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Mapping Research Trends in Materials-Based Science Education for Sustainable Development Goals: A Bibliometric Study

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ABSTRACT

This study maps research trends, knowledge structures, and thematic developments in materials-based science education within the framework of the Sustainable Development Goals (SDGs). A total of 467 documents from the Scopus database (2015-2024) were analyzed using a quantitative bibliometric approach with VOSviewer software. The analysis includes keyword co-occurrence, author collaboration, country contributions, and topic evolution. Results indicate a significant growth in publications since 2020, with authors like Nandiyanto and countries such as the United States being key contributors. Prominent keywords (sustainability, learning, application, and teaching material) highlight a dominant focus on pedagogical and sustainability issues. Overlay visualizations show a thematic shift from technical material issues to competency-based learning approaches. These findings underscore the need for science curricula and teaching strategies that incorporate sustainability principles and material innovation. The study offers a strategic reference point for researchers and educators to align science education with global sustainability challenges.

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1. INTRODUCTION

Science education plays a strategic role in fostering scientific literacy in society and equipping students to tackle the challenges of the 21st century (Nugraha, 2023a; Maryanti & Nandiyanto, 2021; Mirzabek, 2023). Scientific literacy in question does not only include understanding the basic concepts of physics, chemistry, and biology, but also includes critical thinking skills, complex problem solving, evidence-based decision making, and awareness of scientific and technological issues that impact global life (Pacala, 2023; Sombria *et al.*, 2023; Tiong & Bakar, 2022; Lestari, 2024; Theron *et al.*, 2024). Amid the increasingly complex global environmental, social, and economic problems (such as the climate crisis, natural resource degradation, and pollution from synthetic materials) science education is required to be able to equip students not only with theoretical knowledge, but also practical skills and sustainability values (Awalussillmi *et al.*, 2023).

One approach that is developing and relevant to these needs is materials-based science education. This approach emphasizes the use of real materials (such as metals, polymers, ceramics, composite materials, biomaterials, and even household or industrial waste) as a medium to teach science concepts in a contextual and applicable way (Bale *et al.*, 2019; Marquez *et al.*, 2023). Through the exploration of the physical, chemical, and functional properties of various materials, students can more easily relate scientific knowledge to phenomena they encounter in everyday life (Ke *et al.*, 2021). For example, an understanding of thermal conductivity can be learned through a comparison of metal and plastic materials, or the concept of chemical reactions can be related to the processes of corrosion and metal plating (Chen *et al.*, 2022). The use of materials in science learning also opens up space for the application of inquiry approaches and project-based learning, where students are invited to observe, test, modify, and design solutions to real problems (Ogunjimi & Gbadeyanka, 2023; Humphrey *et al.*, 2023). Thus, in addition to improving conceptual understanding, this approach also trains students' scientific thinking skills, collaboration, and creativity (Fajarwati *et al.*, 2024; Tiong & Bakar, 2022; Widodo *et al.*, 2020). Furthermore, the integration of material topics in science education encourages the strengthening of cross-disciplinary connections, considering that materials science is an interdisciplinary field that includes chemistry, physics, engineering, and applied technology (Han *et al.*, 2021).

The contextualization of science materials in global issues such as climate change, environmental degradation, and energy security makes the materials-based approach very relevant in the framework of Education for Sustainable Development (ESD) (Solihat *et al.*, 2024; Rasuma *et al*, 2024; Purwaningsih *et al.*, 2023; Gemil *et al.*, 2024). In science education, this approach not only enriches learning content but also presents dimensions of environmental values and responsibilities that are important for future generations. In the context of the Sustainable Development Goals (SDGs), materials-based science education contributes directly to SDG 4 (Quality Education) by encouraging active, exploratory learning strategies and solving real-world problems. This approach also supports SDG 12 (Responsible Consumption and Production) through learning about material life cycles, resource reuse, recycling principles, and energy and material efficiency (Maryanti *et al.*, 2022). In other words, science education that emphasizes the understanding and exploration of materials not only forms scientifically competent students but also those who are environmentally conscious and sustainability-oriented in their thinking and actions.

Several studies have examined the effectiveness of using materials as a medium for science learning, including in the context of school laboratories (Serrano-Perez *et al.*, 2023; Hu-Au & Okita, 2021), the development of teaching materials (Nurlita, 2023; Nugraha, 2023b), and environmental science projects (Wagner *et al.*, 2023). However, most of these studies are local, fragmented, and do not provide a comprehensive picture of the direction and development of this field globally. Meanwhile, research on science education and the SDGs is also growing in parallel, but its connection to materials science is still relatively rare to be systematically studied. To date, there has been no bibliometric study that explicitly maps how research on materials-based science education in the context of sustainability has developed over time, including who the main actors are, collaborations between countries or institutions, and how important topics emerge and shift. **Table 1** presents a summary of several relevant studies, which serve as an important basis for designing the focus and approach of this study, especially in terms of methodology, data scope, and dimensional analysis used.

Based on this background, this study aims to map the global landscape of science education research in materials within the framework of sustainable development using a bibliometric approach. This study examines scientific publications in the last two decades to identify: (i) publication trends over time; (ii) dominant actors such as the most productive authors, institutions, and countries; (iii) the main keywords and themes that appear most frequently; and (iv) research gaps and potential future development directions. The novelty of this study lies in the systematic mapping of the intersection between three important domains: science education, materials science, and SDGs. In addition, this study utilizes scientific visualization techniques using co-occurrence and co-authorship analysis to illustrate thematic and collaborative structures within these fields. The results of this study are expected to provide significant contributions in building a scientific foundation for curriculum development, learning strategies, and the direction of science education research that is more integrated with sustainability values and global challenges.

Table 1. Previous research on education.

No	Title	References
1	A quantitative approach to challenges facing online and physical classrooms in higher institutions	Babalola and Oludare (2024)
2	Theoretical aspects of creating a scientific and educational platform for information and trading systems	Glushchenko and Inei (2024)
3	Perceived influence of violent television show on pupil learning and academic performance	Salman *et al.* (2024)
4	Perception about student engagement in blended learning instructional design: evidence from Sri Lankan Universities	Jayarathna and Herath (2024)
5	Efforts to improve young generation problem solving in the era of globalization using six thinking hats analyzed with SPSS: Solving literacy, read, and hoax.	Theron *et al.* (2024)
6	Development and acceptability of virtual laboratory in learning systematics	Sison *et al.* (2024)
7	Exploring the impact of online education on higher education	Kamraju *et al.* (2024)
8	Availability and Utilization of Preschool Play Equipment	Saadu (2024)
9	The research trend of statistical significance test: Bibliometric analysis.	Al Husaeni *et al.* (2024)
10	How eyes and brain see color: Definition of color, literature review with bibliometric analysis, and inquiry learning strategy for teaching color changes to student with mild intelligence barriers	Juhanaini *et al.* (2023)

2. METHODS

This study used a quantitative bibliometric approach to map trends, knowledge structures, and thematic dynamics in scientific studies related to material-based science education in the context of sustainable development. The bibliometric approach was chosen because it is able to present a comprehensive picture of the development of literature, scientific collaboration networks, and dominant issues that develop in a scientific field. This study was designed to identify publication growth, main actors (authors, institutions, countries), thematic keywords, and potential future research directions. Bibliographic data sources are obtained from Scopus, which is one of the largest and most credible scientific databases, covering international journals from various disciplines. The data search process was carried out using a combination of keywords designed to cover the dimensions of science education, materials, and sustainability. The keywords used in the Title-Abstract-Keyword column include: "science education" OR "materials education" AND "sustainable development goals". The search was limited to document types in the form of articles and conference papers, written in English, and published between 2015 and 2024. Detailed information regarding this method is explained elsewhere (Rochman *et al.*, 2024; Al Husaeni & Nandiyanto, 2022; Al Husaeni & Al Husaeni, 2022).

The initial search results produced 980 documents. Furthermore, a data cleaning and filtering process was carried out to remove duplications, irrelevant documents, and publications that did not have complete metadata. A further selection process was carried out based on a review of the title and abstract to ensure relevance to the main focus of the research, namely the integration of science education, materials science, and SDGs. After the selection process, the number of documents that met the final criteria was 467 publications, which were then further analyzed.

Data analysis was carried out using two main software programs. VOSviewer was used to build and visualize bibliometric networks, such as co-authorship analysis, keyword co-occurrence, and citation mapping. Meanwhile, additional visualizations were carried out in the form of bar graphs, pie charts, collaboration network maps, overlay diagrams, and density visualizations to explore thematic evolution over time. Interpretation is done qualitatively by linking bibliometric findings to relevant literature, both theoretically and practically.

3. RESULTS AND DISCUSSION

3.1. Publication Trends

Figure 1 shows the trend in the number of scientific publications related to materials-based science education in the context of sustainable development during the period 2015 to 2024. In general, there was a significant increase in the number of publications from year to year, especially after 2019.

In the period 2015 to 2017, the number of publications was relatively low and tended to stagnate, with figures ranging from 10 to 15 documents per year. This indicates that research on this topic has not received much attention from the scientific community at the beginning of the observation period. However, in the period 2018 to 2020, there was a gradual increase, which was then followed by a sharp spike in 2021 and beyond. This significant increase is likely influenced by the increasing awareness of sustainability issues and the importance of integrating environmental aspects into education, along with the increasingly massive implementation of the SDGs globally.

The peak of publications occurred in 2024, with the number of documents reaching more than 120 articles. This shows that the topic of materials science and sustainability education has become a major concern and is increasingly relevant, especially in responding to global challenges such as climate change, the energy crisis, and the transition of education towards a more contextual and applied approach. This decline is most likely not a reflection of a decline in interest in the topic, but may be due to technical factors such as incomplete publication data for the current year at the time of data collection. Since most scientific journals publish articles in stages throughout the year, this number is likely to continue to increase until the end of the year. Based on this, this trend shows that the topic of materials science education in sustainable development is a field that continues to grow and develop, with still very broad research potential to be explored in the future.

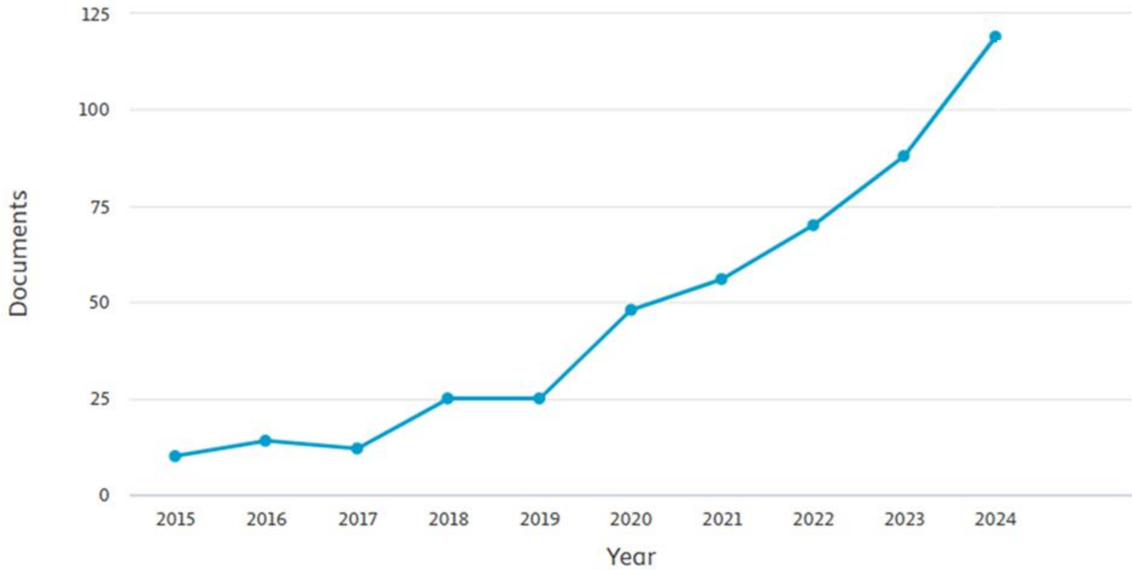

Figure 1. Trend in the number of scientific publications related to materials-based science education in the context of sustainable development.

3.2. Publication Contribution by Authors

Figure 2 presents a list of the top 10 authors based on the number of scientific publications contributing to the field of materials-based science education in the context of sustainable development. From **Figure 2**, Nandiyanto is the most productive author with a total of 4 documents relevant to this research topic. Nandiyanto's contribution is quite prominent compared to other authors, indicating his active role in driving research at the intersection of science education, materials, and sustainability issues.

Other authors, such as Amu, H., Baena-Morales, S., and Ferriz-Valero, A., each contributed 3 documents, indicating a relatively high level of productivity and consistent contribution to the development of scientific discourse in this field. Meanwhile, authors such as Abdulla, F., Adach-Pawelus, K., Adam, K., Ancheta, J.R., Badran, A.S., and Bandholz, T.C. each contributed 2 documents. Although quantitatively their contributions are smaller, their presence indicates a fairly wide geographical and institutional diversity in the scientific community in this field.

Based on the data in **Figure 2**, although research related to material-based science education and sustainability has grown significantly in recent years, the level of collaboration and consistency of productivity among authors is still relatively scattered and has not been concentrated in one particular research group. Thus, this can open up opportunities to build stronger scientific networks through cross-institutional and cross-country collaboration, as well as strengthen the research community that focuses on material-based contextual education approaches to support sustainable development goals.

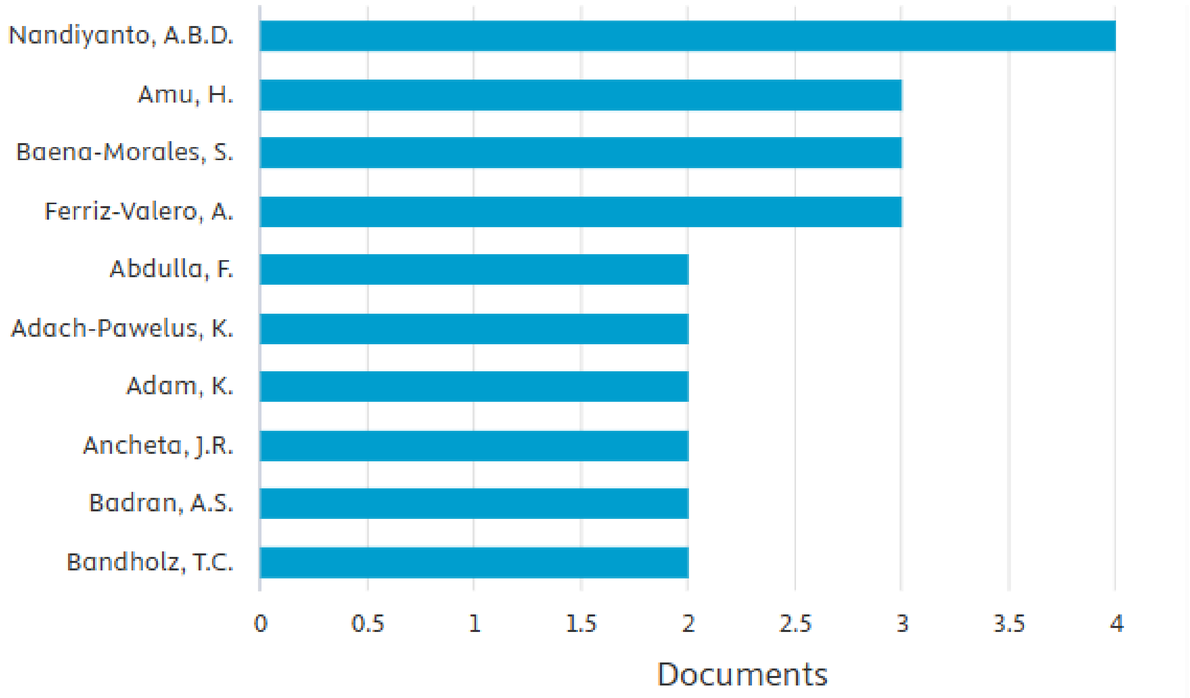

Figure 2. The ten most productive authors in the field of materials-based science education in the context of sustainable development.

3.3. Publication Contribution by Country

Figure 3 shows the contribution of various countries in scientific publications related to materials-based science education within the framework of sustainable development. From the graph, it can be seen that the United States is the highest contributor, with the number of documents reaching almost 70 publications. This initiative signifies the central role of the United States in the development of discourse and practice of science education that focuses on the issues of materials, curiosity, and innovation.

The United Kingdom is in second place with more than 50 documents, followed by European countries such as Germany and Spain, which each include around 30 publications. This shows that Western European countries consistently contribute to interdisciplinary research that combines education, technology materials, and sustainable development. This contribution can be attributed to the European Union's higher education policy and research funding that supports the poverty agenda, such as the Horizon Europe and Erasmus+ programs.

Countries from other regions, such as Australia, India, the Russian Federation, China, South Africa, and Brazil, also show active involvement, each contributing between 20 and 30 documents. This geographical diversity reflects that interest in the integration of science education and the desire to do so has grown globally, both in developed and developing countries.

However, most contributions still provide a snapshot of countries with strong ecosystem research and access to adequate scientific infrastructure. This suggests opportunities to strengthen international collaboration and broaden participation of countries in Southeast Asia, North Africa, and Latin America, which are currently relatively underrepresented in the global literature.

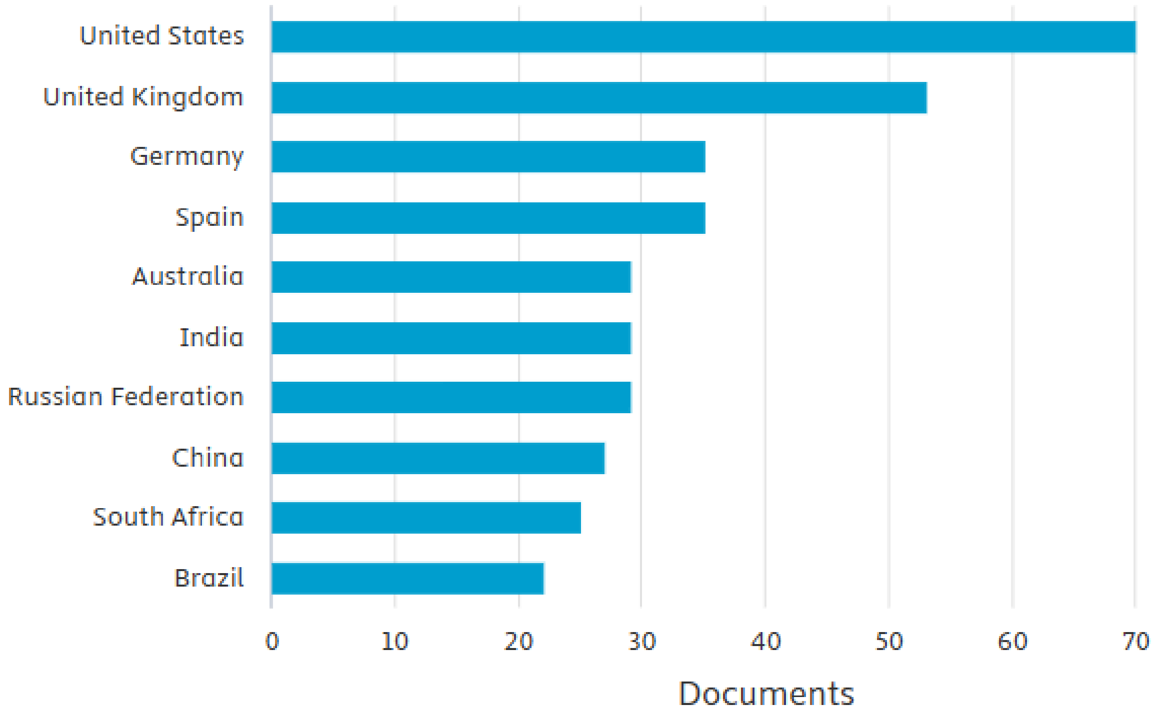

Figure 3. Top ten countries by number of scientific publications in the field of materials-based science education in the context of sustainable development.

3.4. Publication Contribution by Subject Area

Figure 4 shows the distribution of documents based on scientific fields in publications related to materials-based science education in the context of sustainable development. These data provide an overview of the interdisciplinary nature of research development on the topic. The Social Sciences field dominates with a contribution of 29% of the total documents. This reflects those educational issues, policies, and pedagogical approaches are the main focus of this research, in line with the social dimension of sustainability, which emphasizes behavioral change, environmental awareness, and community capacity building.

The second largest contribution comes from the Environmental Science field at 13.8%, indicating a strong link between science education and ecological issues such as natural resource conservation, climate change, and waste management. This indicates that the material-based education approach is often directed at increasing environmental literacy and encouraging real action in the context of sustainability.

Furthermore, the fields of Energy (8.9%), Medicine (7.7%), Computer Science (7.2%), and Engineering (6.4%) also made significant contributions. The involvement of the energy sector indicates that topics such as energy efficiency, renewable energy, and environmentally friendly material technologies are starting to be integrated into the science curriculum and teaching. The contribution from the medical field can be linked to science-based public health education and the use of materials in biomedical or environmental health contexts.

Meanwhile, the fields of Business and Management (4.2%), Humanities (3.5%), Psychology (2.8%), and Economics (2.5%) show that materials-based science education also touches on managerial, value, behavioral, and economic aspects in sustainable development. The “Other” category covers 14% of the total documents, confirming the broad spectrum of sciences involved.

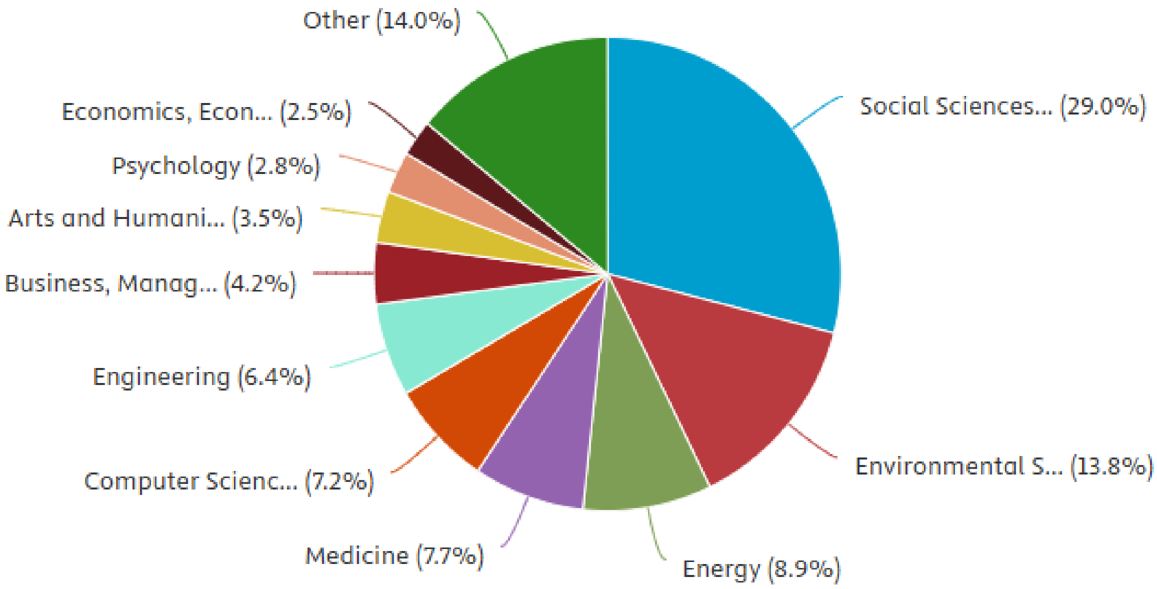

Figure 4. Distribution of documents by subject area in research related to materials-based science education in the context of sustainable development.

3.5. Visualization Mapping

Figures 5 and 6 present visual maps of the relationships between co-occurring keywords in publications related to materials-based science education in the context of sustainable development. These visualizations were generated through a bibliometric analysis with a co-occurrence approach that groups keywords into color clusters based on thematic similarity and the strength of the relationship between the terms.

Figure 5 shows that the terms "sustainability", "learning", "understanding", and "raw materials" are the centers of gravity in the network, indicating that the concept of sustainability and students' understanding of materials are dominant themes in the literature. The green cluster contains terms related to learning, such as learning, application, instruction, and educational materials, indicating a strong focus on pedagogical approaches in materials-based science. Meanwhile, the blue cluster contains keywords such as production, raw material, energy, pollution, and emission, indicating the integration between education and technical issues in materials science and the environment. The red cluster refers to terms such as trend, characteristic, education quality, and gender equality, indicating the social and evaluative dimensions of science education. Meanwhile, the purple and orange clusters reflect connections with the classroom, teaching materials, engineering education, and critical thinking, indicating integration with the classroom context and 21st-century skills.

Figure 6 displays a representation of the strength of the linkage between keywords, with the terms sustainability and science in a central position and connected to almost all clusters. This shows that sustainability is not only the focus of the content but also the main framework that ties together all other topics. The words science, learning, and engineering appear as links between the green (education), blue (energy and materials), and red (social and institutional analysis) clusters, reflecting the multidisciplinary nature of this field.

The close relationship between sustainability, raw materials, energy, and teaching materials shows that the use of real or contextual materials in science teaching is an important trend that supports the achievement of the SDGs in education. It also highlights how the concept of sustainability is not only discussed as a topic but also as a principle that structures the content, methods, and objectives of learning.

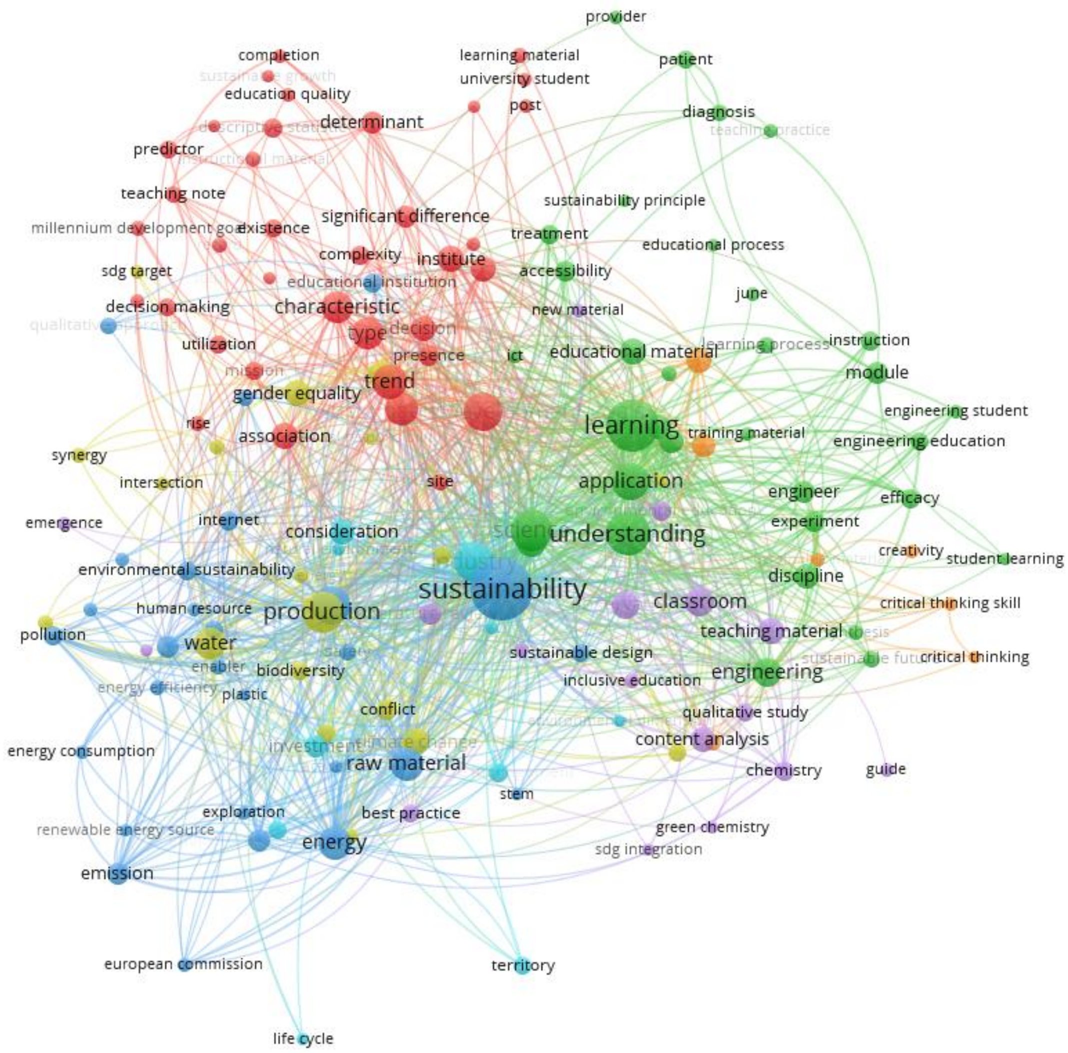

Figure 5. Visualization of keyword network (co-occurrence keyword network).

Figure 7 presents a visualization of the keyword network overlay depicting the temporal evolution of research topics in materials-based science education in the context of sustainable development. The color of each node indicates the average year the keyword appeared in the literature, with a color spectrum ranging from dark blue (old topics) to bright yellow (new topics). In general, this visualization shows a shift in research focus from technical and environmental issues to pedagogical and cognitive aspects in the period 2015 to 2024.

In the early phase (marked in blue to dark green), the dominant themes included sustainability, raw materials, pollution, production, energy consumption, and emissions. These themes reflect the initial attention of the scientific community to the use of materials in science education that are directly related to environmental issues and renewable energy technologies. These topics form the basis for the integration of sustainability principles into materials-based science learning. Entering the period 2021 to 2022 (shown in light green), there is a shift in focus towards learning approaches and instructional design. Keywords such as learning, application, understanding, teaching materials, and engineering education begin to appear more intensively. This suggests that research is beginning to explore how content-based learning can be effectively applied in classroom contexts, as well as how student learning can be enhanced through contextual approaches based on projects and experiments.

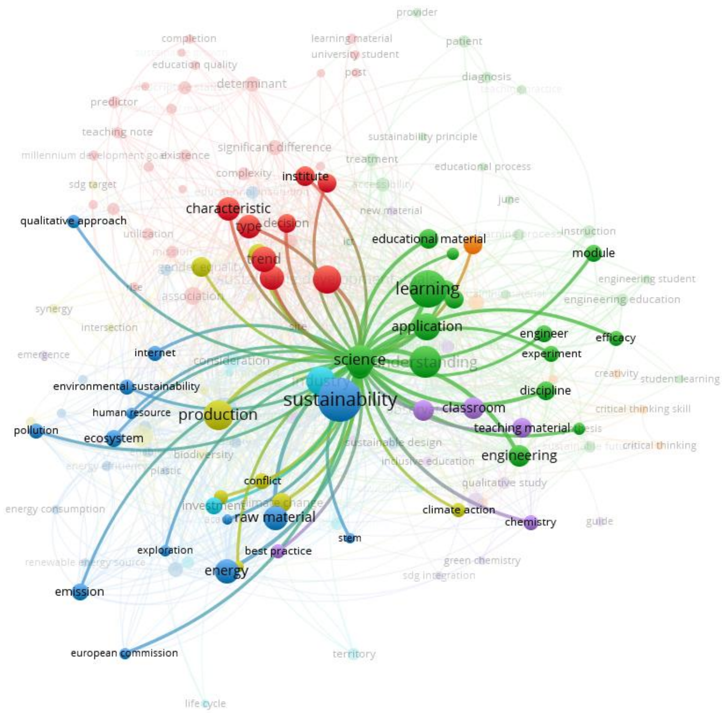

Figure 6. Visualization of focused thematic relationships (network linkage view).

Furthermore, in the current period (2022-2023, marked in bright yellow), emerging topics include educational materials, training materials, modules, efficacy, critical thinking, and accessibility. These themes indicate a new direction in the development of science education that focuses more on learning effectiveness, the development of innovative teaching tools, and the enhancement of critical thinking skills and student creativity. In addition, the emergence of the term accessibility indicates a concern for equitable access to learning resources within the framework of sustainable education.

Thus, this overlay visualization not only shows how key themes have evolved, but also shows that the approach to content-based science education has shifted from a content-based approach to a competency-based and sustainability approach. This evolution reflects the paradigm shift in science education that is increasingly interdisciplinary and responsive to the global challenges of the 21st century.

Figure 8 presents a visualization of the density mapping of keyword networks in publications related to materials-based science education in the context of sustainable development. This visualization displays the density of occurrence of terms (keywords) based on their frequency and strength of association with other keywords. The colors in this visualization represent the level of density, with a gradient from blue (low) to bright yellow (high). The yellow area indicates the thematic cluster that is most frequently discussed and is the center of discussion in the analyzed literature.

The keywords with the highest density are sustainability, learning, science, understanding, application, and teaching materials. This shows that the theme of sustainability and the learning process are the main focus in science education studies that integrate material aspects. The terms science and learning also show a high intensity of relationships with other keywords, thus strengthening their central position in the knowledge structure of this field.

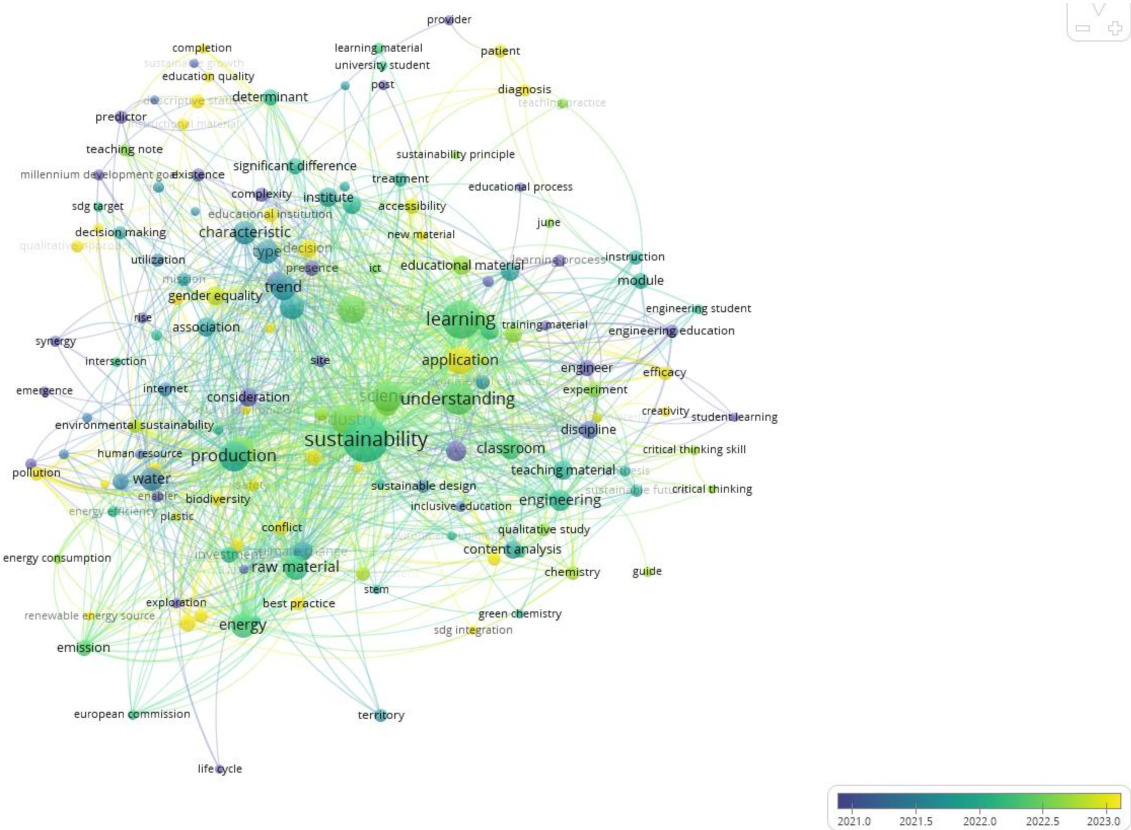

Figure 7. Keyword network overlay visualization.

In addition, terms such as raw materials, energy, production, and engineering also show a fairly high level of density, even though they are in the transition zone (green to yellow). This shows that the technical dimension and application of the use of materials in science education are also important concerns, especially in the framework of implementing project-based learning, engineering, or experiments.

In contrast, some terms, such as emissions, exploration, qualitative approaches, regions, or the European Commission, are in the blue area, reflecting their lower frequency and their peripheral position in scientific discourse. This suggests that these topics are not yet a major focus in the literature, although they are potential areas for further exploration.

Overall, this density mapping provides a visual representation of how thematic structures are formed and distributed in the relevant literature. The densest research focus seems to be centered on the intersection between education, sustainability, and material use, reflecting the scientific community's tendency to integrate pedagogical and ecological approaches in the development of contemporary science education.

Finally, this study adds new information regarding SDGs as reported elsewhere (**Table 2**).

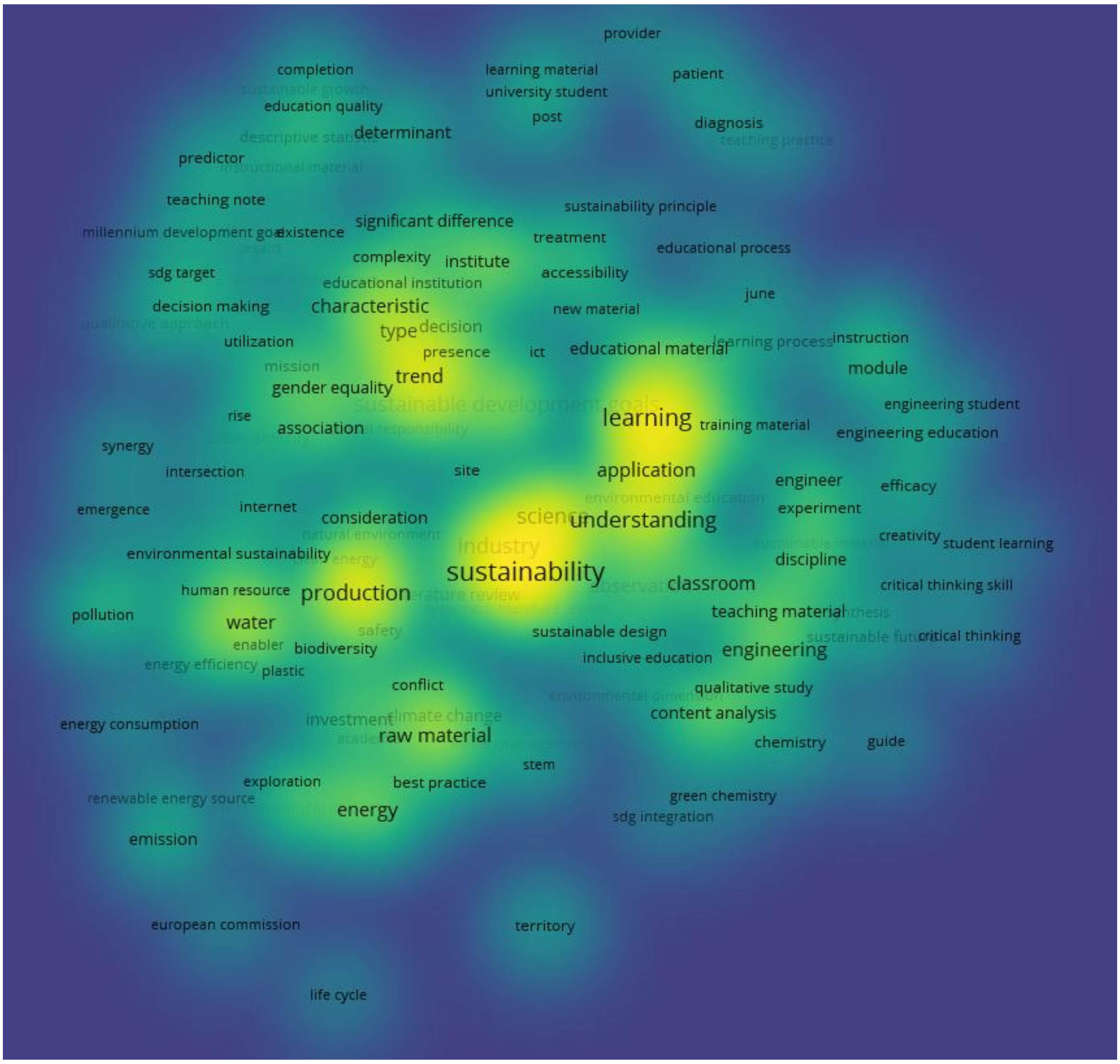

Figure 8. Density mapping visualization of the keyword network.

Table 2. Previous studies on SDGs.

No	Title	References
1	Low-carbon food consumption for solving climate change mitigation: Literature review with bibliometric and simple calculation application for cultivating sustainability consciousness in facing sustainable development goals (SDGs)	Nurramadhani *et al.* (2024)
2	Towards sustainable wind energy: A systematic review of airfoil and blade technologies over the past 25 years for supporting sustainable development goals (SDGs)	Krishnan *et al.* (2024)
3	Assessment of student awareness and application of eco-friendly curriculum and technologies in Indonesian higher education for supporting sustainable development goals (SDGs): A case study on environmental challenges	Djirong *et al.* (2024)
4	Effect of substrate and water on cultivation of Sumba seaworm (nyale) and experimental practicum design for improving critical and creative thinking skills of prospective science teacher in biology and supporting sustainable development goals (SDGs)	Kerans *et al.* (2024)
5	Sustainable packaging: Bioplastics as a low-carbon future step for the sustainable development goals (SDGs)	Basnur *et al.* (2024)

Table 2 (continue). Previous studies on SDGs.

No	Title	References
6	Smart learning as transformative impact of technology: A paradigm for accomplishing sustainable development goals (SDGs) in education	Makinde *et al.* (2024)
7	The relationship of vocational education skills in agribusiness processing agricultural products in achieving sustainable development goals (SDGs)	Gemil *et al.* (2024)
8	The influence of environmentally friendly packaging on consumer interest in implementing zero waste in the food industry to meet sustainable development goals (SDGs) needs	Haq *et al.* (2024)
9	Implementation of Sustainable Development Goals (SDGs) no. 12: Responsible production and consumption by optimizing lemon commodities and community empowerment to reduce household waste	Maulana *et al.* (2023)
10	Analysis of the application of Mediterranean diet patterns on sustainability to support the achievement of sustainable development goals (SDGs): Zero hunger, good health and well beings, responsible consumption, and production	Nurnabila *et al.* (2023)
11	Efforts to improve sustainable development goals (SDGs) through education on diversification of food using infographic: Animal and vegetable protein	Awalussillmi *et al.* (2023)
12	Safe food treatment technology: The key to realizing the Sustainable Development Goals (SDGs) zero hunger and optimal health	Rahmah *et al.* (2024)
13	Analysis of student's awareness of sustainable diet in reducing carbon footprint to support Sustainable Development Goals (SDGs) 2030	Keisyafa *et al.* (2024)

4. CONCLUSION

This study provides a comprehensive mapping of the development and dynamics of research in the field of materials-based science education within the framework of SDGs through a quantitative bibliometric approach. Analysis of 467 publications indexed in Scopus during the period 2015 to 2024 reveals a significant increasing trend in the number of publications, especially after 2020. This indicates increasing global concern for the integration of sustainability principles in materials-based science learning.

In terms of author contributions, authors such as Nandiyanto A.B.D. and countries such as the United States, England, and Germany dominate publication productivity. Visualization of the collaboration network also shows the interconnectedness between authors and institutions from various countries, although the intensity of international collaboration still varies. Keyword analysis identifies key themes that include sustainability, learning, application, teaching materials, and science education. Overlay visualization shows a shift in focus from technical issues, such as raw materials and pollution, to pedagogical approaches that emphasize competency development, such as critical thinking and module design. Density visualization confirms that pedagogical and sustainability aspects are at the center of the discourse in the literature.

The implications of these findings are highly relevant for curriculum developers, educators, and researchers to direct a more integrative, contextual, and real-life challenge-based approach to science education in the 21st century. This study also provides an important basis for further research that seeks to explore the interconnectedness between science education, materials science, and sustainable development systematically and across disciplines.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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