An Examination of Articles on Critical Thinking in Science Education: An Analysis Using Bibliometric Mapping

Fen Eğitiminde Eleştirel Düşünme Konulu Makalelerin İncelenmesi: Bir Bibliyometrik Haritalama Analizi

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ABSTRACT

Critical thinking (CT) is a high-level thinking skill that should be gained in raising individuals who can analyze facts, make independent decisions, make comparisons, and make inferences. On the other hand, these varying states require the inclusion of new acquisitions, such as CT, as the focal point of education. This skill is critical in science education (SE) and has been the subject of many studies. The research examined the articles published on critical thinking in SE using bibliometric mapping analysis. It is crucial to guide researchers by revealing research trends in this field. In the research, 377 articles in SSCI, SCI-Expanded, A&HCI and ESCI indexes related to critical thinking in science education were examined and the last access date is June 2023.The results obtained from the analysis demonstrated that the studies on CT in SE tended to decrease when the distribution of years was examined; the studies focused on STEM and undergraduate education. It has been determined that the country with the most publications in this field is the USA, and the institution with the most references is the State University of New York Suny System. Finally, it was seen that the most cited author was Chang, Shao-Chen, and the journal was Journal of Research in Science Teaching. The results obtained from the research will guide future research since they reveal the current situation in examining the concept of CT in SE.

Keywords: *Bibliometric analysis, critical thinking, science education*

ÖZ

Eleştirel düşünme (ED), olguları analiz edebilen, bağımsız karar verebilen, karşılaştırma yapabilen ve çıkarımlarda bulunabilen bireylerin yetiştirilmesinde kazandırılması gereken üst düzey bir düşünme becerisidir. Öte yandan bu değişen durumlar, eğitimin odak noktası olarak ED gibi yeni becerilerin dâhil edilmesini gerektirmektedir. Bu beceri fen eğitiminde (FE) kritik öneme sahiptir ve birçok araştırmaya konu olmuştur. Araştırmada, fen eğitiminde eleştirel düşünme üzerine yayımlanan makaleler bibliyometrik haritalama analizi kullanılarak incelenmiştir. Bu alandaki araştırma eğilimlerini ortaya koyarak araştırmacılara yol göstermesi açısından önemlidir. Araştırmada fen eğitiminde eleştirel düşünme ile ilgili SSCI, SCI-Expanded, A&HCI ve ESCI indekslerinde yer alan 377 makale incelenmiştir (Son erişim tarihi, Haziran 2023). Analizden elde edilen sonuçlar, fen eğitiminde eleştirel düşünme ile ilgili çalışmaların yıllara göre dağılımı incelendiğinde azalma eğiliminde olduğunu, çalışmaların STEM ve lisans eğitimi üzerine yoğunlaştığını göstermiştir. Bu alanda en çok yayın yapılan ülkenin ABD, en çok atıf yapılan kurumun ise State University of New York Suny System olduğu tespit edilmiştir. Son olarak en çok atıf alan yazarın Chang, Shao-Chen, derginin ise Journal of Research in Science Teaching olduğu görülmüştür. Araştırmadan elde edilen sonuçlar, FE'de ED kavramının incelenmesinde mevcut durumu ortaya koyması nedeniyle gelecekteki araştırmalara yol gösterecektir.

Anahtar Kelimeler*: Bibliyometrik analiz, eleştirel düşünme, fen eğitimi*

INTRODUCTION

Human beings, distinct from other living organisms, engage in the cognitive process of utilizing symbols to represent their environment and solving problems through thinking. This concept spans across philosophy, psychology, sociology, and logic (Batur & Özcan, 2020). As society transitioned into the information age, the emphasis on cultivating effective thinking skills became crucial (Huitt, 1995). In the 21st century, technological advancements have made problem-solving, creativity, and critical thinking (CT) indispensable due to the rapid knowledge production and dissemination (Kestel, 2022). Consequently, the changing landscape necessitates the incorporation of CT as a focal point in education (Huitt, 1998). CT, a fundamental skill of this era, is indispensable for adapting to our current society (Schafersman, 1995) and is highlighted in SE curricula of various countries (NAE & NRC, 2009; NRC, 2012). The SE Curriculum (2018) aims to educate individuals with qualities such as wisdom generation, practical life application, problem-solving, CT, entrepreneurship, influence,

communication, empathy, and contributions to society and culture (MoNE, 2018). As a result, countries are observed updating their education programs to foster students with advanced thinking abilities like CE.

Furthermore, in a summit organized by the OECD on the teaching profession, it is evident that problem-solving, creativity, and CT are among the cognitive competencies that students attending primary and secondary school need to possess when starting their professional careers (Schleicher, 2016). The behaviors expected from individuals today, which include 21st-century skills, a tendency towards universal citizenship, overcoming challenges in life, and achieving high success in actions taken, highlight the importance of teaching CT due to its benefits (Yeşilyurt, 2021). Schools should play a facilitating role in developing critical abilities in all dimensions among teachers and students and encourage their growth (Malamitsa et al., 2008). Once students develop these habits, they will gain mastery over the timing, content, and manner of their thoughts (Osborne et al., 2009, p. 47). Therefore, significant efforts should be made in the educational process, both in terms of instruction and in students' acquisition and use of CT skills, to apply them effectively in educational and everyday life contexts.

CT is a cognitive and philosophical-based process in the relevant literature (Facione, 2007; Paul, 1995). To cultivate individuals capable of analyzing facts, making independent decisions, and drawing inferences, the development of high-level thinking skills is essential (Altuntas et al., 2018). CT, which requires high-level competencies such as problem-solving, decision-making, drawing conclusions, analyzing, interpreting, and evaluating, has been defined in various ways. According to Bloom (1956), one of these definitions, CT, often refers to higher-level cognitive abilities such as analysis, synthesis, and evaluation. Ennis (1987) defines CT as using thinking skills and self-expression habits.

However, Chance (1986) defines CT as the capacity to analyze elements, generate ideas, organize thoughts, defend positions, make comparisons, assess arguments, and resolve problems. Another definition states that CT is analyzing subjects using reasoning, scientific, and analytical methods, collecting and evaluating evidence, discussing, accessing unbiased information, and reaching a conclusion (Fahim & Eslamdoost, 2014). As per Cüceloglu's perspective (1995), CT involves an active and systematic mental process that seeks to comprehend ourselves and the world around us. This process entails being aware of our own thinking, considering the thought processes of others, and applying acquired knowledge. CT involves examining previous experiences, knowledge, and thoughts, evaluating different

perspectives, and reaching a balanced judgment, looking at a subject or event logically and rationally (Nosich, 2018). It is also defined as the process of making objective judgments based on a particular criterion, aiming to identify virtues, truths, errors, and fallacies (Kestel & Sahin, 2018), defining something well and judging its quality (Beyer, 1995), and evaluating the reality and value of an event based on well-founded judgments and specific standards (Onal, 2020).

İlkörücü et al. (2022) assert that CT, which relies on reasoning and inquiry, is a type of thinking that should be introduced and nurtured from early childhood education onward. While thinking is a natural ability inherent in human nature, it requires guidance from teachers, especially for its development (Choy & Cheah, 2009). According to Kuhn (1999), educators should establish learning environments that foster the growth of students' CT abilities and establish suitable objectives for enhancing these skills. Ennis (1993) emphasizes that the teacher is crucial in teaching CT skills. The worldwide focus on cultivating children's CT skills has emerged as a vital educational objective, as it contributes to fostering qualities such as democracy and personal development (Beyer, 1987; Facione, 1992). All individuals, especially children, need to be able to critically evaluate information to discern which rapidly accessible information is reliable (Lone, 2017). CT is necessary for other thinking skills, such as creative thinking, problem-solving, and decision-making (Ennis, 1985; Sternberg, 1985). The CT skill that takes shape from the preschool years onwards develops children's communication skills, helps them recognize biases and errors, gives them a free perspective, enhances their ability for different thinking, opens the way for creative thinking, brings out their potential, and makes them good problem solvers (Florea & Hurjui, 2015).

The literature on CT in educational settings comprises numerous studies, leading to an increased number of analysis studies in this domain. For instance, Orhan (2022) conducted a meta-analysis study revealing a moderate relationship between CT and academic achievement. This study indicated that the effect size remained consistent across CT subgroups based on type, school level, and publication type but varied concerning region, discipline, and type of result. Similarly, in another meta-analysis study by Kestel (2022), the effect size of the examined studies was found to be "strong." Fong et al. (2022) explored the relationship between university students' academic achievement and CT skills, revealing a moderate and positive association between the two. In contrast, a study by Richardson et al. (2016) found a small yet significant and positive correlation between university students' academic achievement and CT skills.

CT is an indispensable skill, particularly in the context of science lessons. According to NRC (1996), SE aims to foster CT skills, including offering alternative explanations, analyzing

secondary sources alongside primary facts, testing the reliability of knowledge, and selecting the best explanations or models based on scientific understanding.

The significance of CT in SE has gained widespread recognition (Bailin, 2002), as it is considered an essential skill for success in various social and professional contexts (Duran & Şendağ, 2012; Facione, 2000; ITEEA, 2020). Consequently, educational institutions should prioritize the teaching, application, and enhancement of CT abilities (Aizikovitsh-udi & Cheng, 2015; Kezer & Turker, 2012). On a global scale, the Organisation for Economic Co-operation and Development (OECD) emphasizes CT as a crucial skill for the future and anticipates its inclusion as a learning outcome in the science curricula of numerous OECD countries (OECD, 2018). The significance of CT in SE is universally recognized (Ma et al., 2023), leading to an abundance of research on the subject.

A well-designed SE program plays a vital role in developing students' CT, as science learning offers ample opportunities to enhance these skills (Zaidah et al., 2018; Rowe et al., 2015). Snyder and Snyder (2008) emphasize the need for learning environments that foster CT skills and provide suggestions for teachers, such as serving as role models, identifying tasks that promote CT through activities, and asking open-ended questions.

Research by Sutiani et al. (2021) demonstrated improved CT skills in students when implementing an inquiry-based learning model in science literacy. Similarly, hand et al. (2018) used the Science Writing Heuristic (SWH) approach and observed the development of CT skills in disadvantaged students. Kabataş-Memiş and Çakan-Akkaş (2020) found that the Argumentation-Based Inquiry Approach was effective in enhancing CT skills based on their study examining its effects.

When exploring the literature concerning CT in SE, it can be noted that numerous recent research investigations have been conducted. This study aimed to provide an overview of the research conducted in this area. Bustamante et al. (2018) examined early childhood SE research and recommended fostering CT in this field. Belova et al. (2015) investigated factors about SE and advertising, emphasizing the significance of CT. Belluigi and Cundill (2017) researched case studies, highlighting how CT differs from traditional teaching methods and contributes to environmental education. Hasanah & Shimizu (2020) analyzed 78 articles and conference proceedings from 17 countries, affirming that CT is crucial in SE. Chou et al. (2019) scrutinized 42 studies and found that most quantitative research focused on CT development in online or

offline discussion environments, particularly in non-traditional e-learning settings. A summary of these studies can be found in Table 1.

Table 1. An Overview of Some Studies on CT Skills in SE

Authors	Title of Research	Aim of Research
Alshamrani & Aldahmash (2020)	A Systematic Review …	To assess academic papers presented at four conferences organized by the European SE Research Association (ESERA) from 2011 to 2017, with a specific focus on examining their research topics, methodologies, objectives, data collection methods, research instruments, and participant selection criteria.
Bustamanteet al. (2018)	Early Childhood…	To explore the potential of studies that employ science and engineering encounters during early childhood as captivating, tactile, participatory avenues to foster essential thinking skills and executive functions in economically disadvantaged young children
Belova et al. (2015).	Advertising and science education..	To examine the prospective application of marketing techniques in SE and the acquisition of knowledge concerning advertising.
Chou et al. (2019)	Research trends ...	To carry out a comprehensive investigation of CT studies conducted in e-learning environments, aiming to thoroughly analyze the existing research on CT in e-learning settings.
Hasanah & Shimizu (2020)	Crucial Cognitive …	To discern the key cognitive proficiencies in SE, we aim to identify three frequently observed aptitudes: process skills, CT skills, and reasoning skills. We can determine the essential competencies necessary for effective SE by examining these skills.
Le et al. (2022)	Computer science …	To investigate the integration of computer SE in schools and assess its impact on enhancing students' computational thinking skills.
Thiengoi et al. (2023)	Freire's perspective…	To examine the impact of Paulo Freire on the professional development of Natural Science educators in Brazil, with a specific focus on the subjects of Chemistry and Biology. This discussion highlights the enduring significance of Freire's educational legacy, particularly when CT is undermined.
Varela-Losada (2016)	Going to action? A literature review on educational proposals in formal Environmental Education	To investigate the educational recommendations presented in formal settings and documented in the two most influential research journals on Environmental Education from 2008 to 2013.

Unlike conventional literature review studies, this research concentrates on the utilization of CT in articles related to SE. The study utilizes bibliometric mapping analysis to explore diverse aspects, such as commonly used keywords, terms prevalent in abstracts, and journals and the most cited authors in articles published to date. It's crucial to mention that the scope of the bibliometric mapping analysis is limited to the variables and analyses provided by

the VOSviewer. Bibliometric mapping analysis enables researchers to gain valuable insights into the structure of their fields by employing mathematical methods to evaluate bibliographic information of scientific publications (Al & Coştur, 2007; Zan, 2019). Such analyses find various applications, including identifying the most cited studies to gauge the impact and visibility level of researchers (Lv et al., 2011).

Additionally, bibliometric studies enable researchers to assess their current status and identify opportunities that can lead to more original and innovative research (Karagöz & Şeref, 2019). Clustering techniques are essential in determining related publications, authors, and journal groups, enhancing the value of bibliometric research (Van Eck & Waltman, 2017). This study is expected to provide valuable insights and serve as a significant resource for upcoming researchers in the field of CT in SE. The research questions addressed in this study include:

1. What is the annual trend in CT publications in SE?

2. Which countries/regions and institutions have produced the most prolific publications in this field?

3. How are the most frequently used keywords distributed in articles on CT in SE within the Web of Science (WoS) database?

4. How are the most commonly used words distributed in the abstract sections of articles on CT in SE within the WoS database?

5. Who are the most cited authors (based on citation and co-citation analyses) in the field of CT in SE within the WoS database?

6. Which journals are the most cited (based on citation and co-citation analyses) for articles on CT in SE within the WoS database?

By addressing these research questions, this study aims to provide insights and comprehensive analyses of CT in SE, contributing to advancing knowledge and guiding future research endeavors.

METHOD

In the study, 377 articles related to critical thinking in science education in the Web of Science were examined by bibliometric analysis. Bibliometric analysis guides the literature on a specific research topic (Falagas et al., 2006; Song et al., 2019). Bibliometric analysis is adequate for quantitatively evaluating a particular research topic's output during a specific

period (Chen et al., 2019). For this reason, this analysis was preferred in the examination of the studies on critical thinking in science education. During the research, we utilized the criterion sampling method to select articles for study. Criterion sampling involves examining situations, persons, or events that meet predetermined criteria (Büyüköztürk et al., 2021). The criteria can either be created by the researcher or selected from a previously prepared list (Marshall & Rossman, 2014). The researcher established the criterion for the study and chose this sampling method because it only included research on critical thinking in science education.

Article Selection Process

In the study, the article was searched by applying the steps used by Arici et al (2019) for bibliometric analysis. The detailed process expressing the selection process of the articles examined within the scope of the research is as shown in Figure 1.

Figure 1. The selection process of the articles examined within the scope of the research

FINDINGS

Publication Countries/Regions

The WoS, data analysis report was used to examine the distribution of published research by country. Based on these data, around 37% of studies on this issue were conducted in the USA. Some publications from other countries/regions are shown in Table 2.

Table 2. Publicatıon Countries/Regions

Ranking	Keyword	f
1	USA	142
2	Spain	31
3	Indonesia	24
4	Turkey	23
5	Taiwan	17
6	Canada	15
7	China	15
8	England	14
9	Australia	13
10	Colombia	13

The information in Figure 2 illustrates the geographical representation of research articles concerning CT in SE across different nations.
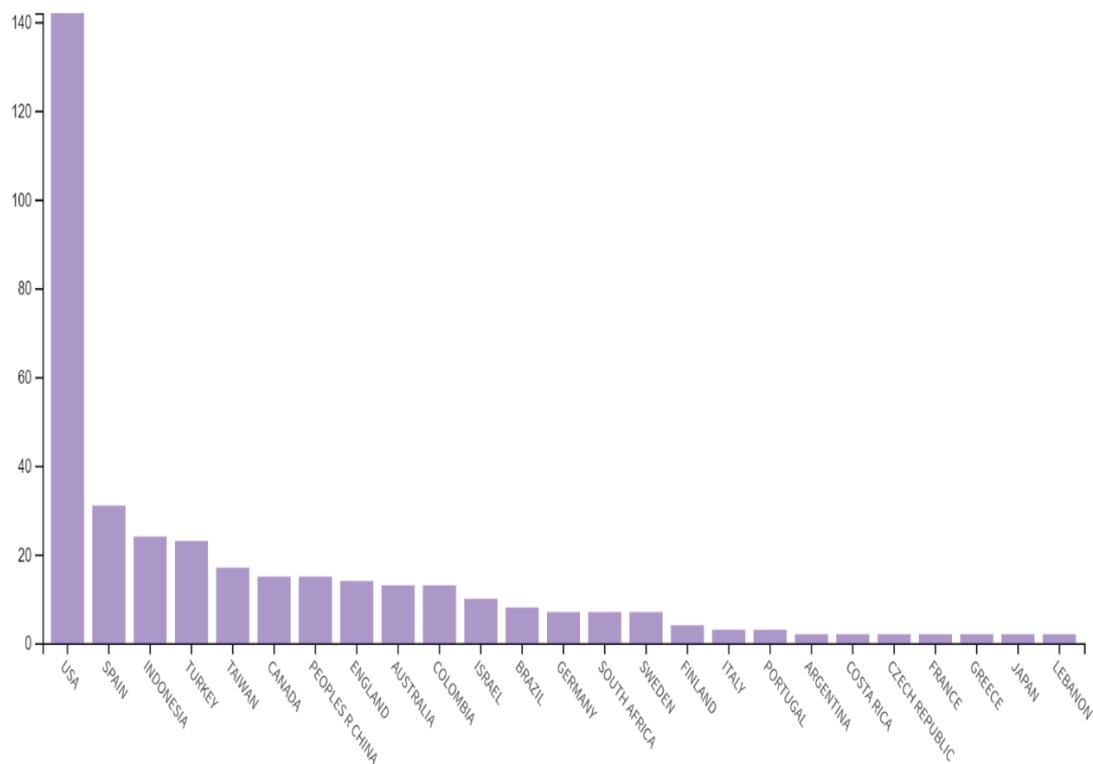
Figure 2. The geographical distribution of CT publications in SE

Publication Years

When we look at the distribution of research by years, it is seen that there are some fluctuations according to the years after the first publication was published in the WoS in 1987. It is seen that the highest number of publications (f=46) is 2021. These data are presented in Figure 3.
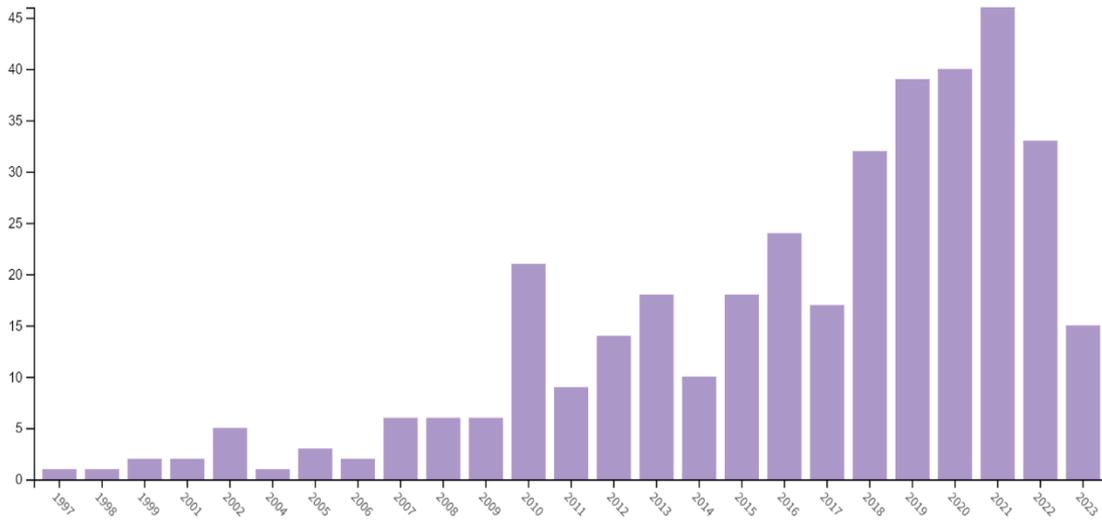
Figure 3. The distribution of research by years

Publication Affiliations

Figure 4 illustrates the distribution of articles on the utilization of CT in SE across various institutes and schools.

Figure 4. Distribution of research according to institutes and schools

Referring to Figure 4, it is seen that the State University of New York Suny System (f=8), State University of New York Suny System (f=7), Autonomous University of Barcelona (f=7), and National Taiwan Normal University (f) =7).

The Predominant Keywords in the Articles on the Utilization of Critical Thinking in Science Education

To construct a map based on textual data defining the frequently employed keywords, a co-occurrence examination was conducted, utilizing author keywords. The lowest threshold of 5 affairs was set for each keyword, and 26 keywords were automatically selected for inclusion. Figure 5 displays the resulting map derived from this analysis.
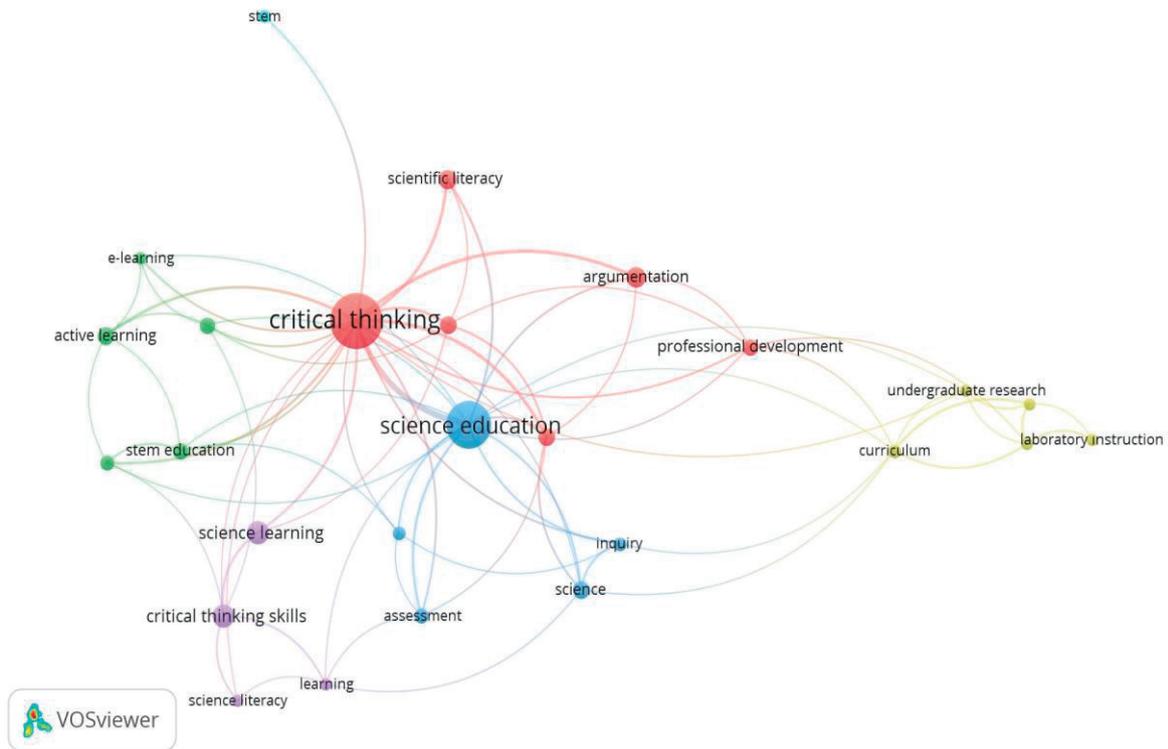
Figure 5. The keywords most commonly employed in articles on CT in SE

According to the findings illustrated in Figure 4, the analysis identified six clusters, with the keyword "critical thinking" being the most frequently used (f=88). Furthermore, the analysis highlights that the keywords "science education" (f=63), "critical thinking skills" (f=16), "science learning" (f=16), "argumentation" (f=12), and "scientific literacy" (f=11) are the most commonly used in articles related to CT in SE. These results suggest that the articles predominantly concentrate on science learning, scientific literacy, and argumentation. Table 3 presents some of the most frequently used keywords in the analysis.

Table 3. The Most Frequently Used Keywords in Studies Related to Critical Thinking in SE

Ranking	Keyword	Occurrences	Total Link Strength
1	Critical Thinking	88	62
2	Science Education	63	42
3	Science Learning	16	10
4	Argumentation	12	9
5	Scientific-Literacy	11	8
6	Socio-Scientific Issues	10	13
7	Science	10	9
8	Active Learning	10	8
9	Science Teaching	9	9
10	Higher Education	8	7

The analysis of the number of articles utilizing the specified keywords over the years reveals a prevailing emphasis on STEM education and higher education in recent times. The distribution of article counts by year, as depicted in Figure 6, indicates a growing scholarly interest in these areas, specifically within the context of CT in SE.
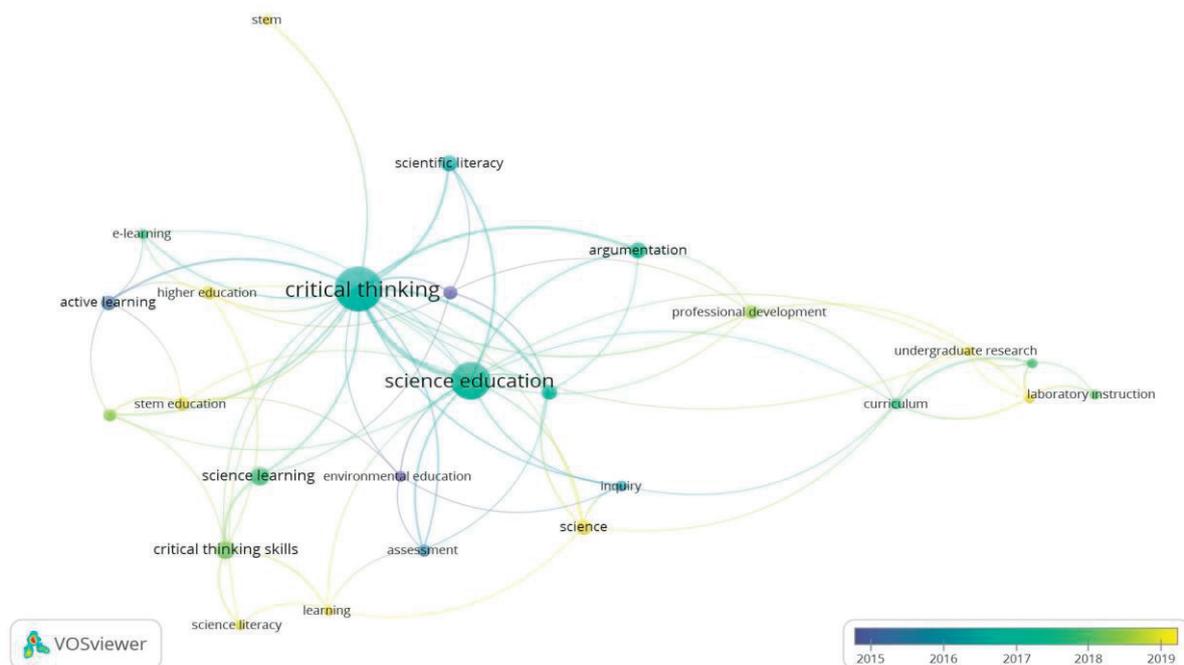
Figure 6. The distribution of the number of the articles using the keywords by years

The Most Used Words in Abstract Sections

The bibliographic database file from the WoS was uploaded to the program to create a visual representation based on textual data, focusing on the words most commonly used in the abstract sections of papers. The program analyzed the abstract field using a binary counting

method. A minimum occurrence threshold of 10 was set for each term, and 123 terms were automatically selected for inclusion. The resulting map can be observed in Figure 7.

Figure 7. The most used words in abstract sections in the articles

Figure 7 shows four clusters in four colors. In addition, summaries of frequently repeated words in the abstract sections of the studies are given in Table 4 below.

Table 4. Frequencies of Some Words in The Summary of The Studies

Ranking	Words in Abstract	f
1	Course	97
2	Science Education	90
3	Group	84
4	Class	77
5	Context	75
6	Issue	74
7	Test	71
8	Year	61
9	Way	53
10	Effect	51

Regarding Table 4, "course" is the most used word in abstracts (f=97). In addition, it is revealed that words of SE (f=90), group (f=84), class (f=77), context (f=75), and issue (f=74) are the most used keywords in articles related to CT in SE.

When distributing these words by years, the articles mainly focus on implication, score, and role recently. The distribution of the most used words in abstract sections in the papers by years is presented in Figure 8.

Figure 8. The distribution of the most used words in abstract sections in the papers by years

The Most Cited Authors

To generate a map highlighting the most cited authors, a citation analysis was conducted with a focus on authors. The lowest threshold for the number of documents attributed to an author was set at 3, while the minimum threshold for the digit of citations was determined as 4. The system automatically determined the number of authors to be included as 11. The resulting map can be found in Figure 9.

Figure 9. Authors with the highest number of citations (analysis of citations)

Figure 9 shows three clusters, five at links. In addition, summaries of the authors for citation analysis are given in Table 5 below.

Table 5. Summarized Findings on Highly Cited Authors (Citation Analysis)

Ranking	*Most Cited Authors*	Documents	Citations
1	Chang, Shao-Chen	4	250
2	Hwang, Gwo-Jen	5	210
3	Hand, Brian	7	57
4	Tsai, Chin-Chung	3	41
5	Molina, Jorge	4	29
6	Solbes, Jordi	3	28
7	Fung, Dennis	3	27
8	Lamb, Richard	3	20
9	Antonio Archila, Pablo	3	12
10	Truscott de Mejia, Anne-Marie	3	12
11	Restrepo, Silvia	3	11

Table 5 showcases the citation counts for authors within the field, highlighting Chang Shao-Chen (250 citations) and Hwang Gwo-Jen (210 citations) as the most frequently cited authors.

Regarding the co-citation analysis, the cited-authors method was employed. The minimum threshold for the number of citations attributed to an author was adjusted to 20, and 40 authors were automatically selected for inclusion. The resulting map can be observed in Figure 10.
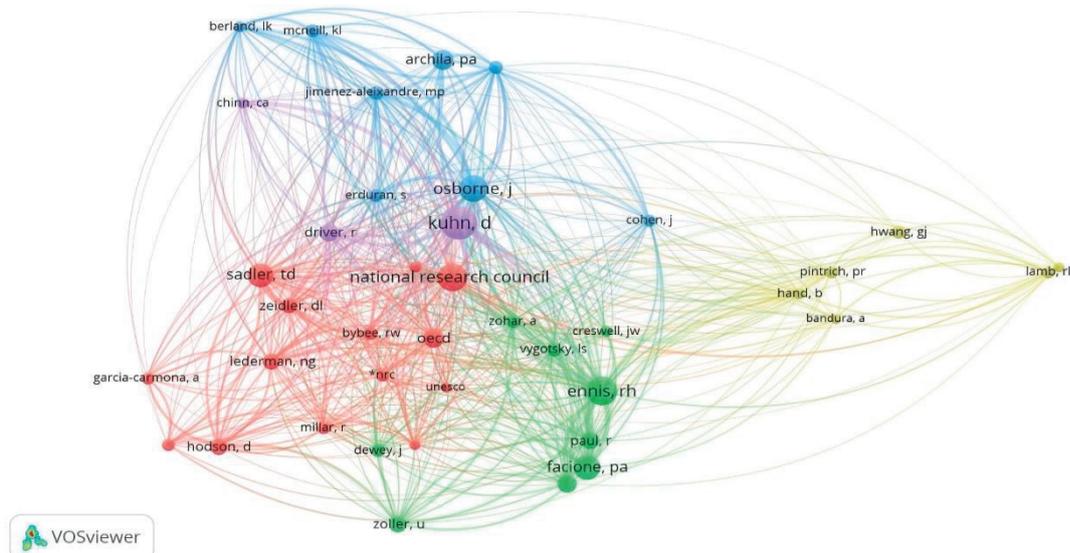
Figure 10. Top authors by co-citation frequency

Figure 10 shows five clusters and forty items at 592 links. In addition, summaries of the authors for the co-citations investigation are given in Table 6 below.

Table 6. Summary of the Most Cited Authors (Co-Citation Analysis)

Ranking	Most Cited Authors	Citations
1	Kuhn, D	106
2	Ennis, R H	84
3	National Research Council	80
4	Osborne J	78
5	Facione, P A	68
6	Sadler, T D	66
7	Archila, P A	49
8	OECD	46
9	Halpern, D F	44
10	Driver, R	42

Table 6 shows that Kuhn (106 citations), Ennis (84 citations), National Research Council (80 citations), and Osborne (f=78) are the most cited (co-citation) authors in this field.

Highly Referenced Journals (Citation and Co-Citation Analysis)

To generate a map highlighting the most cited journals, a citation analysis was conducted with a focus on sources. The minimum threshold for the number of documents attributed to a source was adjusted to 4, while the minimum threshold for the number of citations was set at 4. The number of sources to be included was automatically determined as 28. The resulting map can be found in Figure 11.
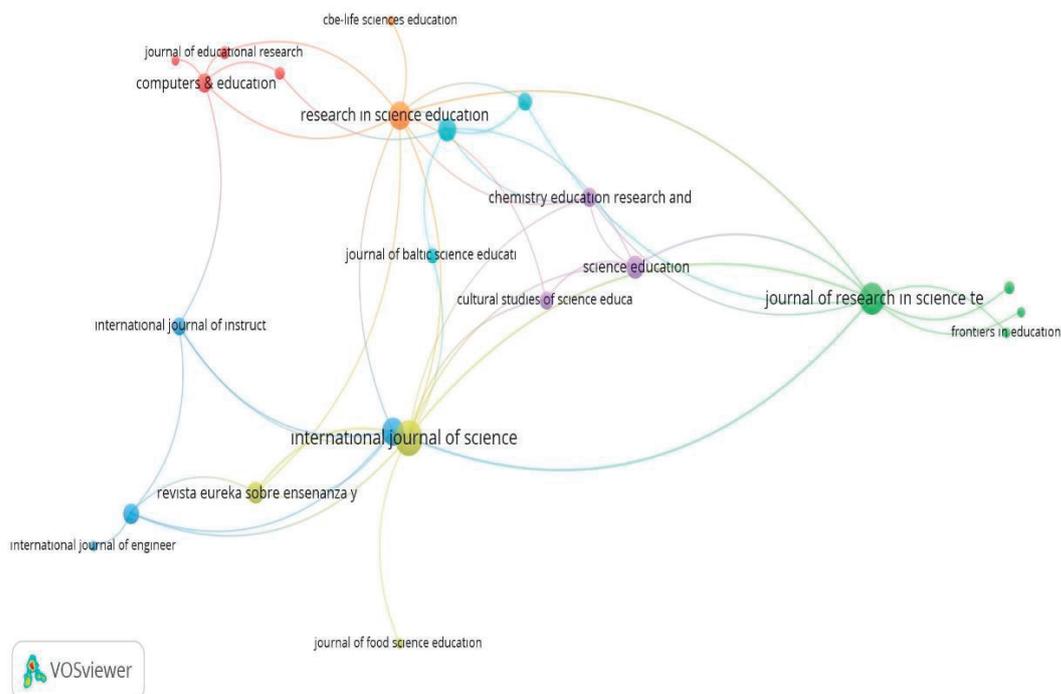
Figure 11. *The most cited journals (citation analysis)*

Figure 11 shows seven clusters and twenty-three items at forty-five links. In addition, summaries of the *most cited journals (citation analysis)* are given in Table 7 below.

Table 7. Summary of Highly Referenced Journals (Citation Analysis)

Ranking	Most Cited Journals	Documents	Citations
1	Journal of Research in Science Teaching	11	1258
2	Science Education	6	451
3	CBE-Life Sciences Education	9	376
4	Research in Science Education	12	311
5	Computers & Education	6	294
6	International Journal of Science Education	20	258
7	International Journal of Science and Mathematics Education	8	158
8	Science & Education	14	117
9	Thinking Skills and Creativity	10	116
10	Journal of Chemical Education	11	108

Table 7 demonstrates the journals with the highest citation counts, including Journal of Research in Science Teaching (1258 citations, 11 documents), Science Education (451 citations, 6 documents), CBE-Life Sciences Education (376 citations, 9 documents), and Research in Science Education (311 citations, 12 documents).

For the co-citation analysis, the cited sources approach was employed to generate a map illustrating the sources most frequently co-cited. The minimum threshold for the number of citations attributed to a source was adjusted to 20, and 103 sources were automatically selected for inclusion. The resulting map can be observed in Figure 12.

Figure 12. The most cited journals (co-citation analysis)

Figure 12 shows six clusters and one hundred and three items at four thousand two hundred forty-eight links. In addition, summaries of the *most cited journals (co-citation analysis)* are given in Table 8 below.

Table 8. Summary of the Most Cited Journals (Co-Citation Analysis)

Ranking	Most Cited Journals	Citations
1	J res sci teach	546
2	Int j sci educ	503
3	Sci Educ	455
4	J chem educ	294
5	Comput Educ	207
6	Res sci educ	144
7	Cbe-life sci educ	139
8	Science	124
9	Rev educ res	117
10	Thesis	116

Table 8 shows that the most cited journals are J res sci teach (546 co-citations), Int j sci educ (503 co-citations), Sci Educ (455 co-citations), and J chem educ (295 co-citations).

DISCUSSION and CONCLUSION

In this investigation, bibliometric mapping analysis was conducted to reveal bibliometric results related to papers on using CT in SE. The findings highlight key insights into the research landscape of this field. The Analysis report that the distribution of published research by country, around 37% of studies on this issue were conducted in the USA. Spain, Indonesia, and Turkey followed the USA. The frequency of publications on CT in these countries can be explained by the fact that education systems include changes to improve CT. Studies have shown that education programs in these countries contain regulations that will emphasize the importance of CT (Cone et al., 2016; Ministry of National Education [MoNE], 2018; Zahrebniuk et al., 2021). According to the results obtained from the research, when the distribution of papers on CT is examined by years, there have been fluctuations in the WoS after 1987, when the first research was published. After most publications were made in 2021, there has been a lowering in the paper trend of research on CT. The increase in the speed of publication since 1987 has contributed to the satisfaction observed in the field, leading to the current situation. The fact that it is a research subject, especially with its 21st-century skills, can be interpreted as its density and decrease recently, and its popularity has decreased with long research. However, due to being an important variable (Hayse, 2018; Voogt et al., 2018), although the rate of increase has decreased, it has still been the subject of much research and

can be interpreted as it will continue to be examined in research because it is an important skill. The analysis revealed that the leading institutions in distributing research on using CT in SE by institute and school are the State University of New York Suny System, State University System of Florida, Autonomous University of Barcelona, and National Taiwan Normal University. It can be said that the annual number of publications in these universities has enabled CT, which is an important variable, to be investigated frequently. The analysis revealed that the most frequently used keywords in articles related to CT in SE include CT, SE, CT skills, science learning, argumentation, and scientific literacy. This suggests a strong focus on STEM, higher, and undergraduate education in these articles. This has shown that recent research has focused more on undergraduate education. This concentration can be interpreted as the importance of undergraduate education gradually increasing. In addition, it is understood from the results that it continues to be popular in STEM education. Puig et al. (2019) stated that STEM education is frequently used in SE with CT and that the importance given to undergraduate education is gradually increasing (Fajrina et al., 2020; Reynders et al., 2020; Solodikhina & Solodikhina, 2019). Examining the distribution of articles using these keywords over the years, it was observed that there had been a recent emphasis on higher education within the context of CT in SE. These results can be interpreted as the fact that CT is a high-level thinking skill (Lam et al., 2019; O'Reilly et al., 2022) and, according to Piaget (1972), the expression that thinking skills develop after the concrete operational stage may have led researchers to think that this age group is the appropriate time for the development of this skill. However, the development of CT is built on several pioneering skills that develop from early childhood through adolescence and adulthood. Therefore, many factors affect the consequence of CT (Ormrod, 2018). Pioneering skills such as social and emotional development, experience, play, communication, mental representations of the environment, and abstract thinking skills form the basis of CT skills in children (Murphy et al., 2014). In order to see how these skills affect CT in adults, studies at the undergraduate level may be focused. Analyzing the abstracts of the articles, the most frequently used words included course, SE, group, class, context, and issue. Moreover, recent articles have placed greater attention on implication, score, and role when considering the distribution of these words over time. These words can be explained by the intensive use of experimental and practice-based research conducted in the classroom. Studies in the field reported more experimental studies (Alshamrani & Aldahmash, 2020; Urdanivia Alarcon et al., 2023). Regarding citations and co-citation analysis, notable authors in the field were Chang, Hwang, Hand, Tsai, and Molina. At the same time, the most cited journals included the Journal of Research in Science Teaching, Science Education, Cbe-Life Sciences Education, Research

in Science Education, Computers & Education, and the International Journal of Science Education. These results showed that researchers are leading researchers in SE. In addition, journals that have an important place in SE can be expressed as prominent journals in this study. The fact that the h-indexes and impact values of the journals are high in the researchers explains these results. These findings collectively provide valuable insights into the research trends, topics, and key contributors within the realm of CT in SE.

Based on the research consequences, the subsequent recommendations can be offered to researchers and for future research:

- Considering the distribution of the research area and the differences between countries, the USA has undertaken a large part of the research on CT. Arrangements can be made to emphasize CT in the education programs of other countries.

- International studies can be carried out by cooperating with institutions with many publications or by contacting researchers in these institutions.

- Researchers should review the work of leading researchers and consider submitting articles to or publishing in leading journals.

- It has been observed that CT is frequently examined, especially in STEM-related studies, and the development of this skill can be investigated with different techniques, technologies, and methods.

- It has been seen that CT is frequently used in higher education, and these studies are more experimental. Studies can be conducted at different education levels and with different methods.

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