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Research Trends in Critical Thinking for Science Education: A Mixed Method Approach Using SLR and Bibliometrics (2014-2024)

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Abstract: A Critical thinking skills play a crucial role in the trends of science education, particularly in 21st-century learning. Numerous researchers have investigated critical thinking abilities to gain deeper insights into the direction of education in this century. The development and application of critical thinking in science education have spanned from 2014 to 2024. This study employs a mixed-method approach, combining Systematic Literature Review (SLR) and Bibliometric Analysis. The bibliometric research follows stages aligned with the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA) guidelines. The study encompasses students from various educational levels, including elementary, junior high, and senior high school, as well as diverse instructional methods that integrate critical thinking techniques. The research employs content analysis, involving the description and analysis of data with the aid of VosViewer and Microsoft Excel. The articles analyzed comprise 120 publications obtained through the Publish or Perish search engine from the Scopus and Google Scholar databases. The findings indicate that studies on critical thinking map the relationships between keywords based on the four color clusters in VosViewer visualizations, including critical thinking, science, education, problem-based learning, and curriculum. These keywords are interconnected and reflect the central themes in educational research. The study's findings are anticipated to provide valuable insights for other researchers regarding aspects such as the number of publications, country of origin, publication types, research methods, research subjects, instruments used, and instructional interventions.

Keywords: Critical Thinking, Science Education, Mixed-Method Approach, Bibliometrics, PRISMA

Introduction

Critical thinking skills are an important element in education, especially in the context of science learning in the 21st century. Critical thinking skills not only help students in understanding scientific concepts, but also prepare them to face complex challenges in the real world. When students are able to relate learning with real complexes, they will find it easier to understand science concepts. This will support students in building stronger characters, who can adapt to new situations and make appropriate judgments about current events (Irfiani et al., 2023), and encourage them to think critically. A critically thinking individual is someone who consciously assesses the quality of their own thinking by carrying out introspective, independent, clear, and logical reasoning. Apiati & Hermanto (2020) explain that the critical thinking process includes the following steps: solving problems, drawing conclusions, formulating, gathering possibilities, and making decisions. Critical thinking ability is a skill that needs to be continuously honed by each individual. Therefore, it is important to continuously improve one's critical thinking skills. especially in science education, which demands in-depth understanding and critical analysis of natural

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phenomena. To support these skills, a learning approach is needed that not only emphasizes on understanding concepts, but also on students' ability to evaluate and connect knowledge with real situations they face.

Furthermore, critical thinking skills also play a role in shaping the character of students who are adaptive and responsive to environmental changes and technological advances. For example, in studying the concepts of waves and light, students can be invited to analyze real applications of these concepts, such as in communication technology or renewable energy. This not only enhances their understanding of the material, but also fosters awareness of the social and environmental implications of the scientific knowledge they are learning. Thus, developing critical thinking skills in science education has a significant long-term impact on students. Not only do they become more competent in academics, but they are also prepared for the complex challenges of life and work in the future. This research aims to identify current trends in the application of critical thinking skills in science education, while offering guidance for educators in designing more effective lessons to achieve this goal.

This study aims to explore research trends related to critical thinking in the context of science education from 2014 to 2024. This study highlights that knowledge mapping and bibliometric analysis are powerful methodologies to identify significant areas of research and trends within a particular field. Bibliometric mapping will benefit the scientific community and the general public as it can help transform publication metadata into maps or visualizations (Tanudjaja & Kow, 2018).

The researcher wanted to identify key areas and dynamics of critical thinking in education today and provide suggestions for future research directions. In this endeavor, the researcher posed three research questions (RQs) that will be addressed in this study:

-RQ1 : What are the current publication trends related to critical thinking in science education?

-RQ2 : What are the common themes that emerge among researchers in this field?

-RQ3 : What is the current intellectual structure of research and the future direction of critical thinking research in science education?

Future research is expected to develop more adaptive teaching methods in science education to enhance students' critical thinking skills

Materials and Methods

Methodology

This research is a mixed research or better known as mixed methods, mixed methods approach allowed this study to integrate quantitative and qualitative perspectives, providing a more holistic picture of critical thinking research trends in science education. With the combination of bibliometrics for quantitative analysis and SLR for qualitative analysis, this study can map and evaluate the literature in depth and provide comprehensive recommendations for the development of critical thinking skills in science learning. Mixed research is research where researchers mix or combine quantitative research approaches and qualitative research approaches in one study. First, conducting bibliometric analysis, White and McCain (1989) state that bibliometrics is a quantitative study of the literature reflected in the bibliography. The second analysis systematic literature review, SLR is a qualitative-based research. This study used secondary data. The research data for this study was collected from the Scopus database, a database of abstracts and citations, which is used to extract information about critical thinking, the analysis in this study covers the period 2014 to 2024. The study covered 10 years, and the literature retrieval used the retrieval option, advanced documents with the search key "Critical Thinking" to download relevant literature published during the specified time period. The search keys used for this bibliometric analysis were : Title-Abstract-Key such as, "Critical Thinking" or "Science Education" or "Learning Approaches" or "Teaching Methods". This key was used to search for relevant literature on critical thinking. Accessed on October 1, 2024, the researcher found 120

documents related to critical thinking in Science Education from 2014 to 2024. In the SLR analysis, the following inclusion and exclusion criteria were used:

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
The study included students from different levels of education (elementary, middle, high school).	Non-Education Subjects
The research used quantitative (surveys, tests) and qualitative (interviews, observations) data.	Non-IPA Context
Year of Study: Studies conducted within a certain time span (last 10 years)	Publication data for more than 10 years
Using English	Traditional learning methods
Open Access Journal	Close access journal

Prosedures

This research adopts SLR and bibliometric analysis techniques, in previous research conducted by Kumar et al. (2019). However, in processing the data, the research used HistCite and BibExcel software. As for this research, the software used is Publish or Perish (PoP) and VOS Viewer. Then for qualitative analysis (SLR) using content analysis. Because of the screening criteria in SLR, this research began by following the research steps using SLR in previous studies. In general, there are four steps suggested by Denyer and Tranfield (2009). These four steps are called the acronym SALSA (Search, Appraisal, Synthesis, Analysis). However, this step only applies to SLR analysis, while for bibliometric analysis using the step technique carried out by Det Udomsap and Hallinger (2020) using PRISMA (Preferred Reporting Items for Systematic Reviews and Meta Analysis). Therefore, this research uses PRISMA. PRISMA was used to ensure that each stage of the literature sorting was conducted systematically and transparently, allowing for repeatability of results if similar studies are conducted in the future. Meanwhile, the SALSA process- Search, Appraisal, Synthesis, and Analysis-assisted in evaluating and sifting through the existing literature to identify key themes in critical thinking skills development.

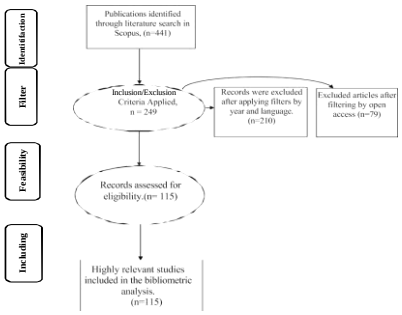

Figure 1. Flowchart of the four-phase data extraction and filtering process.

Results and Discussion

A descriptive analysis of 115 articles was conducted to determine the basic trends of ongoing publications on this topic. To answer the first research question (RQ1), researchers analyzed the publication trends as seen from the total publications by year, author, article, journal, and country.

Year-on-year publication trends

Publication trends by year show an increase in the number of articles related to this topic from 2014 to 2024, with a significant spike especially after 2018. This increase indicates a growing interest in the topic of critical thinking skills, which are essential in the age of global information and complexity (Facione, 2015). While there is a slight drop in 2021 and 2022, which may be due to the impact of the COVID-19 pandemic, the graph shows a peak in publications in 2024 with 20 articles, hinting at a new research push and growing attention to these skills in education and work (Abrami et al., 2015; Halpern, 2014).

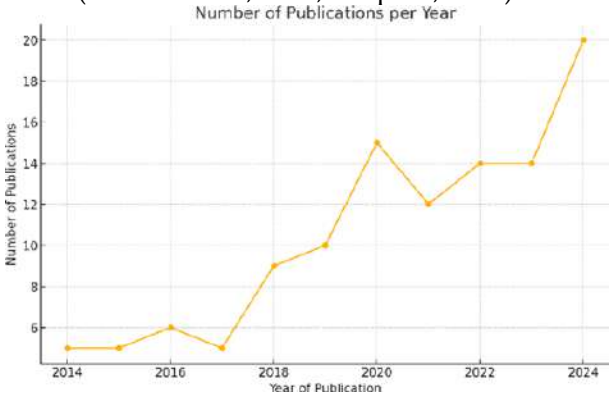

Figure. 2. Publication Trend by Year

Publication Trend in Some Countries

From the publication data by country, it can be seen that contributions to the topic are unevenly distributed across the globe. The United States has consistently been the country with the highest number of publications, indicating 138significant interest and attention to the topic. The steady increase in publications from 2014 to 2024, as shown in Figure 2, reflects a growing academic interest in critical thinking within science education. This upward trend may be driven by the increasing demand for higher-order cognitive skills, which are essential in the modern workforce and in addressing complex global challenges. The heightened focus on critical thinking aligns with educational reforms worldwide that emphasize the need for students to develop analytical and problem-solving skills early in their academic journeys This is followed by countries such as India and Malaysia, which also contribute substantially but in lower numbers than the United States. In addition, some other countries such as Canada, South Africa and Turkey have moderate contributions, while countries such as Russia, Indonesia, Australia and Iran are included in t he top 10 list but with a smaller number of publications.

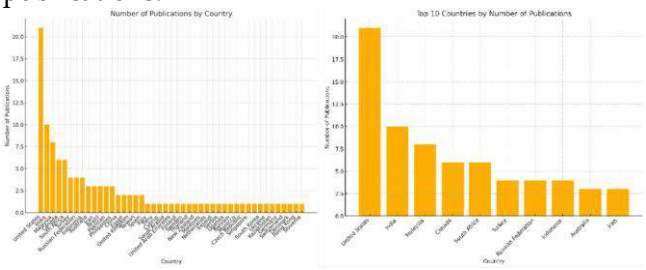

Figure. 3. Publication Trend of Some Countries

Approaches Used in Teaching Critical Thinking

Of the approaches most commonly used in learning critical thinking skills, a number of learning methods have been identified from the available literature. These methods are designed to encourage students to think more deeply, evaluate information critically, and solve problems creatively. Some popular approaches in research include Problem-Based Learning (PBL), Digital Game-Based Learning, and Flipped Classroom. In addition, there are other methods such as Simulation-Based Learning, Project-Based Learning, and Inquiry-Based Learning that are also used to hone critical thinking skills through practical and collaborative activities. The following graph illustrates the frequency of occurrence of each approach in the articles reviewed, providing an overview of the main trends in learning methods used to develop critical thinking skills. analysis of teaching approaches (Figure 4) reveals that Digital Game-Based Learning and Problem-Based Learning (PBL) are the most frequently utilized strategies to foster critical thinking skills. These methods are known for promoting active engagement, collaboration, and problem-solving, which are essential for the development of critical thinking. The prominence of Digital Game-Based Learning and PBL suggests a shift towards interactive and student-centered learning approaches, where students engage in hands-on activities and critical analysis rather than passively receiving information. This trend indicates that educators and researchers increasingly recognize the importance of active and engaging learning strategies, such as games and problem-solving activities, in promoting critical thinking among science students.

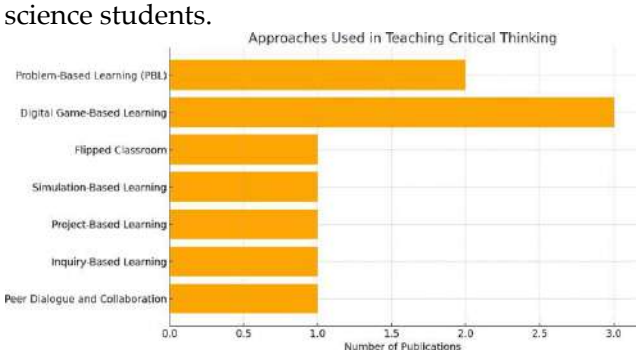

Image. 4. Approaches Used in Teaching Critical Thinking

Author Collaboration Network Analysis

In this study, we use VOSviewer to visualize the co-authorship network of publications in a related field. This network aims to identify patterns of collaboration between authors, identify key authors, and observe collaborative subgroups within the network. The author collaboration network analysis (Figure 4) highlights the importance of international and interdisciplinary partnerships in the study of critical thinking in science education. Notably, countries such as the United States, India, and Malaysia show a high degree of collaboration, reflecting a shared

commitment to advancing research in this area. These collaborations enable the exchange of diverse pedagogical practices and innovations, which can enrich the educational experiences in different cultural contexts. By fostering global research partnerships, the field of critical thinking in education benefits from a broader range of insights and methodological approaches.

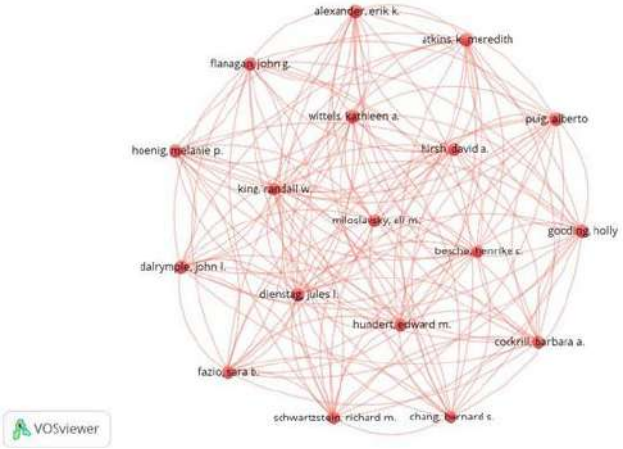

Figure. 5. Author Collaboration Network Analysis

Keyword Network Analysis of Research

This visualization shows the keyword network created using VOSviewer software. Each node (point) in the visualization represents a keyword that frequently appears in related research or publications, while the connecting lines (edges) between nodes show the relationship or co-occurrence of the keywords. This keyword network visualization helps in understanding the central topics and thematic relationships present in the analyzed research. With major keywords such as teaching, critical thinking, and medical education, the network illustrates the main focus of the literature. In addition, the clusters formed indicate the existence of sub-fields or groups of related research. This analysis can serve as a basis for researchers to identify new themes, develop follow-up studies, or focus attention on areas of high relevance in the educational context.. This network offers valuable insights for educators as well, helping them understand effective teaching approaches that are being recognized and studied globally

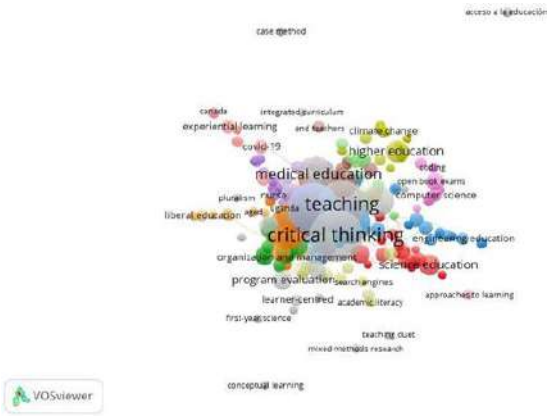

Figure. 6. Keyword Network Analysis of Research

keyword network analysis highlights key themes in critical thinking research within science education, showing strong connections between 'teaching', 'critical thinking', and 'educational methods'. This indicates a focus on effective teaching strategies for enhancing critical thinking. The presence of clusters related to 'medical education' suggests interdisciplinary interest, emphasizing the importance of critical thinking in various fields. This network provides useful insights for researchers aiming to explore emerging themes or address research gaps. keyword network analysis reveals core themes in critical thinking research within science education, highlighting strong connections between 'teaching', 'critical thinking', and 'educational methods'. This suggests a significant focus on effective strategies for fostering critical thinking skills. The presence of clusters related to 'medical education' indicates interdisciplinary interest, underscoring the importance of critical thinking across fields.

This network provides insights for researchers aiming to explore emerging themes or address existing gaps in the literature

Discussion

The analysis conducted in this study provides answers to the Research Questions (RQs) posed, namely regarding publication trends, common themes, as well as the intellectual structure and future direction of research on critical thinking in science education.

RQ1: What are the current publication trends related to critical thinking in science education?

From the analysis of publication trends by year, it can be seen that the topic of critical thinking in education has increased significantly since 2018, with the number of publications continuing to grow until 2024. This surge reflects the growing interest from researchers and educators in the development of critical thinking skills, especially in the context of science education. This trend indicates that in the era of fast-growing information and global complexity, critical thinking skills are considered a key element to equip students with the ability to think logically and analytically. The decline in publications that occurred in 2021 and 2022 may have been influenced by the impact of the COVID-19 pandemic, which hampered many aspects of research and education. However, a recovery was seen in 2024 with the number of publications reaching its peak. This suggests a renewed impetus in research, possibly due to a heightened awareness of the importance of critical thinking in the face of global challenges, such as the pandemic and environmental issues. Overall, these trends confirm the increasing relevance of critical thinking topics in science education in a rapidly changing world.

RQ2: What are the common themes emerging among researchers in this field?

The keyword network visualized with VOSviewer provides an overarching view of the common themes emerging in research on critical thinking in science education. Some of the main themes that stand out are teaching, critical thinking, medical education, science education, and higher education. These themes indicate the focus of the literature on developing critical thinking skills through various teaching approaches and in different educational contexts. The thematic clusters formed in this visualization also help identify sub-fields or groups of topics that are often studied together. For example, there are clusters of keywords focusing on science education and engineering education, suggesting that education in science and engineering plays an important role in developing critical thinking skills. In addition, the emergence of topics such as experiential learning, problem-based learning, and digital game-based learning indicates that researchers are interested in practical and experience-based approaches to hone students' critical thinking skills. Overall, the common themes in this research revolve around teaching methods and practice-based approaches that can be applied in science education. The focus on teaching critical thinking through hands-on experience, problem solving and interactive methods reflects the need to make critical thinking skills more relevant and applicable for students in facing real challenges.

RQ3: What is the current intellectual structure of research and the future direction of critical thinking research in science education?

The intellectual structure of research on critical thinking in science education can be seen from the authors' collaboration patterns and the relationship between themes in the keyword network. Analysis of the author collaboration network shows that there are several researchers who play a central role in developing research in this area, often collaborating with colleagues from different institutions. The strong collaboration in this network suggests that the field is driven by interdisciplinary and cross-institutional cooperation, which strengthens the intellectual basis of research on critical thinking. The keyword network further reveals potential directions for future research. Topics such as climate change and covid-19 are beginning to emerge in the context of science education and critical thinking, suggesting that global issues are being integrated into learning approaches learning methods, such as simulation-based and project-based learning, especially in specific contexts like environmental and health education, where critical thinking is essential.

Implications for Educators and Researchers

This study highlights the importance of adopting active, experience-based approaches to foster critical thinking in students. For educators, implementing methods like project-based and

simulation-based learning can create more engaging and relevant learning experiences. For researchers, the integration of global issues, such as climate change, into critical thinking studies points to the growing trend towards interdisciplinary research, providing opportunities for impactful contributions in educational practices.

Conclusions

Overall, the results of this analysis provide answers to the three research questions. The increasing publication trend indicates that critical thinking in science education is a relevant topic and is receiving growing attention, especially in the fast-changing information age. Common themes that emerged, such as teaching methods and experiential learning approaches, indicate the literature's focus on developing critical thinking skills that are applicable and relevant to the real world. The intellectual structure formed through author collaboration and the themes in the keyword network indicate that this research is developing in an interdisciplinary manner, with future directions focusing on the integration of global issues and practical approaches to improving students' critical thinking skills. These findings suggest that research on critical thinking in science education is not only academically important, but also highly relevant in equipping students with the skills needed to face the challenges of the modern world. Thus, further research in this area can be directed towards developing more innovative and context-based teaching approaches that can address future educational needs.

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