

Bibliometric Analysis of ESD Research in Mathematics Education and Students' Mathematical Abilities



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ABSTRACT

This study aims to analyze the trend of scientific publications regarding the application of Education for Sustainable Development (ESD) in mathematics learning to students' mathematical abilities in the 2020–2025 period. The method used is bibliometric analysis by utilizing article data from Google Scholar through Harzing's Publish or Perish (PoP) and analyzed using VOSviewer software. A total of 991 articles were analyzed to examine the development of publications, citation patterns, and the relevance of research themes. The results showed a significant increase in the number of publications, with a total of 9,304 citations and an h-index value of 46. The focus of research shifted to the topics of mathematical problem-solving, creative thinking skills, STEM integration, and the implementation of ESD-based curriculum. However, the theme of the effectiveness of the application of ESD on students' mathematical abilities directly is still relatively limited. This research is important because there have not been many studies that systematically map the direction, dominant focus, and gaps of ESD research in mathematics learning, so that it has the potential to hinder the development of sustainable and targeted research. The impact of this research is to provide a strategic reference basis for researchers and educators in developing advanced research and ESD-based mathematics learning innovations that are relevant and have an impact on strengthening students' mathematical abilities

Article History

Received 2026-01-10

Revised 2026-01-25

Accepted 2026-02-10

Keywords

Education for Sustainable Development (ESD)
Mathematics Learning
Mathematical Ability
Bibliometric Analysis

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1. Introduction

This template is designed to assist you in preparing your manuscript; it is an exact representation of the format expected by the editor. To use this template, please just Save As to your document, then copy and paste your document here. The work should not have been published or submitted for publication else-where. Education through the learning process has an important role in shaping individual identity, developing character, and exploring their abilities and potential. As a conscious and planned effort, education aims to create a learning atmosphere and learning process that allows students to actively develop their potential, so that they have religious spiritual strength, self-control, personality, intelligence, noble morals, and skills that are useful for themselves, society, nation, and the state (Maryanti & Brand, 2021). Thus, education is carried out to create quality human resources to be able to contribute positively to the progress of the nation and state.

One of the main focuses in the Education 2030 agenda is to create a quality education system as an effort to support the achievement of Sustainable Development Goals (SDGs), which contains 17 goals related to various aspects of sustainability. These efforts are realized through learning that equips students with the ability and awareness to live a sustainability-oriented life. Based on what is posted by Kuhlman & Farrington, (2010) Sustainability or sustainability is a concept that emphasizes the importance of creating a better human life despite the limitations of natural resources. This concept focuses on efforts to maintain a balance between the three main dimensions of life, namely social, economic, and environmental aspects, so that the three can support each other and function harmoniously for the survival of the present and future generations (Khusna et al., 2024).

Connecting math materials with the SDGs makes learning more meaningful. Students not only learn mathematical concepts, but also understand how mathematics is used to solve real problems and foster awareness of the importance of sustainability (Olasoji et al., 2023). Education that plays a role in achieving the goals of the SDGs is known as Education for Sustainable Development (ESD) or Education for Sustainable Development (Wals & Kieft, 2010). Education for Sustainable Development (ESD) or education for sustainable development is an educational approach designed to foster the knowledge, skills, and abilities of students to be able to play an active role in creating and sustaining a sustainable life (Prieto-Jiménez et al., 2021). This idea was originally introduced in the Report Brundtland 1987, which highlights the importance of balancing the development of the present with meeting the needs of future generations (Cahyani & Khusna, 2025).

Education for sustainable development requires that students not only master academic concepts passively, but also develop the capacity for critical, analytical, and reflective thinking in order to meaningfully face social, economic, and environmental challenges. Within this framework, mathematical ability emerges as one of the key competencies because through mathematics, students are trained to see patterns, evaluate data, make predictions, and make evidence-based decisions. According to (Söderström et al., 2024) Students' mathematical abilities reflect their capacity to understand, reason, and solve problems by using precise mathematical concepts, procedures, and representations. In the context of learning, mathematical ability plays an important role as a basis for the development of high-level mathematical reasoning and thinking.

According to The National Council of Teachers of Mathematics (NCTM), (2000) Mathematical skills include several important aspects, namely conceptual understanding, procedural fluency (procedural fluency), reasoning and proof (reasoning and proof), troubleshooting (problem solving), mathematical communication (mathematical communication), and mathematical connections (mathematical connections). These six aspects are the basis for developing students' mathematical thinking skills so that they are able to understand and apply mathematics meaningfully. (Sumarmo, 2013) Explains that mathematical skills have an important role in forming logical, analytical, systematic, critical, and creative mindsets, thereby helping students in making rational decisions and solving problems effectively in various life contexts.

In the last ten years, there has been an increase in the trend of publications discussing the application of Education for Sustainable Development (ESD) in mathematics learning to students' mathematical abilities. This improvement shows that the topic of ESD integration is increasingly attracting the attention of researchers because it is considered to be able to increase learning effectiveness, strengthen critical thinking skills, and develop students' mathematical understanding through a contextual and sustainable approach.

In research (Syurya et al., 2025) proving that the application of ESD integrated learning is able to improve students' mathematical skills, because students become more active, think critically, and are able to produce better answers and solutions than classes that do not use ESD. In line with research conducted by Nurasiah et al., (2025) The results of the study showed that ESD-integrated e-modules significantly improved students' critical thinking skills, as evidenced by the grades posttest and N-Gain which is much higher in the experimental class than in the control class. In addition, the results of this study also show that ESD integration has a positive impact on students' mathematical abilities. ESD-based multiplication board media has proven to be effective in improving the understanding of multiplication concepts, as evidenced by a significant increase in values and N-Gain scores in the high category (Scott, 2025)

There has been a lot of research on the application of Education for Sustainable Development (ESD) in mathematics learning, especially those that focus on improving students' mathematical skills. However, until now, there has not been much bibliometric analysis that specifically reviews the trend of publications related to this topic in the Scopus database. Therefore, this study aims to visualize and analyze research trends on the application of ESD in mathematics learning to students' mathematical abilities over the past decade. The analysis was carried out with a bibliometric approach focused on finding out how publication

trends are developing, who are the authors and affiliates who contributed, as well as the themes or research topics that have become trends in the last ten years.

2. Method

This study uses a bibliometric analysis method. The bibliometric method is a technique for measuring the scientific literature using a statistical approach, so it is included in the application of quantitative analysis. Bibliometric analysis provides a way to understand the intensity of current research on a topic as well as the different areas of research that have been explored by researchers (Tekdal, 2021).

Research data obtained from Google Scholar with the help of the application Harzing's Publish or Perish (PoP). Data collection was carried out using the following keywords: "Implementation of ESD," "Mathematical skills", "Mathematics Learning". The publication year range used is 2020-2025, to obtain results that are representative of the development of research over the past decade. Furthermore, the data was analyzed using VOSviewer software to visualize bibliometric maps in the form of co-authorship, co-occurrence of keywords, citation analysis, and co-citation analysis.

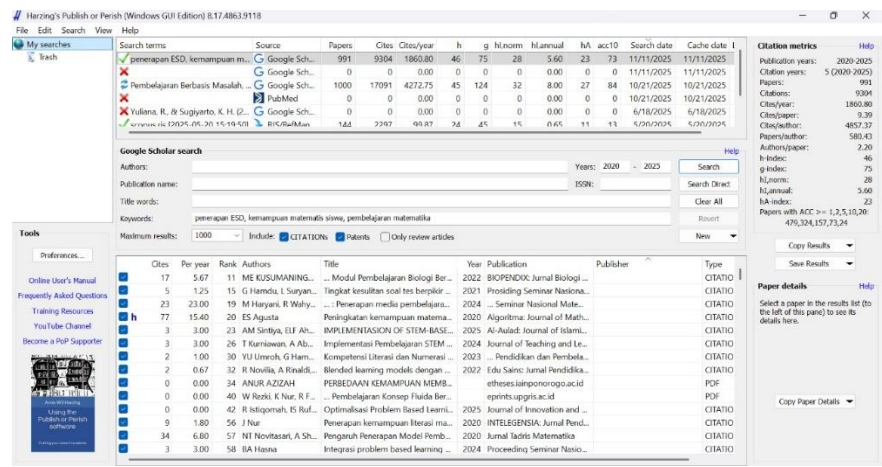


Fig. 1. Data search using Harzing's Publish Or Perish

Based on the results of the initial search using PoP, a number of articles relevant to the research topic were obtained. After being selected according to the criteria and suitability of the theme, as many as 991 articles were determined as research samples. The search results are shown in Figure 1, which shows quantitative data in the form of the number of articles, year of publication, number of citation marks, average citations per year, and h-index value. The data on the citation marks illustrates the level of influence and dissemination of publications in the field of the application of ESD in mathematics learning to students' mathematical abilities. The number of articles analyzed also affects the level of detail of the bibliometric map produced, the more articles analyzed, the more detailed the patterns of relationships between authors, keywords, and institutions that can be mapped. The following is an explanation of the results of citation marks that have been obtained:

Table 1. Citation Marks

Results	Remarks
Keywords	"Implementation of ESD," "Mathematical skills", "Mathematics Learning".
Year of Publication	2020-2025
Year of Citation	5
Article	991

Number of Citations	9.304
Citations Per Year	1860.80
Writing Per Article	4857.37
H Index	46
Table of Contents	75
Individual H-Index	28
Annual H-Index	5.60
Index Ha	23

The results of the citation marks obtained will be further elaborated in the results and discussion section. The data in the table shows the keywords used in the article search process, namely "Implementation of ESD," "Mathematical Ability", "Mathematics Learning", with a publication year range of 2020-2025. The bibliometric information is processed and stored in . RIS, then analyzed using VOSviewer software. The results of the analysis were visualized in the form of a bibliometric map to illustrate the relationship between journals, authors, and the relationship between keywords in publications regarding the application of ESD in mathematics learning to students' mathematical abilities. This visualization method was chosen because it was able to provide a comprehensive overview of the development and relevance of research themes during that period.

The population in this study includes all scientific articles obtained from the initial search results in Google Scholar PoP with keywords and time constraints as mentioned above. After screening by considering the suitability of the theme, completeness of metadata, and relevance to the research topic, a total of 991 articles were designated as research samples.

The data analysis technique uses quantitative and qualitative descriptive approaches. Quantitative data was analyzed to see the number of publications, year of publication, number of citations, and bibliometric indexes (h-index, g-index, and others) obtained through Publish or Perish (PoP). Furthermore, the exported data is processed using Microsoft Excel to present graphs and statistical tables, while VOSviewer is used to visualize a network map of keywords, authors, and institutions. The results of the visualization were then analyzed in a qualitative descriptive manner to provide a comprehensive picture of publication trends and the relationship between research variables.

3. Results and Discussion

Based on the results of data search through the Google Scholar database using Harzing's Publish or Perish (PoP) software as shown in Table 1, from the maximum limit of 1,000 articles and the publication time range 2020–2025, a total of 991 articles were found relevant to the topic of applying Education for Sustainable Development (ESD) in mathematics learning to students' mathematical abilities.

From these results, there were 9,304 total citations, with an average of 1860.80 citations per year, 4857.37 authors per article, and bibliometric index values which included the h-index of 46, the g-index of 75, the h-individual index of 28, the annual index of 5.60, and the hA index of 28.

The development of publication trends on this topic during the period 2020 to 2025 can be seen in Figure 2, which shows the increasing attention of researchers to the integration of sustainability concepts (ESD) in mathematics learning as well as its relation to the development of students' mathematical skills.

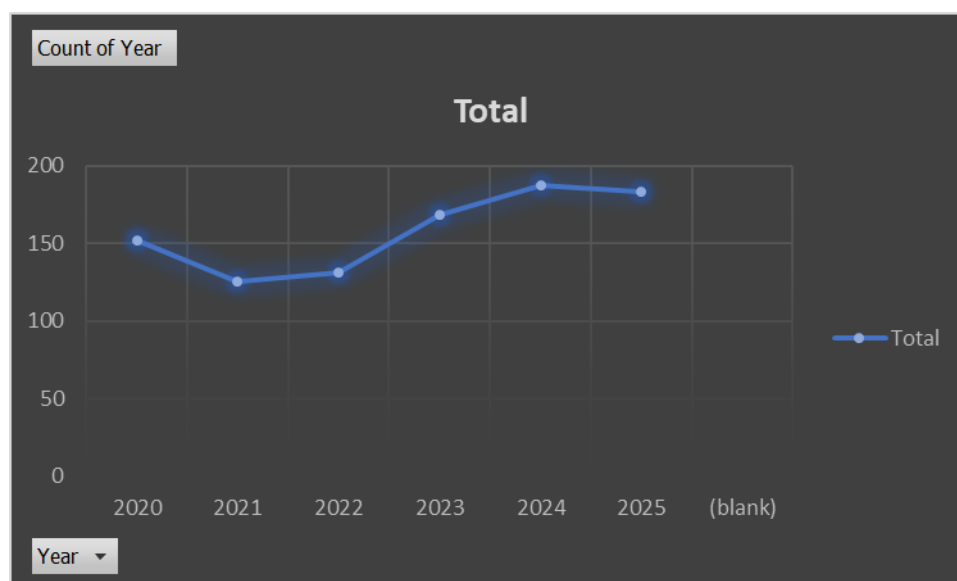


Fig. 2. Number of Related Publications (ESD) in mathematics learning on students' mathematical abilities Range 2020-2025

Figure 2 shows the trend in the number of scientific publications that discuss the topic of the application of Education for Sustainable Development (ESD) in mathematics learning to students' mathematical abilities during the period from 2020 to 2025. In general, the graph shows a fluctuation in the number of publications each year, but with an increasing tendency in recent years.

In 2020, the number of publications was in the range of 150 articles. Then in 2021, the number decreased to around 125 articles, before increasing slightly again in 2022 with a total of around 130 articles.

Furthermore, there will be a significant increase in 2023 with a total of around 165 articles, and will reach a peak in 2024 with around 190 articles. Meanwhile, in 2025 the number of publications will decrease slightly to around 185 articles, but still shows a high number compared to the beginning of the period. Overall, this graph illustrates that although there was a decline at the beginning of the period, the trend of research on the application of ESD in mathematics learning to students' mathematical abilities showed a consistent increase, indicating an increasing attention to the importance of ESD integration in efforts to strengthen students' mathematical skills.

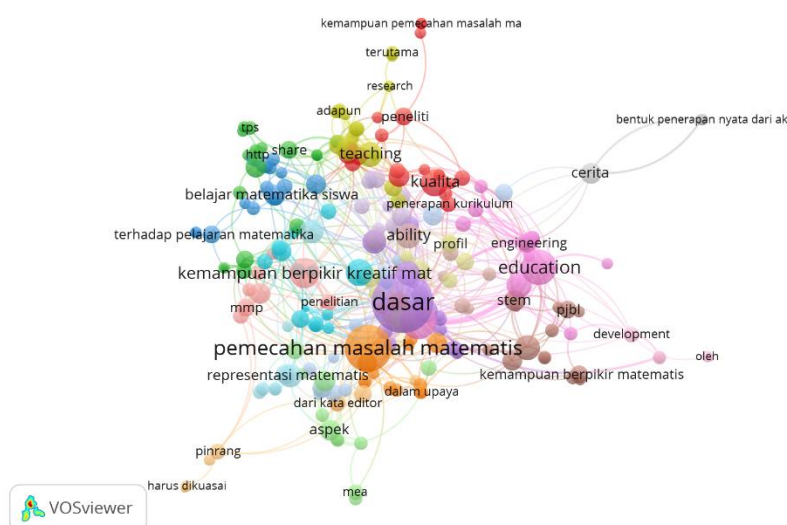


Fig. 3. Network Visualization

Figure 3 shows the results of Network Visualization using VOSviewer software which illustrates the relationship between keywords in publications related to the application of Education for Sustainable Development (ESD) in mathematics learning. Each color indicates a cluster of interrelated research themes. The size of the circle signifies how often the keyword appears in the research document, while the thickness of the line indicates the strength of the relationship between themes. Keywords that stand out with large sizes and center center such as "basics," "mathematical problem-solving," and "mathematical creative thinking skills" indicate that these topics have been the main focus of research over the past few years. Meanwhile, keywords such as "teaching", "education", "stem", and "pjbl" appear to be quite closely connected to the main topic, indicating that project-based learning approaches and STEM integration are becoming an important part of the implementation of ESD in mathematics education.

However, there are also keywords that are still separate and have a small size such as "real application form of activity", "story", and "engineering", which indicates that these themes are still rarely studied in depth. This shows that there are opportunities for further research to expand the implementation of ESD through a more applicable and cross-disciplinary learning context.

These findings are in line with Vásquez et al., (2023) emphasized that the integration of ESD in mathematics and statistics education is increasingly studied in literature studies because of its perspective that is able to bridge sustainability issues with the context of holistic mathematics learning. Bulut & Ferri, (2025) shows that training programs that combine Education for Sustainable Development and mathematical modelling can improve prospective teachers' understanding of sustainability concepts and their readiness to integrate them in real mathematics learning, illustrating the shift in research from conceptual studies to pedagogical interventions and the improvement of professional competence. At the local level, research on the development of ESD-based learning tools is also increasingly being carried out, such as in the development of worksheets and outdoor learning methods designed to connect the context of the real environment with students' mathematical understanding (Nugraheni et al., 2025).

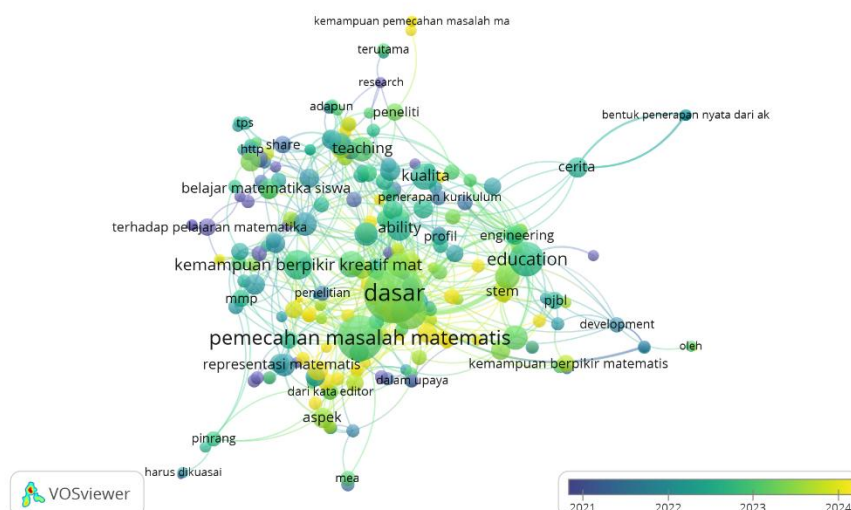


Fig. 4. Overlay Visualization

In the Image, there are variations in blue, green, and yellow colors that show the distribution of the year of publication of each research keyword. Blue depicts keywords that appear in publications in the early years, around 2021 and below, while green marks a transition period around 2022, and yellow denotes more recent research, namely 2023 to 2024. Based on the results of the visualization, the dominating topics in recent years are related to mathematical problem solving, mathematical creative thinking skills, education, and teaching that are interrelated with the concept of Education for Sustainable Development (ESD). The latest

keywords that look more contemporary are colored yellow, including STEM, engineering education, and curriculum implementation, which indicates that the latest research direction is starting to focus on the application of ESD through an integrative approach based on curriculum and technology.

These findings are in line with bibliometric results conducted by (Yang & Xiu, 2023), which shows that the focus of ESD research in recent years has shifted from just conceptual studies to concrete applications in the context of competency-based learning. In addition, the research (Khusna et al., 2024) also reveals that the theme mathematical problem solving and creative mathematical thinking increasingly associated with ESD as both emphasize the development of high-level thinking skills that are aligned with sustainability principles. Similar results were also found by Acceptance & Goalkeeper, (2024), which confirms that current research directions tend to integrate ESD with STEM education as an effort to strengthen the relevance of mathematics learning to global challenges. Thus, this visual map not only shows the density of relationships between keywords, but also illustrates the dynamics of the development of ESD research themes in mathematics learning that are increasingly oriented towards students' mathematical abilities holistically.

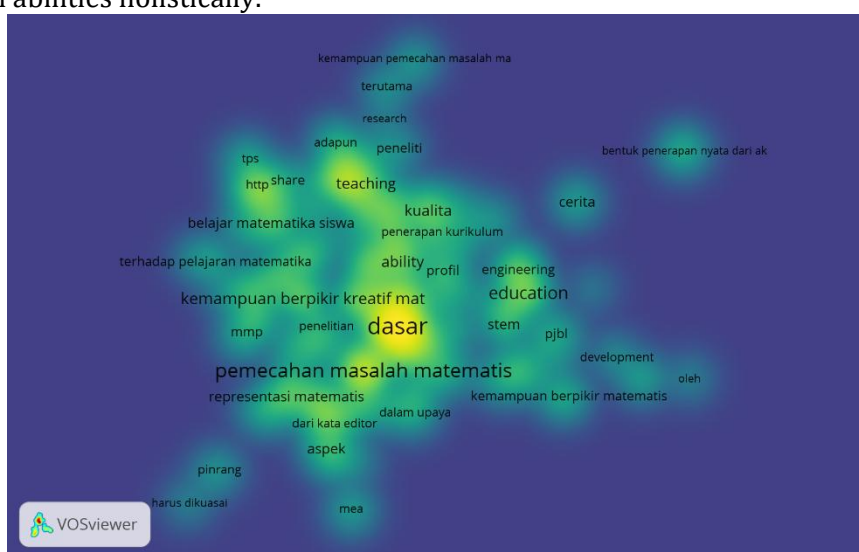


Fig. 5. Density Visualization

The results of Density Visualization using VOSviewer software in Figure 5 show the level of density of research themes related to the application of Education for Sustainable Development (ESD) in mathematics learning to students' mathematical abilities. The bright yellow color indicates that the theme has been researched a lot, while the fainter color indicates that the theme is still rarely studied. Based on the visualization results, it appears that themes such as "grade", "effectiveness", "mathematics education", "teaching mathematics", "case", and "memory aid" have fainter colors than other themes. This shows that although mathematics learning has become a broad field of study, the integration of ESD concepts in it is still relatively limited. Themes such as "effectiveness" and "grade" illustrate that research that measures the effect of the application of ESD on the improvement of students' grades or mathematical abilities is still not widely done. Meanwhile, the theme of "memory aid" indicates new research opportunities that focus on how ESD approaches can help students' memory and retention of mathematical concepts.

These findings are in line with the results of a bibliometric review conducted by Bran et al., (2019) In the article titled "Education for Sustainable Development: Evolution and Perspectives—A Bibliometric Review of Research, 1992–2018" states that the development of publications on ESD has increased significantly since 2015, but its application in specific areas of learning, such as mathematics, is still relatively small.

This is reinforced by Khusna et al., (2024) who in his study titled "Bibliometric Analysis on ESD Research Trends in Mathematics Learning" found that although the trend of publications increased from 2017 to 2024, the focus of research that directly examined the relationship between ESD and students' mathematical abilities was still limited. Thus, the results of this density mapping show the existence of novelty opportunities (novelty) research in the field of the application of ESD in mathematics learning, especially those that highlight aspects of effectiveness, improvement of learning outcomes, and strengthening students' mathematical abilities.

4. Conclusion

This research shows that the integration of Education for Sustainable Development (ESD) in mathematics learning continues to grow and makes a real contribution to strengthening students' mathematical skills. The publication trend in the 2020–2025 period shows a consistent increase, reflected in the high number of citations and the achievement of a strong h-index. The focus of research has also shifted towards themes such as mathematical problem-solving, creative thinking skills, STEM approaches, and the implementation of ESD-based curriculum.

On the other hand, studies on the effectiveness of direct ESD implementation and its impact on the retention of mathematical concepts are still relatively limited. This condition opens up opportunities for more in-depth follow-up research. Overall, the results of the analysis confirm that the development of ESD-based mathematics learning is not only relevant to the demands of continuing education, but also has the potential to comprehensively strengthen students' mathematical abilities.

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