25 (3), 2024, 1317-1328

Jurnal Pendidikan MIPA

e-ISSN: 2685-5488 | p-ISSN: 1411-2531

http://jurnal.fkip.unila.ac.id/index.php/jpmipa/

Research Trends About Education for Sustainable Development (ESD) in Science Learning: A Bibliometric Analysis During 2014-2024

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Abstract: Education for Sustainable Development (ESD) has become a critical focus in science learning as it addresses global challenges such as climate change, sustainability awareness, and resource management. However, research on ESD in science education lacks a cohesive understanding of its thematic trends, global contributions, and the role of educators. This study aims to analyze the research landscape of ESD in science learning, identify dominant thematic trends, determine leading countries in publications, and emphasize the importance of teacher understanding in implementing ESD. A bibliometric analysis was conducted using the Scopus database, with data retrieved on May 17, 2024, using the keywords "ESD in Science Learning." The study analyzed 79 publications from 2014 to 2024, including journal articles, conference papers, reviews, and proceedings. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework was applied to screen and organize the data. Bibliometric mapping with VOSviewer revealed key thematic trends, including sustainability education, climate change, collaborative learning, and innovation in teaching. Results indicate that most research originates from developed countries, with social sciences and environmental science as the dominant subject areas. Additionally, findings highlight the urgent need for teacher capacity building to effectively integrate ESD principles into science curricula. In conclusion, this study provides a comprehensive overview of ESD research in science learning, identifies gaps, and highlights opportunities for future research and teacher training to promote sustainable development goals (SDGs).

Keywords: education for sustainable development, science learning, bibliometric analysis, PRISMA.

▪ INTRODUCTION

Every country's citizens require education to set the stage for the knowledge and attitudes that will grow and build a sustainable society (Aikens et al., 2016). After the 2015 Education Decade for Sustainable Development, the United Nations approved 17 Sustainable Development Goals (SDGs), showing the growth of global efforts to achieve a sustainable society. According to Hallinger, P., & Chatpinyakoop, C. (2019), education can help the next generation of global citizens develop values, attitudes, and sustainable behaviour, which is essential for accomplishing all of the SDGs and bringing about the change needed to create a sustainable nation (Kioupi & Voulvoulis, 2019).

Education for Sustainable Development (ESD) has become a global imperative in addressing interconnected challenges such as climate change, biodiversity loss, and social inequality. As emphasized by (UNESCO, 2018), ESD equips learners with the critical thinking and problem-solving skills to navigate sustainability issues. Science education is particularly vital in this effort, as it provides a foundation for understanding environmental systems, fostering awareness, and inspiring action toward sustainable

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DOI: http://dx.doi.org/10.23960/jpmipa/v25i3.pp1317-1328
Received: 22 November 2024
Accepted: 18 December 2024
Published: 23 Deccember 2024

practices (Sposab & Rieckmann, 2024). The rising urgency of achieving the United Nations Sustainable Development Goals (SDGs), particularly SDG 4 on quality education and SDG 13 on climate action, underscores the critical role of ESD integration into science learning (United Nation, 2022).

Science education serves as a powerful platform for engaging students in sustainability. By exploring topics such as renewable energy, ecosystem balance, and sustainable consumption, students gain insights into the interdependence of social, economic, and environmental systems (Berglund et al., 2014). This holistic approach deepens their scientific understanding and empowers them with the skills and attitudes to contribute to sustainable development initiatives.

Despite its importance, the integration of ESD into science education still needs to be improved. Many curricula must adequately address sustainability concepts or provide educators with the tools for effective implementation. Furthermore, existing studies on ESD often require a comprehensive overview of research trends, hindering the ability to identify effective strategies for embedding sustainability into science learning (Vilmala et al., 2022). Educators face numerous challenges in implementing ESD within science education, including limited training, insufficient resources, and time constraints within the curriculum. These barriers affect the quality of sustainability education and limit students' ability to develop essential competencies such as systems thinking and anticipatory skills.

Given the rapid growth of research on ESD, a comprehensive synthesis is essential to map existing knowledge, identify gaps, and provide strategic insights for future studies. Bibliometric analysis can serve this purpose by revealing trends, influential authors, and collaboration networks in ESD research within science education (Grosseck et al., 2019). This approach offers a systematic and data-driven method to evaluate the development of ESD as a field and its impact on science learning.

While meta-analysis and systematic reviews are commonly used to synthesize research, they summarize findings from specific studies. On the other hand, bibliometric analysis offers a broader perspective by examining publication patterns, citation networks, and thematic evolution over time, making it particularly valuable for understanding the overall landscape of ESD research. Bibliometric analysis provides unique insights into research trends by identifying key themes, leading contributors, and emerging areas of interest. It also helps trace the evolution of ESD research in science learning, offering a comprehensive view of its progress and potential directions (Grosseck et al., 2019). This makes it an ideal approach for synthesizing research on a rapidly evolving topic like ESD. Considering the advantages of bibliometric analysis, this study adopts it as the primary method for analyzing research trends on ESD in science learning. By leveraging bibliometric tools, the study aims to provide a detailed overview of publication trends, identify influential works and authors, and uncover thematic patterns that can inform future research and policy directions.

The findings of this bibliometric analysis are expected to have significant implications for educators, researchers, and policymakers. For educators, it can offer insights into practical strategies for integrating ESD into science curricula. For researchers, it visualizes the intellectual structure, conceptual dynamics, diffusion of knowledge, development over time, research trends (identifying the fast-growing/popular, topical areas), core authors, top journals, leading countries and

institutions, the impact of collaboration, etc (Grosseck et al., 2019). For policymakers, it highlights the importance of supporting initiatives that promote sustainability education.

This study emphasizes the critical need to understand and advance ESD in science learning through a comprehensive bibliometric analysis. By identifying trends, challenges, and opportunities, it aims to contribute to the global effort of achieving sustainability through education. The results of this research can serve as a foundation for developing evidence-based strategies to enhance the role of science education in promoting sustainability (UNESCO, 2018).

▪ METHOD

Research Design

This evaluation is based on precise quantitative inquiry. We assessed the writing on advanced innovation within the field of instruction by bibliometric examination; bibliometrics utilizes a quantitative approach to degree, track, and analyze the social and auxiliary connections between different components of the writing (Donthu et al., 2021; Rojas-Sánchez et al., 2023).

Study Search Procedure

We assessed the Scopus display on May 17, 2024, and conducted a web display with the ESD in Science Learning slogan. The distribution period is 2014 - 2024. Using mottos and article titles, questions about bunches and points use Scopus sources. The database contains 79 articles related to ESD in Science Learning, including 12 conference papers, 61 articles, three conference surveys, and three surveys. The filtered information is compiled using flow graphs that utilize Favored Announcing Things for Precise Surveys and Meta-Analyses (PRISMA) (Moher et al., 2009; Angelito & Angeline, 2023; Sarı & Aypay, 2024).

In the identification stage, a total of 109 documents were retrieved from the SCOPUS database as the initial dataset for the study. This stage focuses on compiling a comprehensive list of potentially relevant documents without applying any filtering criteria, ensuring an inclusive search to capture all documents related to the research topic. During the Screening stage, an initial review was conducted of the 109 identified documents to assess their relevance. This involved evaluating the titles and abstracts of the papers to determine their alignment with the study's objectives. As a result, five documents were excluded for being irrelevant to the research focus, leaving 104 documents that passed this initial screening. This step aims to refine the dataset by eliminating documents that do not meet the basic relevance requirements.

The Eligibility stage involved a more detailed and manual review of the 104 remaining documents. Full texts of these documents were analyzed to ensure they met predefined inclusion criteria, such as methodological rigor, relevance to the research objectives, and availability of required data for analysis. Following this in-depth evaluation, 25 documents were excluded due to reasons such as lack of alignment with the research scope or insufficient data. Consequently, 79 papers were identified as eligible for the subsequent analysis. Finally, in the Inclusion stage, the 79 eligible documents were incorporated into the quantitative bibliometric analysis. This stage represents the final selection, confirming that all included documents meet the necessary standards for validity and reliability in the study. These documents form the dataset for the analysis and are expected to provide valuable insights into the research topic. Each stage of the process

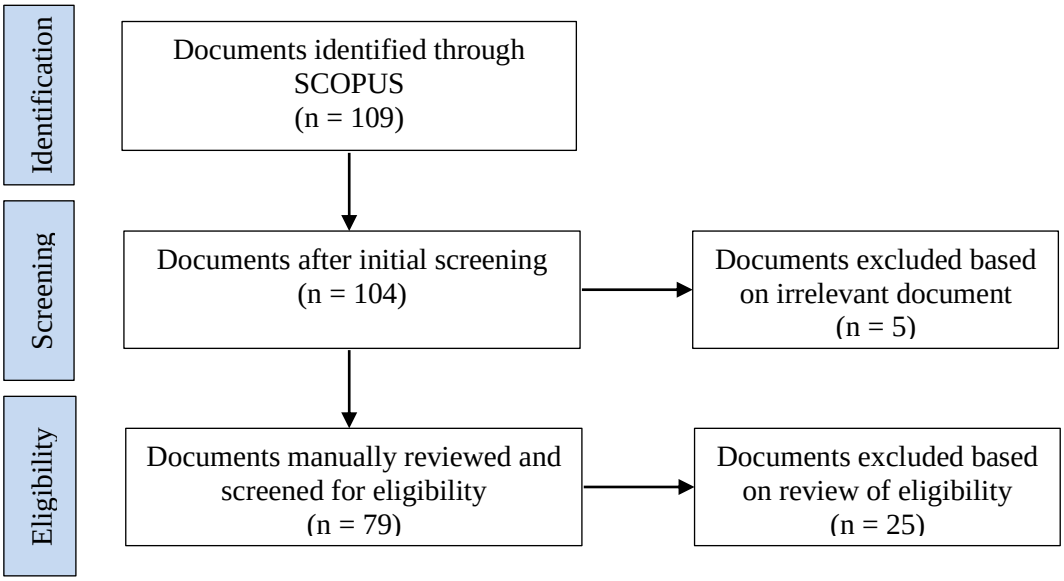
was meticulously designed to ensure the systematic and rigorous selection of documents.

Inclusion and Exclusion Criteria

The researcher is guided in making precise and well-informed selections about which papers to analyze based on the inclusion and exclusion criteria. The studies that were selected for this study met the following precise criteria: To ensure that current and pertinent research is included, the publications must first have been published between January 2014 and May 2024. Second, as long as the papers were indexed and recognized by the SCOPUS database—which is renowned for its extensive and superior collection of scholarly publications—they might come from any nation. Third, to guarantee consistency and accessibility in the analytic process, only English-language papers were included. Finally, to be in line with the goals and scope of the study, the studies must specifically address Education for Sustainable Development (ESD) about scientific education. Only research that satisfied all of these conditions was included in the final analysis thanks to the methodical use of these precisely specified inclusion criteria, which were used to filter and choose the most pertinent publications. The validity, applicability, and quality of the study findings were all preserved by this exacting screening procedure.

Data Analysis

In this study, sample articles from Scopus in *RIS formats are processed using the VOSviewer to facilitate visualization and trend detection (Novia et al., 2021; Salmi et al., 2017; van Eck & Waltman, 2010). The Center for Science and Technology Research has created VOSviewer, software for creating and viewing bibliometric networks. The distribution of publications by year and genre, publication time and type trends, producing countries and universities, and research areas studied at Leiden University can be seen (Kousha & Thelwall, 2018). The VOSviewer can also evaluate online bibliometric data, including citation relationships between publications or journals, collaboration between researchers, and co-publishing of scientific publications (Strozzi et al., 2017).



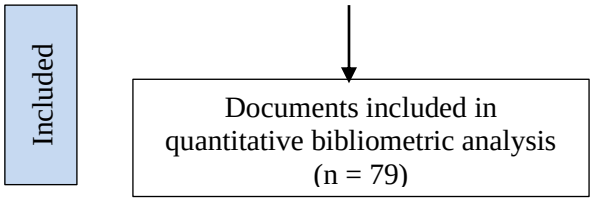


Figure 1. PRISMA guidelines describing the collection of documents from SCOPUS

▪ RESULT AND DISSCUSSION

The study, after the discoveries, examines the writing on issues related to Instruction for Education for Sustainable Development (ESD) in Science Learning, which has been accomplished within the parameters of the inquiry about the venture. Investigate discoveries are displayed within the frame of tables and figures.

The Thematical Trend

Ten-year public productivity trends (2014-2024) are based on the Scopus database and highlight relevant variations. In this case, the trend of sustainable education in learning varied over ten years. The number of published documents proves this. Figure 2 shows the annual publication trend.

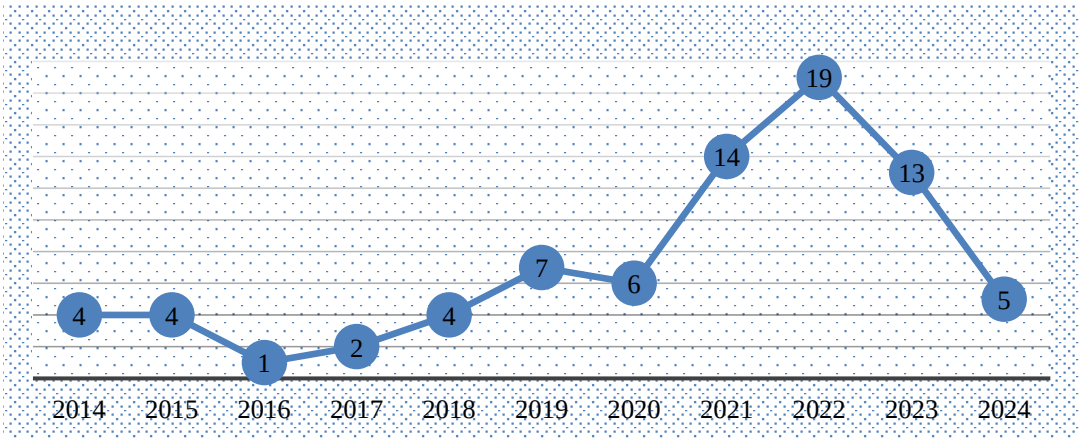


Figure 2. Papers regarding digital technology on physics experiments published in one decade

Figure 2 illustrates the number of research papers published each year from 2014 to 2024, focusing on applying digital technology in physics experiments, showing a fluctuating trend with notable periods of stability, growth, and decline. Initially, the publication rate was relatively low, with four papers published in both 2014 and 2015, followed by a decrease to 2 documents in 2016 and 2017. Starting in 2018, there was a gradual increase, with four papers that year, 7 in 2019, and a slight decrease to 6 in 2020. This upward trend accelerated significantly in 2021, reaching 14 publications, and peaked in 2022 with 19 papers, marking the highest point in the decade. However, the number of publications declined, with 13 papers in 2023 dropping further to 5 in 2024, indicating a possible shift in research interest or other influencing factors affecting publication output

in this field. As with the bibliometric analysis carried out by Kanaya (2023), the number of artifacts increases and decreases every year.

Top Countries in Publications About Education for Sustainable Development (ESD) in Science Learning

Counting articles by country for the keyword ESD in science education, ten countries have publications on sustainable education in science education. These countries are Germany, Indonesia, Spain, Japan, Portugal, Australia, Norway, South Africa, Sweden and Taiwan. Germany is the country that has published the most articles on sustainability in science learning, with 15 articles. The second country is Indonesia, which has 14 articles; Spain, which has six articles; Japan and Portugal, which has four articles; and Australia, Norway, South Africa, Sweden, and Taiwan, which has three articles each. Germany has the highest number of ESD articles in science education. This statement is obtained from VOS Viewer 1.6.18 results with CSV and RIS files. Table 1 shows the top 10 countries/regions using digital technology to study physical exams.

Table 1. Top-10 Countries/Territory for digital technology in physics experiments research

Country/Region	Frequency
Germany	15
Indonesia	14
Spain	6
Japan	4
Portugal	4
Australia	3
Norway	3
South Africa	3
Sweden	3
Taiwan	3

In addition, since scientific publications are divided into different categories, Figure 3 illustrates the top 10 topics. In particular, the main subjects that are most present are social sciences (55, 30.6%), environmental sciences (29, 16.1%), and energy (23). , 12.8%), informatics (20, 11.1%), engineering (14, 7.8%), physics and astronomy (12, 6.7%), mathematics (6, 3.3%), medicine (4, 2.2%), Business and Management (3, 1.7%) and Agriculture and Biology (2, 1.1 %), which are the least published fields (Strozzi et al., 2017).

Social Sciences dominate the field of study, reflecting the important role of sociocultural factors in ESD research. Implementing Education for Sustainable Development (ESD) based on climate change in social studies education (Septiani, 2020). Environmental science is important in ESD, focusing on natural resource management, environmental literacy, and ecological awareness. The energy sector is important in ESD research, especially in promoting renewable energy education (Agung et al., 2024). In computer science, ESD-related studies highlight using technology, simulations, and digital tools to support sustainability learning. Engineering research emphasizes

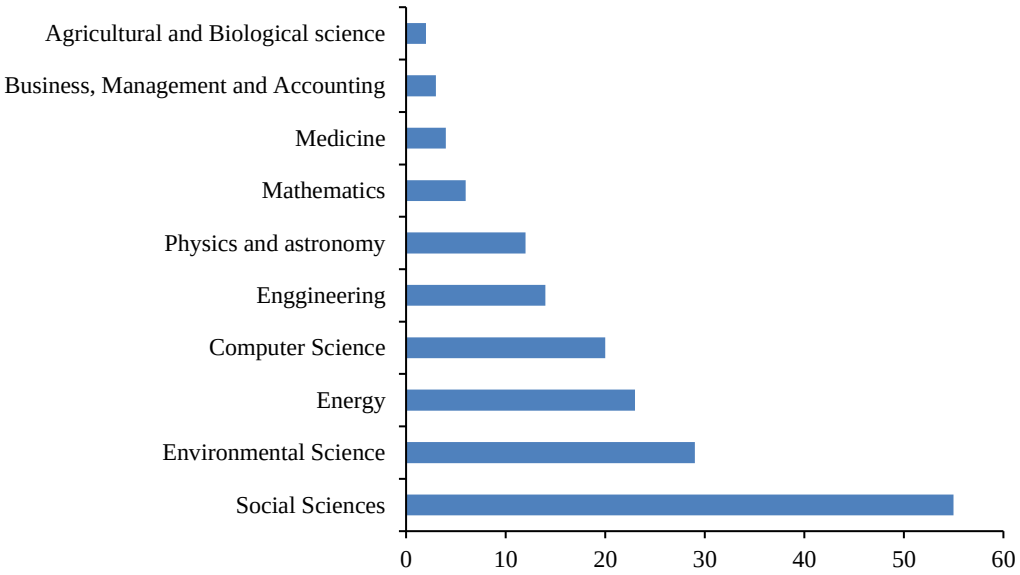


Figure 3. Visualization of subject area from Scopus analysis

integrating sustainability principles in design, manufacturing, and infrastructure development. ESD research in physics and astronomy tends to focus on energy conservation, renewable energy technologies, and planetary sustainability. Mathematics in ESD emphasizes quantitative analysis, modeling, and systems thinking. Research in medicine focuses on environmental health, sustainable healthcare practices, and education about the impact of pollution and climate change on human health. This study area emphasizes sustainable business practices, corporate social responsibility (CSR), and environmental accounting. Research in agriculture focuses on sustainable agriculture, food security, and biodiversity conservation. Digital transformation has emerged as a transformative force that is reshaping business paradigms across functional domains (Zulkifli et al., 2023).

Keywords can aid in the clarification of the primary research issue and research direction of "ESD in science learning" and are regarded as "macroscopic-level content descriptors" (Chen et al., 2019). Figure 4 shows the number of publications by document type. Articles are the most numerous (77.2%), conference papers (15.2%), conference reviews (3.8%), and reviews (3.8%). There is great potential for this research to be researched and published, but also how interesting it is to be published in credible conference papers.

The Main Trend of The Education for Sustainable Development (ESD) in Science Learning

Previous studies have suggested mapping metadata keywords to find innovations (Gamage et al., 2022; Goerlandt et al., 2021; Chen et al., 2021). Consequently, it's critical to observe the relationship between more minor or less significant terms. Figures 5, 6, and 7 visualize the mapping of keyword occurrences in all Education for Sustainable Development (ESD) in Science Learning (2014–2024). It is noteworthy to highlight the classification of research subjects related to ESD in scientific learning since 81 words met the criteria out of a minimum of 549 keywords that appeared. Additionally, the network

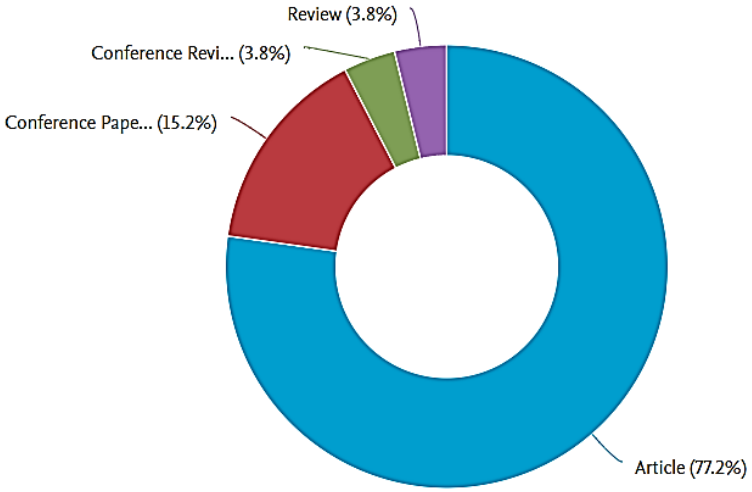


Figure 4. Publications based on documents by type issued

visualization was divided into seven clusters. The clusters are orange, sky blue, purple, yellow-green, green, and blue. According to (Zhang et al., 2022), larger circles correspond to higher document keyword frequencies. The network visualization created with VOSviewer is shown in Figure 5, emphasizing the networks and phrases that are most often used.

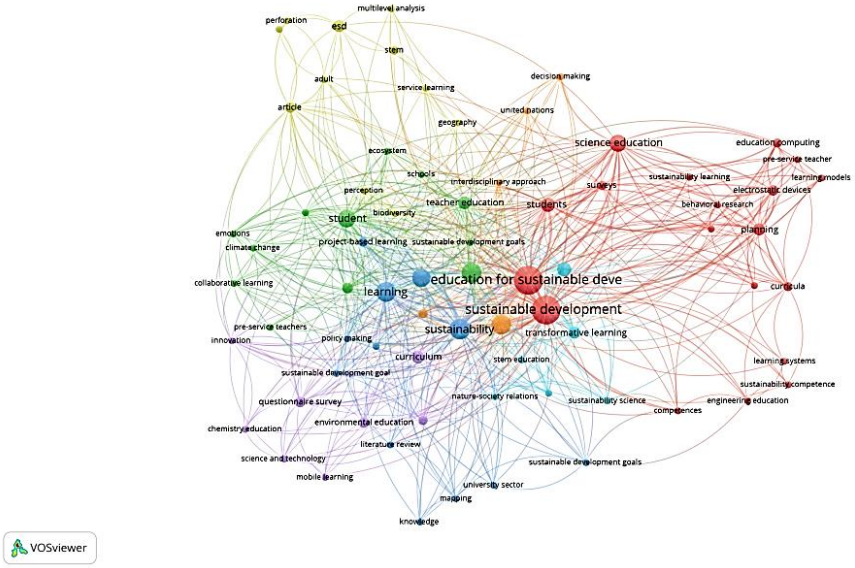


Figure 5. Network visualization of co-occurrences with index keywords

The overlay visualization was symbolized by the colours showing yearly experimental trends, where purple and yellow prioritized years of study and recent analysis, respectively. These recent trends focused on the following terms: climate change, emotions, educational status, collaborative learning, human experiments,

sustainable development goals, education for sustainable development, innovation, and teaching. The overlay visualization of co-occurrence is shown in Figure 6.

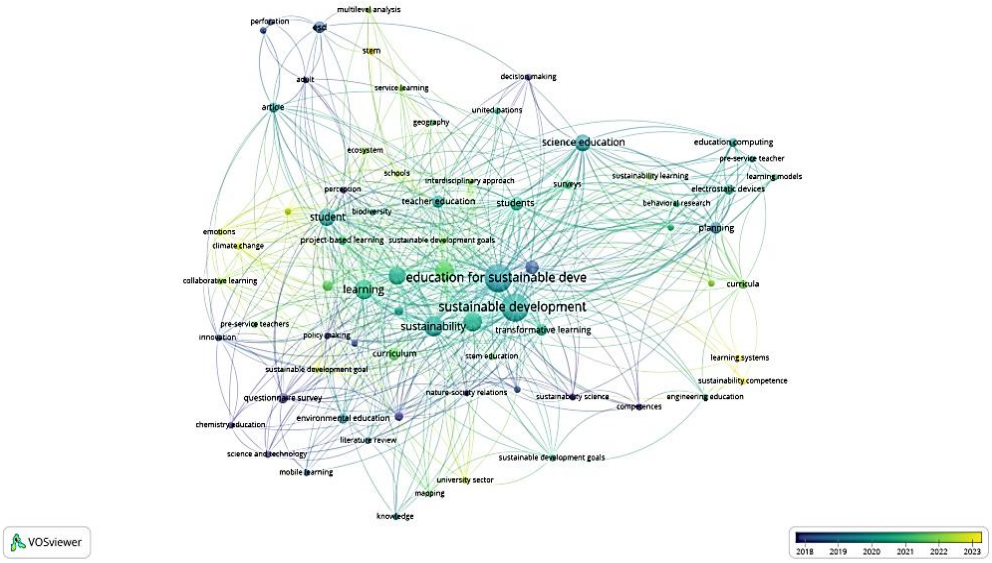


Figure 6. Overlay of visualization of co-occurrences with index keywords

The saturation of a topic, where the blue, yellow, and red colours indicated areas that needed more analysis, were rarely investigated, and were highly regarded, was caused via density visualization. This suggested that brighter image colours induced the frequent use of the studied phrase in a pertinent experiment. The keyword density distribution also demonstrated the frequent level of study topics (Huang et al., 2020). For instance, sustainable development goals and education sustainable goals were frequently applied analytically. In contrast, pertinent terms infrequently examined were behavioural research, learning systems, educational computing, multilevel analysis, chemistry education, sustainability learning, and electrostatic devices. The density visualization of problem-solving and decision-making abilities on keyword index is shown in Figure 7.

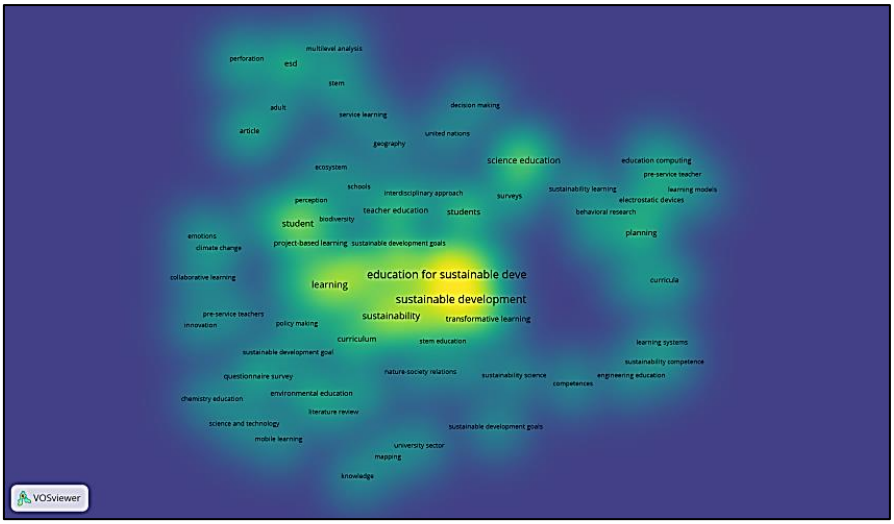


Figure 7. Density visualization of topic decision-making and problem-solving based on keywords

The Need for Teachers to Understand Education for Sustainable Development (ESD) in Science Learning

The need for teachers to understand Education for Sustainable Development (ESD) in science learning has become increasingly critical in addressing global challenges such as climate change, resource depletion, and environmental degradation. As educators play a pivotal role in shaping students' knowledge, skills, and values, teachers must integrate ESD principles into science curricula to foster sustainability awareness, critical thinking, and problem-solving abilities among learners (UNESCO, 2018). Teachers well-versed in ESD can design engaging, interdisciplinary, and context-specific science lessons that connect scientific concepts to real-world sustainability issues, enabling students to understand the interconnectedness between environmental, social, and economic systems (Barth et al., 2018). Furthermore, empowering teachers with ESD competencies ensures they can promote active learning strategies, such as project-based learning, collaborative inquiry, and systems thinking, which are key for preparing students to contribute to sustainable development goals (SDGs) (Filho et al., 2023). However, research highlights that many educators face challenges in effectively implementing ESD due to a lack of professional development, and limited resources. Addressing these barriers by providing teacher training programs and supporting resources is crucial to enable educators to integrate ESD seamlessly into science learning, ultimately equipping future generations with the skills and values needed for a sustainable future (UNESCO, 2018).

▪ CONCLUSION

This manuscript provides a comprehensive overview of global research trends in ESD in the context of science learning. By analyzing 79 Scopus-indexed publications collected on May 17, 2024, using bibliometric methods, including keyword analysis and VOSviewer, this research identifies thematic trends, leading countries in publications, and the main directions of ESD research. These findings reveal significant growth in research addressing sustainable development goals, climate change, innovation, and collaborative learning as dominant themes in recent years. Furthermore, this analysis highlights the important role of teachers in understanding and implementing ESD to foster sustainability awareness and critical thinking in science education. These insights underscore the need for professional development programs to bridge knowledge gaps among educators and increase the integration of ESD into science curricula. Overall, this research offers a clear perspective on developments in ESD research, providing a foundation for future research and educational initiatives to promote sustainable development through science learning.

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