Research Progress, Trends, and Updates on STEM Learning-ESD: A Bibliometric Analysis

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Abstract: The aim of this paper is to analyse research trends and address knowledge gaps in order to improve STEM-ESD learning. Technical terms are explained upon first use, and sentence structure is clear and unambiguous. The bibliometric review examines current research progress, trends, and updates related to STEM-ESD learning. The study used the Scopus database to select documents and VOSviewer software to investigate bibliometrics. STEM-ESD research shows an upward trend based on the analysis of 19 collections of STEM and ESD learning papers from 2010 to 2023. Indonesia leads in conducting STEM-ESD research, with the highest number of publications on this theme in 2022. In 2010, the significance of STEM-ESD research was its application in the STEM curriculum. STEM-ESD research has facilitated the inclusion of various social science topics in the learning process. This fosters 21st-century skills in students through a project-based learning model. Further STEM-ESD research can be advanced by improving pedagogical design capacity, biodiversity, sustainable development goals, formal and initial teacher training, biology education, and sustainable learning. This will lead to more innovative research.

Keywords: Bibliometric analysis; ESD; STEM

Introduction

STEM education is crucial for developing problem-solving, critical thinking, creativity, and collaboration skills that are essential in the 21st century (Fajrina et al., 2020; Piddiachyi, 2022; Suherman et al., 2022). Moreover, it prepares students for productive activities and forms the competencies required for industrial development (Fathoni, 2020). By integrating science, technology, engineering, and mathematics, STEM education offers a comprehensive methodology that empowers students with essential proficiencies and knowledge necessary to succeed in an ever-evolving world. Education for sustainable development (ESD) is important because it equips individuals with the knowledge and skills needed to address pressing global challenges and promote a sustainable future (Hübscher et al., 2023). It helps individuals understand the concept of sustainable development and its three dimensions: environmental, economic, and social (Faustino & Kaur, 2023). Education plays a crucial role in shaping behavior and promoting sustainability in various sectors, including business and economics (Huang, 2023). It empowers individuals to think and act in favor of sustainable development, fostering a mindset that supports sustainability in future activities (Machado & Davim, 2023). Access to quality education is essential for the proper functioning of a sustainable society (Lorek et al., 2023). By integrating sustainability education into higher education, students can develop a comprehensive perception of sustainability issues and become active participants in addressing them. Overall, education for sustainable development is crucial for creating a more sustainable world by promoting awareness, knowledge, and action towards sustainable practices.

A comprehensive review is necessary to establish an objective understanding of the significance of STEM and ESD education. This includes analyzing research

gaps and trends while updating data sets to enhance knowledge in STEM-ESD learning. To determine gaps in the field, it is crucial to utilize scientific findings from published literature. Biometric analysis has been proven effective in outlining current research trends across several fields, as demonstrated in Table 1.

Table 1. Previous Research on Bibliometric Analysis

Title	Topic discussion	Ref
Bibliometric analysis of scientific publications in the field of online education	A bibliometric analysis on education is conducted to study the conceptual apparatus of online education before and after the COVID-19 pandemic and identify current trends in the field.	(Shcherbachenko & Kotenko, 2023)
Bibliometric Analysis: Technology Studies in Science Education	A bibliometric analysis on education is conducted to provide important information to researchers and to identify trends and relationships in the field of education.	(Kadirhanogullari & Kose, 2023)
A bibliometric analysis of digital storytelling in language education	A bibliometric analysis on education was conducted to examine the growth and development of digital storytelling in language education.	(Avci & Kasimi, 2023)
A Bibliometric Analysis of Biodiversity Education	A bibliometric analysis was conducted to evaluate the importance of biodiversity education and its relationship to scientific studies, researchers, and journals in the field.	(Derman, 2023)
Bibliometric Analysis and Benchmarking of Life Cycle Assessment of Higher Education Institutions	A bibliometric analysis on education is conducted to identify patterns, best practices, and key challenges faced by universities when applying life cycle assessment.	(Deda et al., 2023)

To elucidate progress and trends in STEM-ESD learning, this paper presents a bibliometric analysis based on a review of Scopus articles from 2010-2023. The analysis focuses on the following research inquiries: What are the developing trends in STEM-ESD learning research? What are the current STEM-ESD learning trends? and What is the current status of STEM-ESD learning research? Unlike previous review articles that relied solely on literature searches to identify and explain important concepts and advancements in the STEM field, this research explores the integration of ESD in STEM to pinpoint crucial gaps that require further study. The novelty of this article lies in its bibliometric review of STEM learning combined with ESD. The challenges in STEM-ESD research in Indonesia include the lack of knowledge and application of STEM approaches in science instruction at schools.

Method

Bibliometric analysis was employed to investigate publication and citation patterns, identify prominent contributors and themes, analyze partnership structures, and recognize developing research trends (Shcherbachenko & Kotenko, 2023). Bibliometric analysis is a quantitative assessment tool used to classify and evaluate bibliographic material in a scientific discipline. It involves analyzing bibliographic data from electronic databases and extracting indicators such as the h-index. These analyses are increasingly accepted in the medical literature to identify influential papers, authors, and institutions on a given topic (Lazarides et

al., 2023). It is also used as a literature review tool to determine the development course of a field or publication institution, identify deficiencies, and guide future studies. Over the years, there have been advances in data availability and analytic techniques for bibliometric analysis, but validity and relevance issues remain, such as how to validate results and appropriately use them externally. The bibliometric analysis was carried out on October 20, 2023, using the Scopus database and the keywords STEM AND learning AND ESD. No year constraints were imposed on the screening process, and 19 articles were published between 2018 and 2022. In Figure 1, data is presented on the distribution of publications by document type.
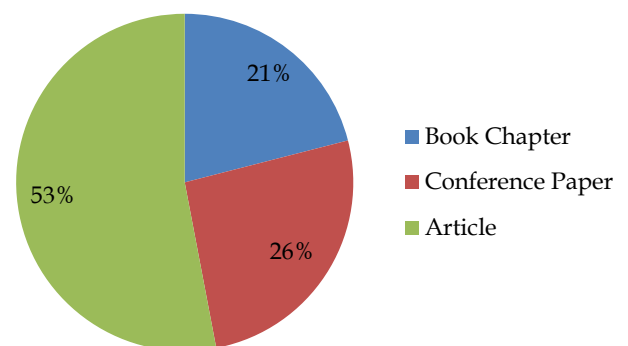

Figure 1. Presentation of publications based on document type

The data was collected and saved in CSV format, and then analyzed using VOSviewer software. VOS Viewer is a tool for visual clustering analysis of

literature, publication profiling, and trend analysis within research fields (Lin et al., 2023; Rofik et al., 2022).

Result and Discussion

STEM-ESD Learning Research Development

The development of STEM-ESD research from year to year tends to increase this can be seen from the number of article appearances from year to year which has increased. The increase in STEM-ESD research development from year to year is in Figure 2.
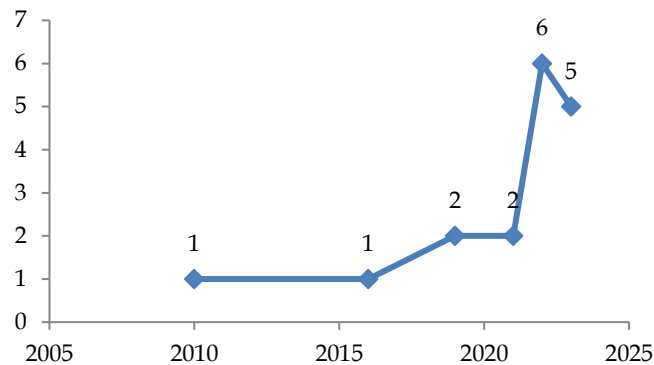

Figure 2. STEM-ESD research from 2010-2023

In the Figure 2, STEM-ESD research first appeared in 2010 with a total of 1 study, after which it reappeared in 2016. The development of STEM-ESD research is seen to have increased in the period 2019-2023. The year 2022 saw a significant development with a total of 6 studies. The increase in research data has opened up new dimensions of scientific knowledge, but it also requires the development of new methods and tools to fully utilize the vast amount of data available (Balter, 1995). The increase in research data provides unprecedented opportunities for conducting research (Chiarelli, 2023).

The research by country with the keyword STEM-ESD exists in 11 countries. The country with the most STEM-ESD research is Indonesia, followed by the United Kingdom and Spain, as shown in Figure 3.

Indonesia ranks highest in STEM ESD research. STEM education research in Indonesia faces several challenges. One of the challenges is the low quality of education, including unbalanced education output, inadequate facilities and infrastructure, and low quality and behavior of teachers (Nu'man et al., 2022). Another challenge is the lack of understanding and implementation of STEM education by teachers. While science teachers generally have a good understanding of STEM education, not many of them have applied the STEM approach in the classroom, leading to a weak understanding of STEM learning among students (Anggraeni et al., 2022). Additionally, there is a need for teacher training and development to reorient and

implement STEM learning systematically and continually (Madhakomala et al., 2022). Furthermore, there are challenges related to the differences in learning objectives and teaching methods compared to developed science education countries, which affects the teaching materials, learning process, and assessment in science education (Permanasari et al., 2021).
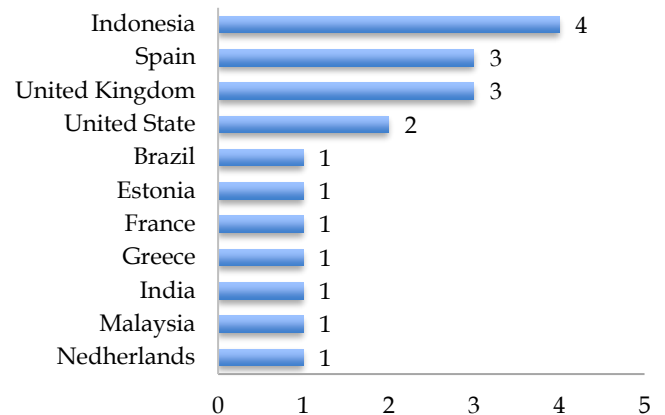

Figure 3. Ranking of STEM-ESD research countries/regions

Overall, addressing these challenges is crucial for the improvement and effective implementation of STEM education in Indonesia. ESD research in Indonesia faces several challenges. One challenge is the lack of material and non-material rewards for Indonesian scientists, which discourages them from returning to the country (Setiawan et al., 2023). Furthermore, there is a gap between academic research and industry, hindering the development of functional foods in Indonesia (Kusanagi, 2022). These challenges highlight the need for active collaboration between research institutes, universities, and industry, as well as supportive regulation systems, to enhance ESD research in Indonesia. Indonesia is crucial to achieving sustainable development in Southeast Asia (Tiawon & Miar, 2023). Environmental education is recognized by the country as being vital for promoting sustainable development and conservation practices (Charina et al., 2022; Parmawati et al., 2023). Indonesia's role in achieving education for sustainability is to promote quality education that incorporates knowledge, ethics and values related to sustainable development (Sr Yuliani & Hartanto, 2020).

Research trends in STEM-ESD learning

It is necessary to analyze some of the research results that have been conducted in order to find out the trend of STEM-ESD implementation. Table 2 shows 19 titles of articles that discuss the methods used and the results of STEM-ESD research.

Table 2. Articles about STEM-ESD Between 2010-2023

Title	Year
Practical pedagogy for embedding ESD in science, technology, engineering and mathematics curricula	2010
The great problems seminars: Connecting students with external stakeholders in project-based approaches to sustainable development education in the first year	2016
Social, transformative, and sustainable learning in a jamaican school and community	2019
Results, results, results: Seeking spaces for learning in a European global learning and STEM project	2019
Addressing sustainable development: Promoting active informed citizenry through trans-contextual science education	2020
Enculturing sustainable development concept through chemistry curriculum for education for sustainable development	2020
Integrating mathematics and science teaching in the context of education for sustainable development: Design and pilot implementation of a teaching-learning sequence about air quality with pre-service primary teachers	2021
Pre-Service Teachers' Perspectives: STEM as a Solution to Promote Education for Sustainable Development	2021
13th International Conference on Computer Supported Education, CSEDU 2021	2022
Foldscope Embedded Pedagogy in Stem Education: A Case Study of SDG4 Promotion in India	2022
ESD Based Environmental Pollution Learning Design for Junior High School Students	2022
Service Learning as an Education for Sustainable Development (ESD) Teaching Strategy: Design, Implementation, and Evaluation in a STEM University Course	2022
Implementation of STEM-Based Learning in the Context of ESD in Equipping Students' Problem Solving Ability	2022
Using STEM Learning Concepts with IoT Technology on the Road of Education for Sustainability: A Short Literature Review	2022
Impacts of integrating engineering design process into STEM makerspace on renewable energy unit to foster students' system thinking skills	2023
Capturing Pedagogical Design Capacity of STEM Teacher Candidates: Education for Sustainable Development through Socioscientific Issues	2023
Sustainable Development Goals and Science and Technology Education	2023
Socio-(im)material-making activities in Minecraft: retracing digital literacy applied to ESD	2023
Educational alliances for the implementation in french of key competences for sustainability in STEM; [Alianzas educativas para la implementación en francés de las competencias clave para la sostenibilidad en el área STEM]	2023

Based on the findings in Table 2, it can be inferred that STEM-ESD research first emerged in 2010, relating to ESD's application in the STEM curriculum (Hopkinson & James, 2010). In the subsequent years, STEM-ESD research's focus shifted towards its incorporation into the learning process (Kanapathy et al., 2020; Martín-Sánchez et al., 2022; Rico et al., 2021) by integrating numerous socioscientific issues (Maruli et al., 2022; Rico et al., 2021). Project-based learning is a teaching approach employed to foster students' 21st-century skills, such as problem-solving ability, systems thinking skills, and digital literacy (Stouthart et al., 2021; Yulianti & Kaniawati, 2022; Abdurrahman et al., 2023; Impedovo & Cederqvist, 2023). This method finds application in the implementation of STEM-ESD education, as reported in Daly & Brown (2019) and Pfeifer & Rosbach (2016). STEM approach to enhance students' science process skills (Syukri et al., 2021), creative thinking skills (Sawu et al., 2023). STEM-ESD research starts with the implementation of the ESD curriculum and then develops its implementation in the learning process by integrating it with other approaches to enhance students' 21st century skills (Asrizal et al., 2023).

STEM-ESD Learning Research Update

The VOS Viewer application was utilized in STEM-ESD learning research updates. This application facilitates the mapping of articles and identification of research uniqueness (Alifariki et al., 2022). Additionally, it aids in selecting research subjects by identifying fundamental themes and areas that have not been extensively studied (Effendi et al., 2021). VOSViewer offers three types of visualization for bibliometric mapping: network, overlay, and density (Ekaputra et al., 2022). Figures 4, 5, and 6 depict the network, overlay, and density visualization of STEM-ESD keywords in research publications indexed in Scopus.

Figure 4 visualizes a keyword or term that often arises, the larger the circle, the higher the intensity of its occurrence. The analysis resulted in 4 clusters with a total of 54 items, 268 links and a total link strength of 277. VOS Viewer's network visualization provides several benefits. Firstly, it allows for the analysis of research scope on specific topics by identifying basic themes and relationships between different topics (Alifariki et al., 2022). Secondly, it enables the visualization of network structures and states of nodes in ad-hoc networks, making monitoring and understanding of the network easier. Additionally, VOS Viewer's network visualization can be used to generate a semantics-constrained citation sub-network, focusing on specific

issues of interest in legal research (Gupta & Vlachos, 2020). Lastly, it facilitates the graphical display and comparison of performance statistics, such as viewer traffic, for different shows or events at discrete time intervals.

Overlay visualizations also allow for the analysis of readership activity within research fields, helping to identify differences in readership activity and trends within specific areas of study (Lazarides et al., 2023).

Figure 5 displays color discrepancies depicting the progression of article publications annually. This color variance can be utilized to identify gaps in previous research, allowing for fresh and innovative approaches in subsequent articles. The current topics being discussed, such as pedagogical design capacity, biodiversity, sustainable development goals, and formal, are represented by the yellow color.
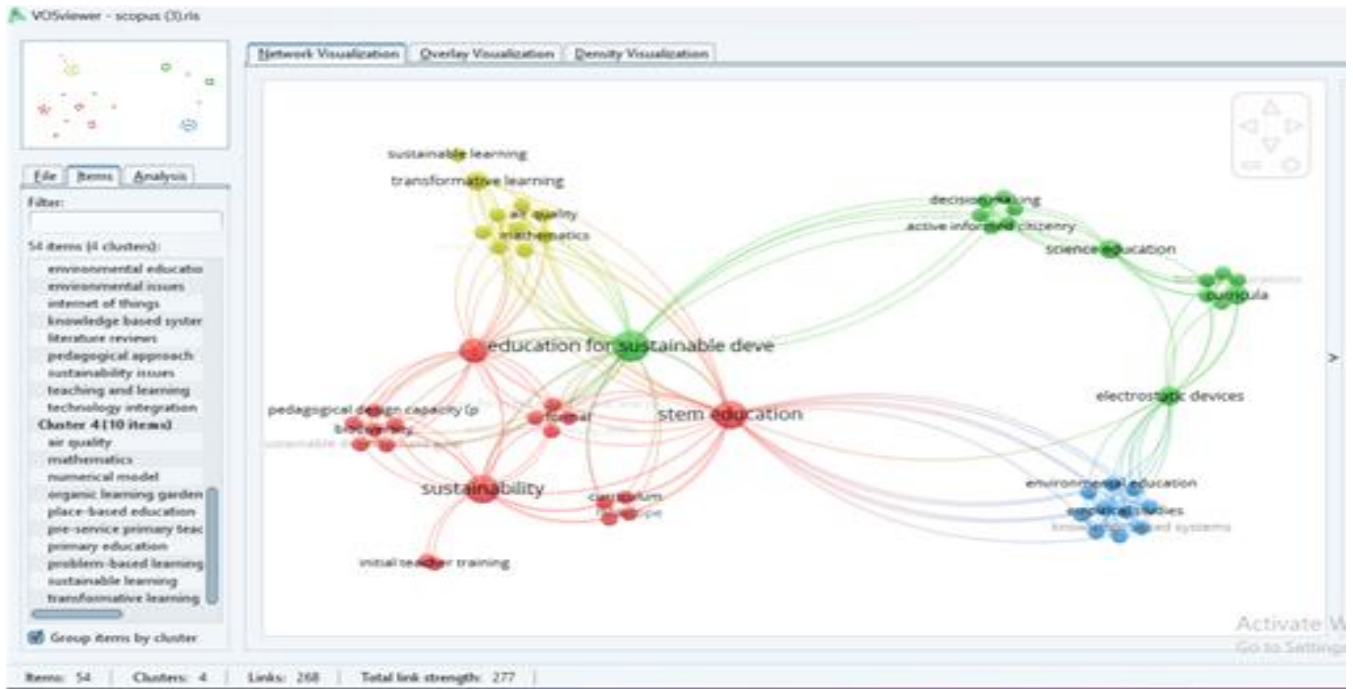

Figure 4. Presents a visualization of the topic areas via VOS Viewer's network visualization
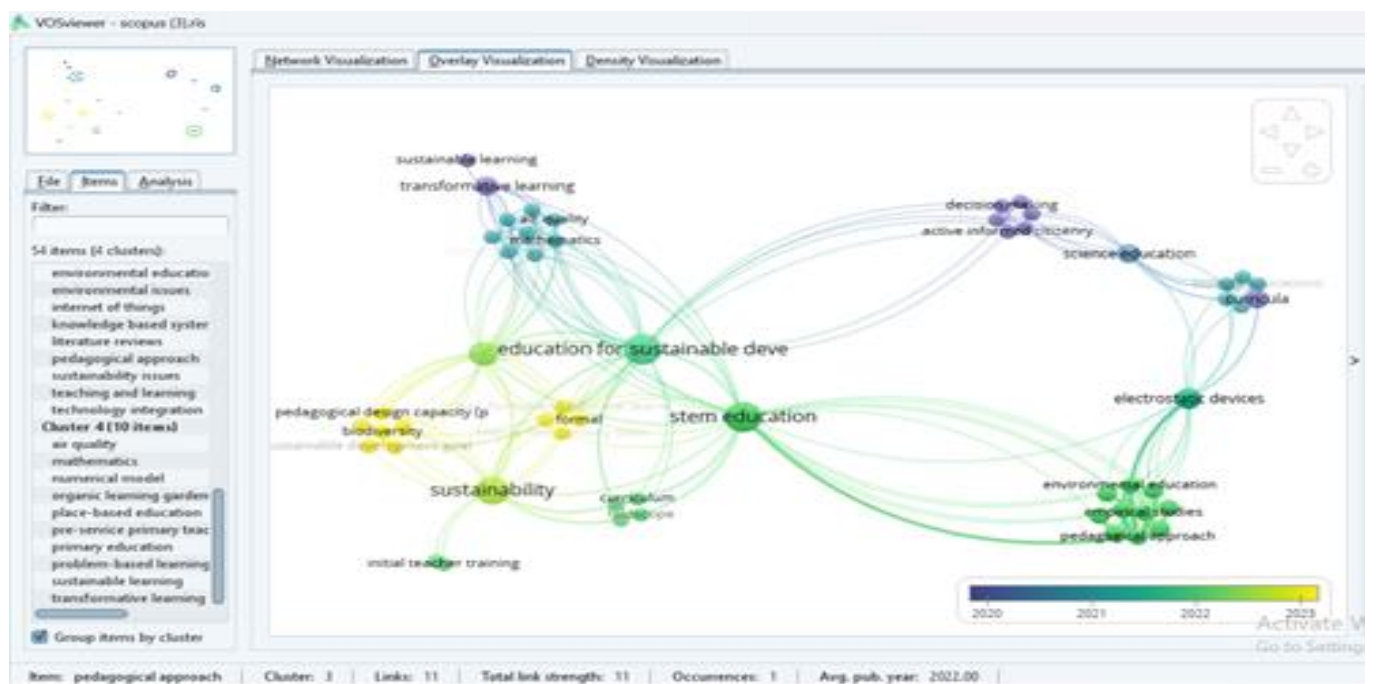

Figure 5. Visualization of topic areas using VOS Viewer using overlay visualization
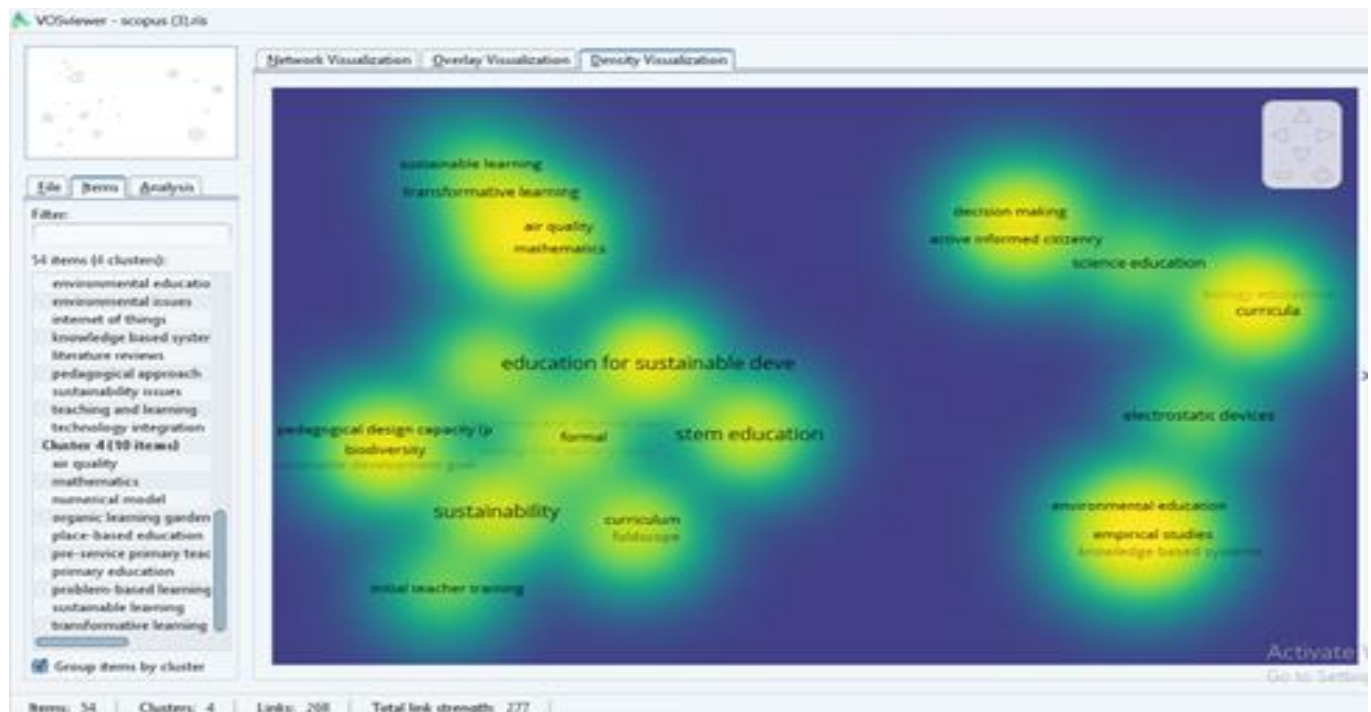
Figure 6. Visualization of topic areas using VOS viewer using density visualization

Figure 6 reveals variations in research density among the items. The yellow shading shows the intensity level. The more extensive the yellow portion, the more commonly researched or discussed the theme is. The fainter the color, the lower the saturation level, and, consequently, the rarer the research theme. The graph above illustrates that STEM education and Education for Sustainability Development are the most researched or frequently studied keywords. Conversely, keywords such as initial teacher training, biology education, and sustainable learning are still under-researched or rarely studied. This indicates that less explored themes can be investigated for potential research opportunities in the future.

Conclusion

Based on the results and discussion, it can be concluded that the research on STEM-ESD development, trends, and updates has increased from 2010 to 2023. Indonesia leads in STEM-ESD research, with the highest number of publications expected in 2022. 19 articles have been published as of now. STEM-ESD research began in 2010, with primary focus on the application of ESD in STEM curriculum. In the coming years, the STEM-ESD research topic will drive implementation in the learning process by utilizing various socioscientific issues to foster students' 21st-century skills through a project-based learning model. Future STEM-ESD research updates can explore pedagogical design capacity, biodiversity, sustainable development goals, formal and initial teacher training, biology education, and sustainable learning to uncover fresh insights for further research.

Author Contributions

As the primary author, S.S.L made contributions to idea generation, research, authoring research articles, data collection, processing, and analysis, and article writing. As the second, third, and fourth authors, A.W, I.K, and S.S helped to instruct and guide the first author.

Conflicts of Interest

The authors have disclosed that there are no conflicts of interest in relation to the publication of this paper.

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