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A Decade-Long Trend in The Development of Systems Thinking Skills on Science Learning : Contributions to Elementary Schools

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Abstract: This study aims to identify trends in systems thinking research within the context of science education over the past decade and providing education researchers with a global perspective on the development of systems thinking. The bibliometric analysis research method is a quantitative approach used to analyze scientific literature to identify trends, publication patterns, collaborations between authors or institutions, and emerging research topics in a field of science. The data used for bibliometric analysis is the research trend of systems thinking in science learning from 2014 to 2024, based on the Scopus database, utilizing the R Package Bibliometric and VosViewer Software. The obtained articles were then processed using thematic analysis techniques with the R Bibliometric Package to analyze primary information, annual scientific publications, article citations per year, total citations of top journals, Sankey diagrams, top author production, countries with the highest productivity, most productive affiliations, and thematic maps. The findings of this study indicate that research on systems thinking in science learning has experienced an annual growth rate of 9.6% and an average citation rate of 13.6 citations per document. Furthermore, it analyzes the thematic mapping of the obtained keywords, where the motor themes in this study such as curriculum, teaching, elementary school, student learning, and system theory are well-developed and essential for shaping research in systems thinking in science learning. The thematic mapping reveals a strong interconnection among three key themes: systems thinking, science learning, and elementary schools. These themes hold significant potential and are highly relevant for further exploration due to their high centrality, yet they remain relatively underexplored to date. The study of systems thinking skills in science learning should also consider previous research findings related to sustainable development goals, climate change, gender similarity, and conceptual frameworks.

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Introduction

The human ability to engage in effective systems thinking is crucial for the future of the world. The application of systems thinking extends across multiple disciplines, connecting and supporting them in ways that are not intuitive but highly impactful (Laszlo, 2021). So far, systems thinking skills have been overlooked in education for various reasons, one of which is the lack of a clear approach or model that provides context for introducing and developing systems thinking (Cabrera & Cabrera, 2023). Some define systems thinking too vaguely, while others oversimplify it, and both perspectives fail to capture the systemic essence of systems thinking (Asikainen, 2016). Systems thinking consists of three key components: elements (in this case, characteristics), interconnections (the ways these

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characteristics relate to and/or influence one another), and function or purpose (Leung et al., 2024). Furthermore, to facilitate understanding of the concept of systems thinking, it is necessary to define it clearly. The definition of systems thinking includes a clear purpose, key elements of systems thinking, and a description of the interconnections between these elements (Arnold & Wade, 2015). Systems thinking focuses on recognizing the interconnections between parts of a system and synthesizing them into a unified perspective (Cabrera et al., 2023). Moreover, systems thinking involves identifying patterns and reciprocal relationships and learning how to structure these interconnections into a more effective and efficient way of thinking (Blatti et al., 2019). This definition synthesizes the most common and critical systems thinking competencies discussed in various literature sources, which can be used to support the teaching of systems thinking across multiple disciplines (Monat & Gannon, 2015).

Specific systems thinking skills encompass cognitive abilities such as: (a) thinking in terms of dynamic processes (causality, feedback relationships); (b) understanding how system behavior emerges from the interaction of components over time (dynamic complexity); (c) identifying and representing feedback processes underlying observed system behavior patterns; (d) recognizing relationship patterns; (e) identifying causality and understanding its impact; (f) identifying nonlinear patterns; and (g) engaging in scientific thinking, which involves the ability to measure relationships, formulate hypotheses, and test assumptions and models (Gero et al., 2021; Gray et al., 2019; Randle & Stroink, 2018). There is a strong connection between the characteristics of systems thinking and other higher-order thinking skills (Gero et al., 2021). Effective systems thinking also requires strong scientific reasoning skills, such as the ability to utilize various qualitative and quantitative data sources (Lavi & Dori, 2019). These abilities are associated with higher-order thinking skills, including scientific and mathematical reasoning, problem-solving, critical thinking, and refining ideas in a creative manner encompassing complex characteristics of higher-order thinking (Sun et al., 2022).

Given the longstanding debate on whether thinking skills or problem-solving strategies should be taught within the context of specific disciplines or as separate subjects, this issue appears to be reinforced by the findings which suggest that content-based methods have a significant influence on the development of systems thinking skills (Cammarata et al., 2016). The finding that all students who overcame cognitive barriers were highly engaged in the learning process may indicate that students' systems thinking is not only influenced by their initial cognitive potential in a learning process but also by the use of appropriate learning strategies (Cammarata et al., 2016; Y. Chen, 2021). Another finding suggests that such learning should be based on inquiry-based learning, both indoors and outdoors, and should incorporate knowledge integration activities (Mambrey et al., 2020; Spektor-Levy et al., 2013). A content-based approach grounded in inquiry-based learning can be utilized to develop systems thinking in science education. Science learning is designed to provide students with opportunities to nurture their natural curiosity, develop questioning skills, seek answers to natural phenomena based on evidence, and cultivate scientific thinking (Y.-C. Chen & Jordan, 2024). Science instruction involves abstract concepts and processes that are often invisible or intangible (Kersting et al., 2021). Numerous studies highlight the challenges in learning and teaching science due to its association with abstract phenomena and processes (Barak & Dori, 2011). Science encourages students to develop scientific curiosity (Lindholm, 2018). This, in turn, helps students enhance their capacity to ask questions and find solutions to surrounding phenomena through systematic scientific reasoning (Chin & Osborne, 2008; Quintana et al., 2018). Science education should emphasize students' curiosity and interest, as well as their understanding of the world around them (Spektor-Levy et al., 2013).

Furthermore, to understand the relationship between science learning in elementary schools and systems thinking, this study presents information on research trend analysis focusing on the topic of systems thinking in science education. Several studies have been conducted on the implementation of systems thinking competencies. For instance, research has shown that sixth-grade elementary school students have the potential to develop systems thinking skills (Evagorou et al., 2009). Additionally, a study on concept mapping of systems thinking involving 150 fourth-grade students in Germany positively influenced students' performance in concept mapping (Brandstädter et al., 2012). The effectiveness of developing an interactive learning environment through contextual topics has been shown to promote systems thinking among students in six elementary schools in Italy, with positive results (Ceresia, 2017). Developing a systems perspective requires less time when introduced to young, curious, and open-minded elementary school students compared to individuals whose thinking has already been conditioned to perceive the world through a linear cause-and-effect lens (Chaojing, 2023). However, fostering systems thinking skills at the elementary school level presents additional challenges due to children's relatively basic language proficiency and developing abstract thinking abilities (Forrester, 2007).

In further examining systems thinking and science learning, several previous studies have analyzed trends in science education using bibliometric analysis. These include research on trends in the use of augmented reality in science learning (Arici et al., 2019), an analysis of inclusive education in science learning (Comarú et al., 2021), a review of science education research over the past 40 years (Tosun, 2024), and the integration of Sustainable Development Goals (SDGs) in science learning (Maryanti et al., 2022). Additionally, bibliometric analyses of systems thinking trends include studies on systems thinking in education in general (Bozkurt & Bozkurt, 2024). Therefore, bibliometric analysis is necessary to uncover this information. Bibliometric analysis is an effective method for evaluating the impact of a paper on scientific advancement. A bibliometric study that specifically maps trends, collaborations, and dominant topics in systems thinking research, especially in the context of education or learning. This study aims to identify trends in systems thinking research within the context of science education over the past decade, providing education researchers with a global perspective on the development of systems thinking. This research will explore the development, implementation, and evaluation of systems thinking in science learning.

Research Method

The bibliometric analysis research method is a quantitative approach used to analyze scientific literature to identify trends, publication patterns, collaborations between authors or institutions, and emerging research topics in a field of science. This study used bibliometric methods to understand global research trends in a specific field based on academic publication outputs from both the Scopus and WoS databases (Alsharif et al., 2020). In this research, bibliometric analysis is used to identify and explain research trends related to systems thinking in elementary schools to support science learning. The bibliometric method follows several stages: 1) Defining the objectives and scope of the bibliometric study, which must be established before selecting bibliometric analysis techniques and collecting bibliometric data. 2) Designing the bibliometric study, where the appropriate analysis techniques are chosen to meet the study's objectives and scope. 3) Collecting the necessary data for the selected bibliometric analysis techniques. 4) Conducting the bibliometric analysis

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and reporting the findings (Donthu et al., 2021). This approach helps researchers identify potential future research directions. To perform bibliometric analysis, access to bibliographic databases is required, as they provide essential information about scientific publications, such as titles, authors, abstracts, keywords, and references. Scopus is often chosen as a primary database due to its extensive coverage of global and regional scientific journals, conferences, and books (Amiruddin et al., 2024).

Data search and collection were conducted using the Scopus database. The primary focus of this study is research articles that include the keywords systems thinking, elementary school, and science learning in their abstracts and titles. The earliest publication in the dataset is from 2014, while the most recent is from 2023, using the following search query: (TITLE-ABS-KEY ("System thinking skill") OR ("System thinking") AND ("science education") OR ("science learning") OR ("elementary school") OR ("primary education")). The data were then filtered based on titles, abstracts, and keywords. The data collection was restricted to studies published between 2014 and 2023. A more detailed representation is provided in the following figure 1.

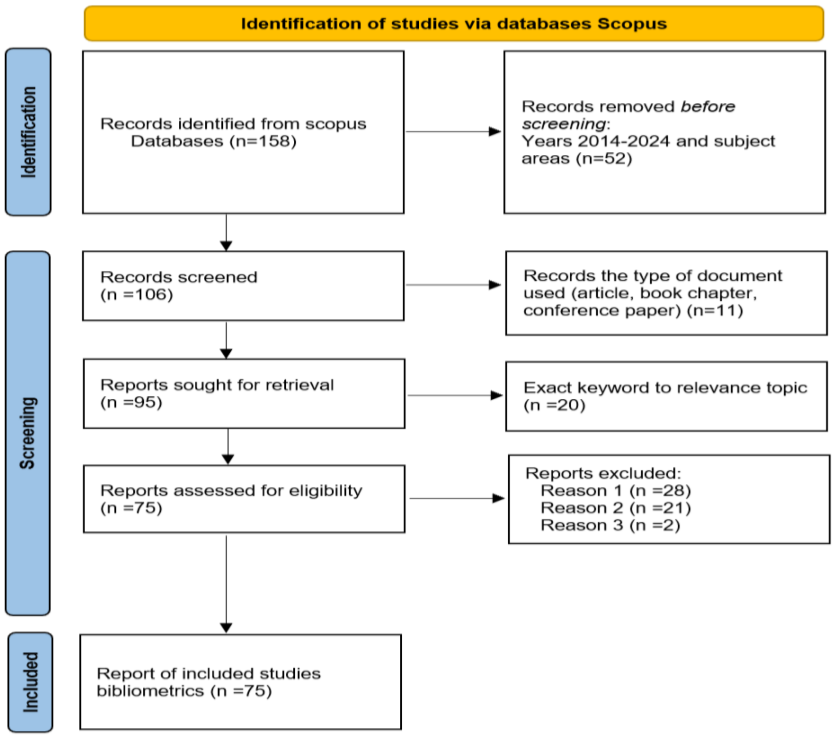

Figure 1. Flowchart of article selection

*note: reason 1: year; reason 2: subject area; reasion 3: keyword.

The obtained articles were then processed using thematic analysis techniques with the R Bibliometric Package to analyze primary information, annual scientific publications, article citations per year, total citations of top journals, Sankey diagrams, top author production, countries with the highest productivity, most productive affiliations, and thematic maps. Additionally, the VOSviewer application was used to analyze keyword mapping. The bibliometric summary and the creation of network visualization summaries directly inform the writing of this paper and support future research. This bibliometric data analysis encourages researchers in the field of elementary education to develop in depth discussions based on relevant trends rather than merely reporting bibliometric summaries. This means

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that bibliometric visualizations both in figures and tables should be used to curate analytical discussions.

Results and Discussion

The Main Information of System Thinking on Science Education

Research trends serve as a reference for researchers to understand current issues, providing insights for future research planning. The main information from the Scopus database on research trends in systems thinking in science learning from 2014 to 2023 reveals several key findings. It was found that research on systems thinking in science learning has experienced an annual growth rate of 9.6%, with an average of 13.6 citations per document, drawing from 3,904 references. The topic of systems thinking and science learning involved 231 authors, with only 8 single authors (non-collaborative), while 12% of the authors engaged in international collaboration. In total, 63 documents were published in journals, 8 in book chapters, and 4 in conference papers (Scopus-indexed). These findings indicate that the research trend on systems thinking in science learning has the potential to be further promoted at the elementary school level.

Annual Publication Production Trends

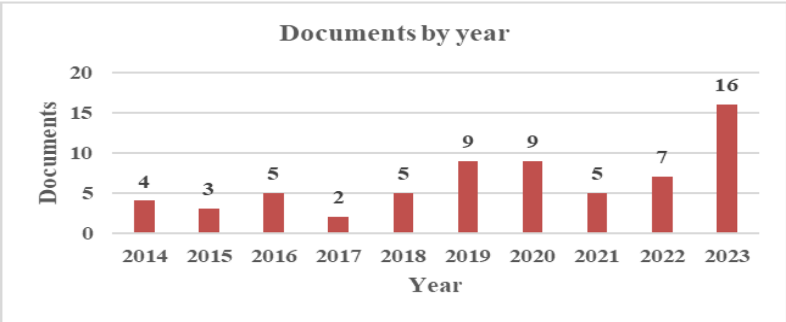

Figure 2. Annual Scientific Publication

Over the past ten years (2014–2023), the number of scientific publications has significantly increased, with 16 publications in 2023, compared to 4 publications in 2014. Although there were some declines in publication numbers in certain years, these fluctuations were not significant. Additionally, the total citations per year for each published scientific work can be seen in Table 1 below.

Table 1. Article Citation Per Year

Year	MeanTCperArt	N	MeanTCperYear	CitableYears
2014	25,50	4	2,32	11
2015	28,67	3	2,87	10
2016	11,40	5	1,27	9
2017	4,50	2	0,56	8
2018	23,20	5	3,31	7
2019	33,56	9	5,59	6
2020	24,67	9	4,93	5
2021	6,40	5	1,60	4
2022	6,86	7	2,29	3
2023	2,31	16	1,16	2

Table 1 generally illustrates that the highest number of annual citations is found in older publications, with the peak in 2015 and the lowest in 2023.

Total Citation of Journal

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The top citation analysis in bibliometrics serves several important functions in understanding the research landscape of a particular field. These scientific works are considered highly influential as they have made significant contributions to the advancement of knowledge. The publication trends on the topic of system thinking in science education at the elementary school level, which have been periodically published in various journals, can be analyzed through the distribution of citations, as shown in Figure 3 below.

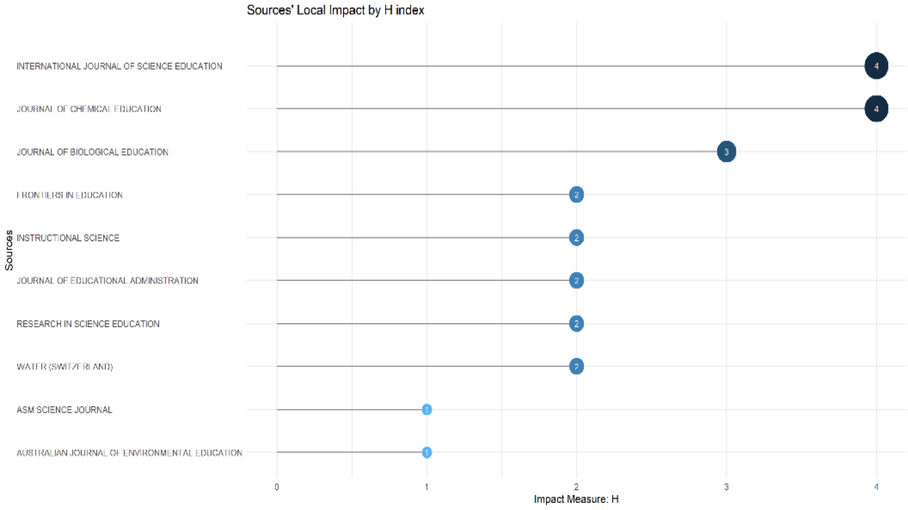

Figure 3. Top Journal Total Citation

From Figure 3, it can be seen that the "International Journal of Science Education" has the highest number of citations, while the "Australian Journal of Environmental Education" has the lowest.

Thematic Development

In bibliometrics, thematic development refers to the analysis of the evolution and changes in research topics over time. It focuses on how a research field develops, how new topics emerge, how older topics disappear or shift in focus, and how the relationships between topics change. This section provides an overview of the connections between keywords, authors, and countries, as shown in Figure 4 below.

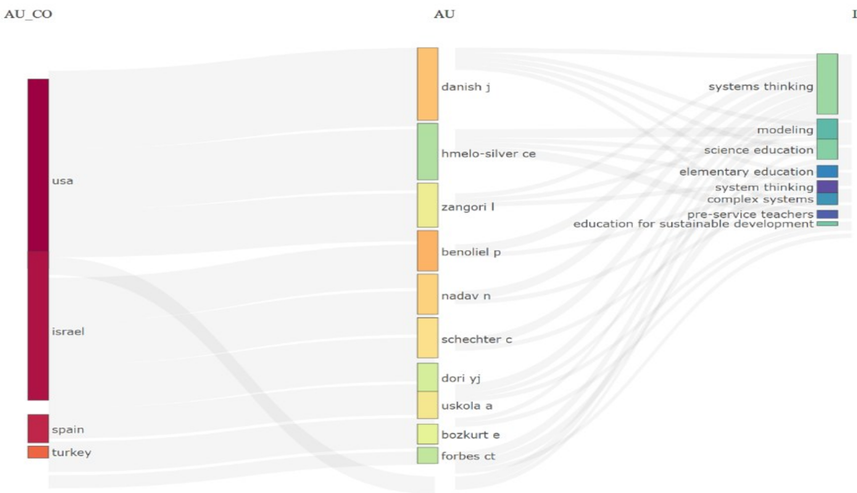

Figure 4. Sankey Diagram of System Thinking on Science Education in Elementary School

Figure 4 above shows that the dominant keywords are system thinking, science education, and elementary education. The author associated with these three dominant keywords is Danish.

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Network Visualizations and Thematic Map Keyword

Network Visualizations in bibliometrics is a graphical representation technique used to map and analyze relationships between entities in bibliographic data. These entities can include authors, publications, keywords, institutions, or countries. This visualization helps in understanding the structure and dynamics of a research field in a more intuitive and comprehensible way. All keywords were used to create a Co-occurrence map using VOSviewer, which further provides insights into the thematic map. The visualization results are presented in Figure 5 and Figure 6 below.

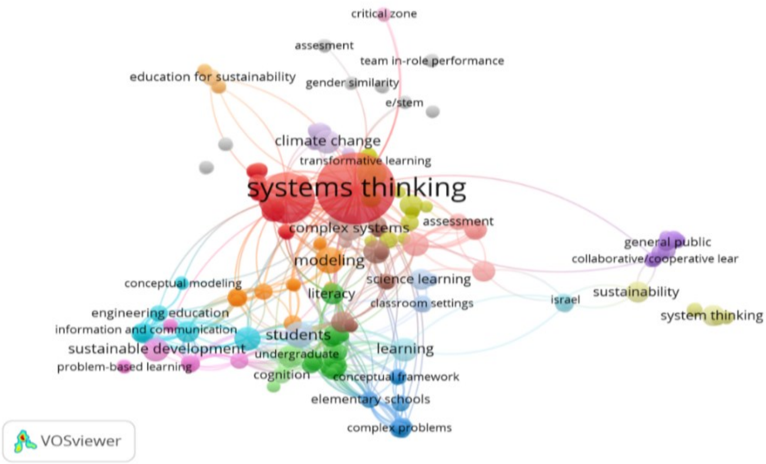

Figure 5. Mapping Keywords

Additional analysis using VOSviewer was conducted to confirm the bibliometric analysis results obtained with Biblioshiny. Figure 5 shows that keywords related to systems thinking have been widely used by previous researchers across various topics. Several themes remain interesting research issues, including sustainability development goals, climate change, gender similarity, and conceptual frameworks, among others. Future research can follow current topic trends, particularly by exploring the connections between systems thinking, science learning, and elementary schools.

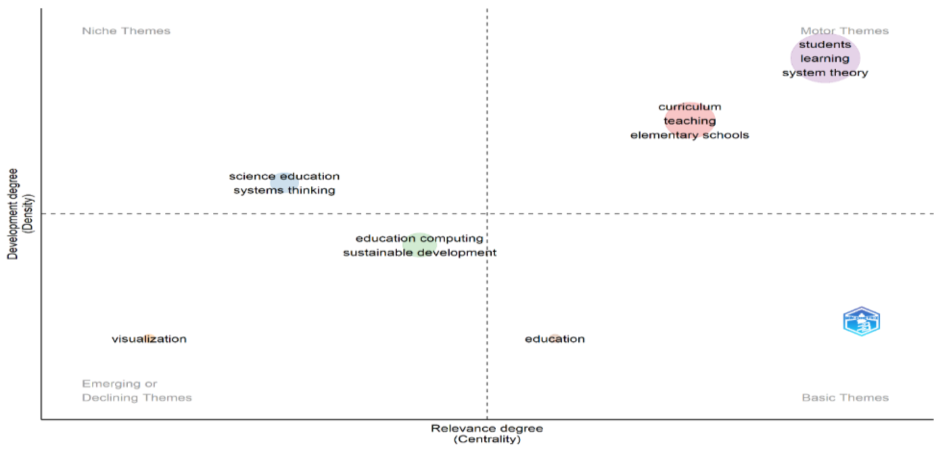

Figure 6. Thematic Map

Figure 6 is one of the most important figures in this study. This research analyzes the thematic map by dividing it into four thematic quadrants based on density and centrality. The upper right quadrant contains themes that should be further developed and studied, as it represents motor themes. This means that topics such as curriculum, teaching, elementary school, student learning, and system theory are well-established and crucial for shaping future research in this field. The upper left quadrant includes specific yet rare themes that are highly developed, characterized by high density but low centrality, such as science education and systems thinking. The lower left quadrant consists of declining trend topics, including education computing and sustainable development. The lower right quadrant features fundamental themes with high centrality but low density, such as education. The thematic map highlights the relationship between three key themes systems thinking and elementary schools both positioned in the upper right quadrant. Further research on the connection between systems thinking in elementary schools and science education presents a significant opportunity and is highly worth exploring, as it has high centrality but remains relatively underexplored to date. Science education in Indonesia, especially since the implementation of the 2013 Curriculum to the Merdeka Curriculum, has increasingly emphasized the importance of mastering 21st century competencies (Critical thinking and problem solving, Creative thinking, Collaboration, Communication). However, systems thinking skills have not received much attention in science learning practices at the elementary and secondary levels. Although the concept of systems thinking skills has great potential in improving the quality of science learning in Indonesia, research trends in this field are still relatively limited and have not been consistently focused. The development of the national curriculum and the challenges of continuing education open up great opportunities for researchers and educators to develop approaches, assessments, and learning models that can foster systems thinking skills in an integrated manner in science education in Indonesia.

The importance of learning that develops systems thinking skills in the context of science education lies in the fact that many surrounding phenomena are examples of complex systems, and understanding their functions requires systemic thinking (Evagorou et al., 2009). Therefore, students with systems thinking skills are expected to better understand how changes in one part of a system can affect other parts, as well as how each component is interconnected. Systems thinking is defined as a set of strategic and analytical skills aimed at enhancing the ability to identify and understand a system, predict human behavior, design, and modify something to assist human tasks (Arnold & Wade, 2015). In line with this, systems thinking is also the ability to reason systematically in relation to biological characteristics (Gilissen et al., 2020). The application of systems thinking skills contributes to an integrated decision-making framework, stimulating students to conduct a thorough examination before making decisions (Davidson & Venning, 2011). Students' ability to understand the dynamics of living systems will develop through systems thinking competence (Schuler et al., 2018). Additionally, systems thinking competence can help improve standard operating procedures in disaster management and similar future events (Lin & Chien, 2019). Systems thinking competence includes: 1) The ability to recognize and understand relationships, 2) The ability to analyze complex structures, 3)The ability to understand how systems are embedded in different domains and at various scales, and 4) The ability to deal with uncertainty (Rieckmann, 2017). Therefore, systems thinking is highly suitable for elementary education, as it serves as a key competency that can help students understand living systems and address sustainability challenges.

On the other hand, students' perceptions have shown that they tend to see systems as separate or fragmented pieces of information rather than interconnected structures. They lack a dynamic and systemic perception of systems (Brown, 2014). This indicates that with the right instructional approach, students can develop their systems thinking skills. The research provides a positive answer to the question of whether such systems thinking skills can be cultivated at the elementary school level. The explanation above supports the possibility of developing systems thinking competence in elementary school students. It highlights that any educational approach can promote systems thinking in schools, based on the assumption that students can only actively participate in sustainable development if they are able to identify and understand complex global interconnections (Schuler et al., 2018).

The findings of the research trend on systems thinking skills indicate that science learning needs to shift from a linear approach to a holistic and contextual approach. Conceptually, this strengthens the understanding of science as an integrated science that plays an important role in continuing education. Practically, teachers, curricula, and assessments must be redesigned to develop students' systems thinking skills, so that they are able to understand and solve complex problems in the real world.

Conclusion

Based on the bibliometric analysis, it can be concluded that systems thinking skills can be promoted through science learning in elementary schools. The interconnections among keywords highlight a motor theme that requires further research, supported by curriculum studies and teaching approaches. The study of systems thinking skills in science learning should also consider previous research findings related to sustainable development goals, climate change, gender similarity, and conceptual frameworks. Furthermore, this bibliometric analysis is expected to strengthen education as a fundamental topic. The results of this analysis present an opportunity for future research on the implementation of systems thinking skills in science learning in Indonesian elementary schools.

Recommendation

The recommendations from this bibliometric analysis are aimed at researchers, teachers and practitioners regarding the need for the implementation of science learning at the elementary school level in Indonesia which specifically develops systems thinking skills. The science curriculum at the elementary school level needs to explicitly include a systems thinking approach in learning. The follow-up for science teachers is integrating systems thinking skills into learning plans, using contextual and interactive learning models, developing or adapting systems thinking assessment instruments, using visual media and simulations to build systemic understanding, linking science learning with global and local issues, attending training or professional learning communities. This recommendation aims for science teachers to not only convey scientific concepts linearly, but also train students to see the world as a whole and interconnected. With systems thinking skills, students will be better prepared to face complex and dynamic real-world challenges.

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