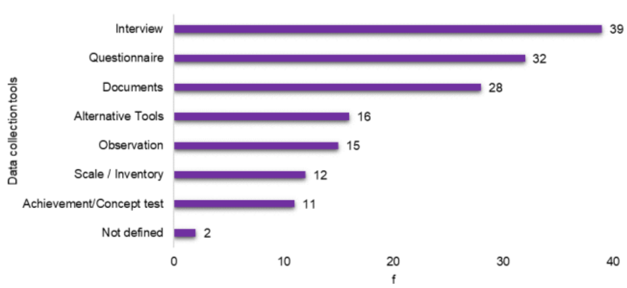


Figure 13 Data collection tools of CT articles in SER

Science education is a multifaceted research area in terms of its content, including information related to daily life and spanning more than one field. Many studies have been conducted on science education to date, both to address problems encountered in science education and related fields and to support countries' efforts to raise more qualified citizens. New studies are being added to these efforts every day (Weinberg, 2013).

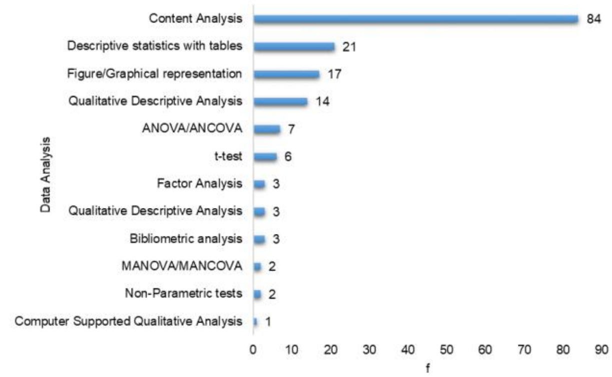


Figure 14 Data analysis of CT articles in SER

While there was only one publication in 2015, this number increased to 21 in 2024. It can be assumed that the use of CT skills in SER in recent years, owing to the increasing trend towards computer science and technology, has led to an increase in the number of studies. However, while the number of publications continued to increase from 2015 to 2022, a slight decrease was observed in the following years. Figure 3 shows a visible increase, especially during the COVID-19 period, between 2020 and 2022. Given the emphasis on technology in education, it is expected that the number of studies in this field has increased in recent years (Kite & Park, 2022).

The author has divided the keywords into three groups: technology, pedagogy, and target groups. The keyword "technology" has mainly referred to programming, drawing, simulation, and coding in previous years. However, due to changing educational practices and the rise of computational skills in recent years, the topics examined are artificial intelligence, Python, Arduino, and algorithms. In addition, topics such as m-learning, augmented reality, virtual reality, smart technologies, and e-learning are included (UNESCO, 2023). They are common in educational studies, yet are missing from the SER literature. The common topics in the second group are "pedagogy," project-based learning, computational modelling, and problem-solving, while topics such as TPACK (the interaction between technology, pedagogy, and content), digital education, and integrated STEM are emerging. However, topics such as the flipped classroom, the learning cycle, and design-based learning are not studied in CT papers in the SER literature. It has been observed that the common topics among the third group of "target group" preservice teachers and elementary schools differ from those studied in recent years, which have focused on teachers and middle schools. However, topics such as secondary school, preschool, high school, and graduate school were not prevalent. Figure 4 also shows that between 2015 and 2018, the studies focused only on the concept of CT. From 2019 to 2020, a variety of topics, such as computer science education, science education, teaching/learning strategies, and teacher education, became visible alongside CT. However, this trend has not lasted long, and CT has become the dominant topic, supported by the assessment concept, from 2021 to 2022, which is known as the COVID-19 pandemic. In 2023--2024, topics such as programming, assessment, computer science education, robots, science education, and teacher education were addressed alongside the CT topic. This may be due to the extensive integration of technology into chemistry education during and following the COVID-19 pandemic (Ketelhut et al., 2020).

In terms of country trends, the United States ranks first in terms of the number of publications and citations. Türkiye and China rank second. However, Spain ranks first in terms of the number of citations per publication. The analysis by country reveals that publications are concentrated in the United States and Europe (Kite & Park, 2022).

The content analysis results indicate that the technology used in 64 publications is not reported, and that coding and programming are the most common technologies used in CT papers in SER. In addition, robotics and Scratch are used in 12 and 9 publications, respectively. Moreover, in the pedagogy category, STEM is the most preferred, with 41 publications. Regarding the working group, the studies focus on teachers and teacher candidates, but those with teachers rank first with 49 articles, while those with teacher candidates rank second with 25 articles. In today's educational world, it is reasonable to consider computational thinking skills necessary for the professional development of teachers and the training of teacher candidates. It is important to integrate computational thinking skills into education.

Among the research designs used in CT articles published in the SER literature, case studies are the most frequent, followed by document analysis. Qualitative designs are more likely to identify gaps in the literature. Of the publications examined, 61 used qualitative designs, suggesting that the interview technique was preferred because it provides more detailed information for educational research. For this reason, content analysis is also considered a preferred method.

4. CONCLUSION

The results of the study show that programming, Scratch, simulation, and coding technologies are the most frequently cited in CT-related publications. However, technologies such as m-learning, augmented reality, virtual reality, smart technologies, and e-learning are frequently used in science education. However, these methods are lacking in CT studies. Future research should extend SER studies to cover these technologies. The results indicate that project-based learning, computational modelling and problem-solving, TPACK, digital education, and integrated STEM are extensively used in current studies. In contrast, CT studies lack a flipped classroom, a learning cycle, and design-based learning, which have recently been the subject of much SER research. Further studies in these areas will undoubtedly extend the current literature.

Preservice teachers, teachers, and primary and secondary school students are frequently studied samples. Future studies should include preschool, high school, and tertiary students to extend the use of CT in science education across all academic levels. Furthermore, North America and Europe are the dominant regions in this field of study. In future research, it is essential to include a diverse range of countries in the analysis and to conduct comparative studies on the use of CT in science education. Qualitative research methods are commonly employed. However, given that qualitative studies often utilize small sample sizes, it is crucial to recommend more quantitative studies with larger sample sizes to ensure more generalizable results in future research.

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